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ACCELERATING MOVING WALKWAY SYSTEMS

Safety and Human Factors

Engineering Research and Development Division
THE PORT AUTHORITY OF NY & NJ
One World Trade Center New York, N.Y. 10048

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FINAL REPORT

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16. Abstract

An Accelerating Moving Walkway System (AMWS) is a pedestrian assist device having the capability through changing treadway configuration to accelerate pedestrians to 4 to 5 times normal moving way system speeds after boarding and to decelerate prior to discharge. Conventional moving way systems, escalators and moving walks, enjoy wide public acceptability and rank as one of the safest transportation modes in terms of numbers of passengers carried. Accelerating moving walkways will introduce several new operating characteristics which may influence accident experience. Depending on the system, treadway surfaces will expand and contract or change relative position, and handrails will expand and contract or be used in series at varying speeds. Based on the report studies which include an overview of transportation safety, identification and evaluation of possible AMWS hazards, an analysis of moving way accident experience on conventional escalators, the reports of Project Safety consultants and the proceedings of a Project Safety Seminar, there appears to be no apriori reason why an AMWS cannot be operated in a public demonstration mode at acceptable levels of safety. This assumes that a basic safety program is followed addressing human factors and equipment design, equipment operation and maintenance, instruction of passengers in correct use, and that the demonstration environment is appropriate and controls are maintained to assure proper system use.

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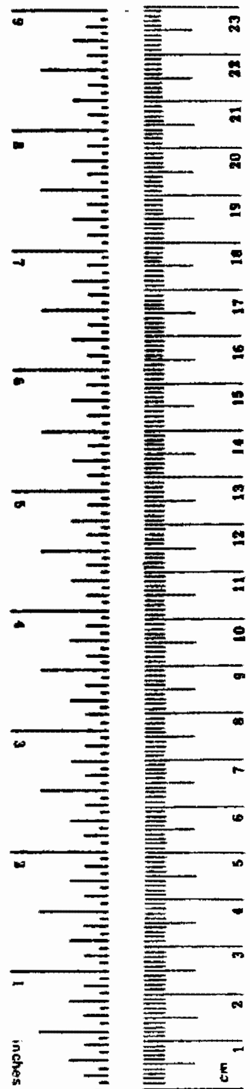
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

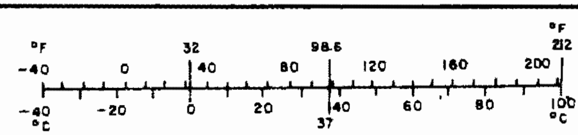
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1.0 AMWS SAFETY OVERVIEW

1.1 General Introduction

Accelerating Moving Walkway Systems (AMWS) are an extension of conventional escalator and moving way technology, in the general classification of continuous service moving way transportation systems. Escalators and moving walks rank as one of the safest transportation modes in terms of the numbers of passengers carried, enjoying wide public acceptability and use for more than 80 years. It has been estimated that there are currently more than 15,000 escalators and moving walkways in the United States. Estimates of use differ, but annual passenger volume may be as high as 30 billion trips. [1] Serious accidents on these systems are relatively rare, and overall accident frequency is well below that of other means of transportation. [2] Although specific national moving way system accident records are not maintained, fatalities are a most unusual occurrence. For example, the Port Authority of New York and New Jersey, a large metropolitan transportation agency with 334 escalators and 10 moving walks installed at its various facilities, has not experienced a passenger fatality on these systems during a period when it is estimated that more than 3 billion uses occurred. All available moving way transportation system accident data indicates that accident experience is well within the norm experienced with typical pedestrian activities.

For example, the National Bureau of Standards has estimated that deaths relating to the use of stationary stairs occur about once in one half billion uses. [3]

Accelerating moving walkway systems will introduce several new operating characteristics which may influence accident experience. Depending on the system, treadway surfaces will either expand and contract, shift direction, or be comprised of rollers, as compared to present systems where the treadway surface is of a constant linear moving configuration. The expansion and subsequent contraction of the treadway surface may produce dense crowding as pedestrians close ranks in decelerating sections of the system. Instead of a continuous moving handrail of constant speed and configuration, multiple handrials moving at different speeds, or expanding and contracting handrails will be encountered. Additionally, there is the question of the adaptability of different elements of the user population to the acceleration, deceleration and higher constant speeds of the new systems. A primary consideration will be the acceptability of these new operating characteristics to the elderly and handicapped.

On the basis of limited passenger tests of existing prototype accelerating moving walkways, the probable safety experience with the new systems may fall somewhere between that of existing moving walks and the escalator, which generally has a higher rate of accidents than the level walk. However, the final determination of the actual safety and acceptability of the new systems can only be made in the context of an operational demonstration and use by the general public. The purpose of this report is to identify the human factors and safety considerations associated with the accelerating moving walkway technology, and to establish as accurately as possible the probable degrees of user risk.

Figure 1.1 following illustrates the evaluation process that will be undertaken to determine the acceptability of an Accelerating Moving Walkway System for general unsupervised public use. The initial phase of the evaluation process is divided into three basic assessment procedures: (1) the determination of system operating characteristics and identification of potential accident hazards through an assessment of the available technology; (2) the assessment of moving way transportation system accident experience and its potential relationship to the probable frequency and severity of AMWS accidents; and (3) an assessment of the human factors that would be active in the use of an AMWS by the general public, including the elderly and the handicapped. The prospective risks of the candidate systems will be evaluated on the basis of the above and the preliminary operational acceptability of the candidate systems will be determined. As a result of this determination, it may be considered necessary to require modifications of the equipment prior to acceptance as a demonstration candidate, or to institute controls in its prospective manner of use (or both). This aspect of the evaluation process will be extended into the pre-demonstration factory testing of the successful candidate supplier for the demonstration, to assure that the system will perform as anticipated prior to its shipment to, and installation at, the demonstration site.

The final phase of the system safety evaluation will be the public demonstration program. This program will begin with an initial period of user tests prior to the opening of the system to general public use. During this period, tests will be made with representatives

SAFETY EVALUATION

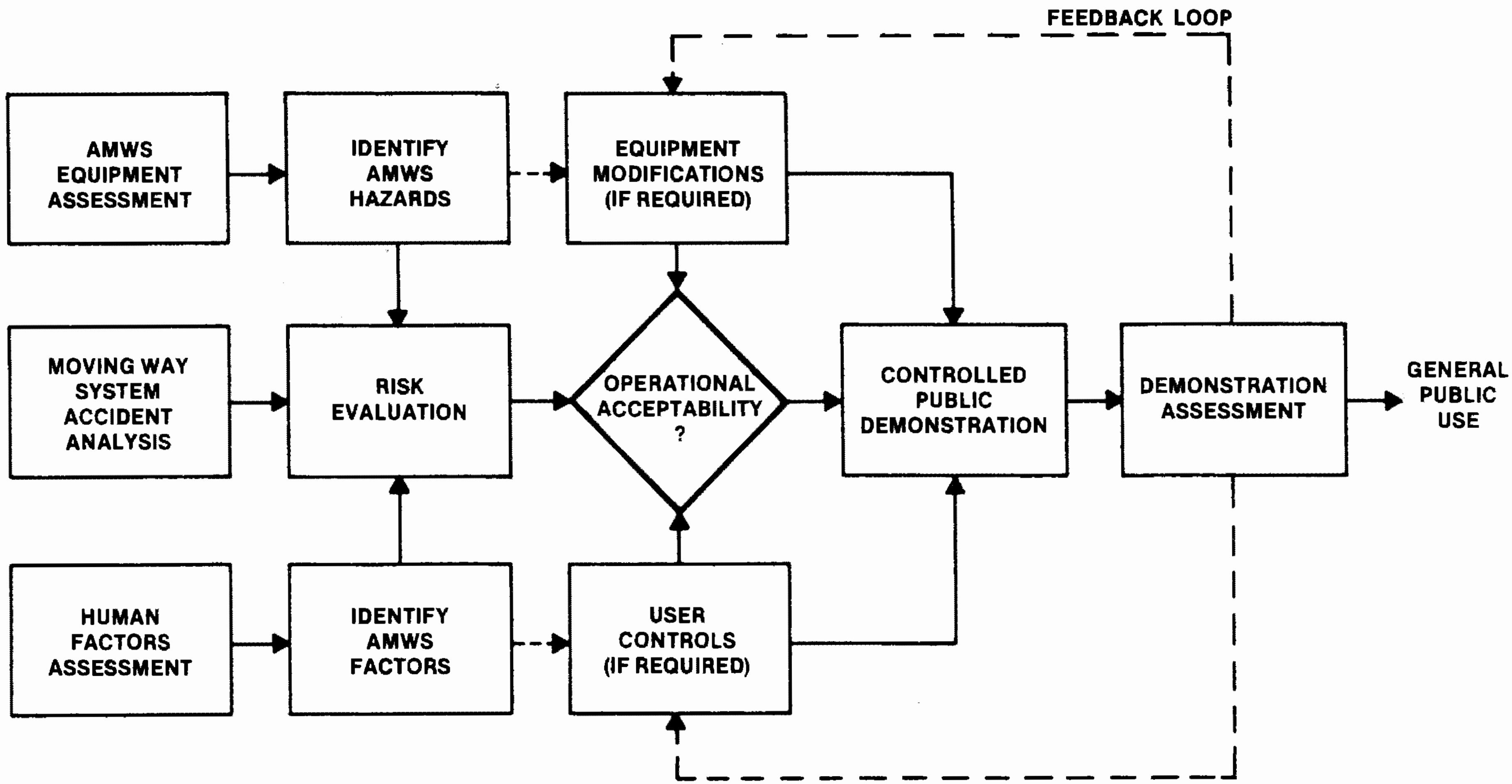


FIGURE 1.1 ACCELERATING MOVING WALKWAY SYSTEMS

of the general user population as well as the elderly and various categories of the handicapped. User difficulties will be observed during this period, and if necessary, modifications in equipment operation or system use made to minimize these difficulties in the later general public use demonstration. The pre-demonstration tests will include evaluation of emergency stopping procedures as well as other response procedures to user incidents or equipment malfunctions. Detailed data will be collected during the public demonstration of the system including evaluation of all accidents or equipment malfunctions, near accidents, missteps, or other factors needed to establish user adaptability to the system and the degree of potential accident risk for unsupervised general public use.

1.2 Transportation Safety Overview

Urban transportation systems have been classified as "inherently hazardous" from the standpoint that any mechanical system operating in close proximity to, or occupied by large numbers of the general public is likely to experience some degree of accident risk. [4] As shown in Table 1.1 following, accidents vary significantly by transportation mode, with escalators having one of the lowest accident risks in terms of occupant exposure. Fatalities are a very rare occurrence, estimated at about one in more than five billion uses.

The table also shows that stationary stairs have ten times the fatality rate of escalators. Comparable statistics are not available on moving walkways but it is known that the accident rate is lower than escalators because many escalator accidents are associated with the

SAFETY PERFORMANCE DATA - TRANSPORTATION MODES [1]

MODE	NO. UNITS (THOUS.)	NO. ANNUAL OCCUPANTS (BILLIONS)	ANNUAL FATALITIES	FATALITIES PER BILLION OCCUPANTS	ANNUAL INJURIES	INJURIES PER BILLION OCCUPANTS	COMMENTS
Urban Bus	49.6	5.38	15.0	2.79	31,579(a)	6,865	(a) passenger accidents only
Rail Transit	10.6	2.00	10.0	5.5	18,062(a)	9,265	
Taxi Cabs	180.0	4.14	125.0	30.0	N.A.	N.A.	
Scheduled Air	2.17	0.16	120.0	745	141	876	
General Air	130.0	0.08(b)	1335.0	17,000(b)	1,846	23,700(b)	(b) assumed 200 annual flights 3 occupants/ flight
Passenger Railroads	8.5	0.27	25.0	92.0	570	2,084	
Auto	92,800	185.6 (c)	34,200	184.3 (c)	1,250,000	6,735(c)	(c) assumed 1000 annual uses vehicle occupants 2/use
Motorcycle	3.787	3.79(d)	2700.0	712.4 (d)	N.A.	N.A.	(d) assumed 1000 annual uses vehicle, 1 occupant/use
Elevator	321	36.47	13.0	0.37	533	14.6	
Escalator	12.7	1.78	0.33	0.19	640(e)	360	(e) based on hospital case data
Stairs [2]	N.A.	1953	3800	1.95	2,660,000(f)	700	(f) disabling accidents

NOTES: [1] Source: "Safety in Urban Mass Transportation" - Report No. UMTA RI-06-0005-75-2 - Battelle Institute - except for estimates for general air, auto and motorcycle use.

[2] Source: Preliminary Report - "Stair Safety Performance Requirements for Retrofitting Buildings" - John Archea, National Bureau of Standards, August 1976. [Ibid. ref. 3]

TABLE 1.1

30-degree angular inclination of these systems as well as the emergence and retraction of the stepped treadway surface. An accident sampling study conducted by the Boston Moving Walkway Authority showed that moving walk accident experience was about one sixth that of escalators. [5]

The difficulty with comparing the accident experience of the different systems on a national basis is associated with the establishment of their relative exposures as well as the means of accident reporting. Exposure involves not only the total number of persons using a system, but the system environment and the characteristics of the users themselves. Port Authority escalator and moving walk accident rates at its different bus, rail transit and air terminal facilities vary significantly. One terminal serving bus commuters almost exclusively has a much lower rate per bus passenger than another larger and more heavily used facility which serves a more mixed passenger population comprised of greater numbers of elderly as well as more occasional users. The commuter group is more likely to represent a middle age bracket, physically active working population using the same facility on a repetitive basis. With regard to accident reporting, the larger bus facility has greater employee coverage, increasing the likelihood of reports of minor accidents.

1.3 The ANSI A17 Safety Code

The A17.1 American National Standard Safety Code for Elevators, Dumbwaiters, Escalators and Moving Walks is a model safety code which has been widely adopted by states and municipalities as their official code. [6] The provisions of the code cover materials, dimensions, loadings, mechanical and electrical design, equipment speeds and other factors considered necessary to maintain the operation of lifts and moving way systems at high standards of safety.

The code is kept current by the Americal National Standards Committee, A17, which operates under American National Standards Institute (ANSI) procedures. The A17 Committee has balanced membership comprised of representatives from government, equipment and component manufacturers, professional societies, organized labor, insurance interests, equipment owners, and other interested individuals.

Changes to the code may be recommended by committee members or by others not affiliated with the committee. Generally, changes are proposed when a design feature or method of operating the equipment is believed to have a contributing role in accidents. The proposed changes to the code are referred to technically specialized subcommittees for review. After consideration, the subcommittees report their findings and code changes if recommended to an Executive Committee. Any proposed change in the code must be voted upon, by letter ballot, by the entire standards committee. Even one negative vote, accompanied by a reason, is sufficient to cause reconsideration. The final vote on recommended changes to the code, and possible revision of the prospective change, while not requiring unanimity, does require a general concensus rather than a simple majority. All actions of the A17 Code Committee are subject to procedural review by the Secretariat, the American Society of Mechanical Engineers (ASME) and American National Standards Institute. The procedures and the varied technical expertise of the members combine to produce a code that is widely recognized and adopted throughout the United States, and frequently referenced internationally.

A special subcommittee of the A17 Code Committee has been convened to address prospective changes or additions to the safety code required for the design and operation of an accelerating moving walkway. The special subcommittee has been addressing areas not covered in the existing code such as maximum recommended walkway speed, acceleration and deceleration, the rate of change of acceleration (RCA), handrail design, balustrade detailing and other features of the new technology. The revised version of the code will provide a basis for the development and evaluation of accelerating walkways. As AMWS operating experience is gained, further revisions to the code may become necessary.

1.4 AMWS Safety - Goals and Objectives

Although moving way systems rank as one of the safest means of transportation, the relative safety and acceptability of accelerating walkways will be based on the users' personal experience, by observations or reports of other users of the system, or through media coverage. A safe system may be perceived as unsafe by users because of its characteristics of operation, observation of a serious accident, albeit a rare or unusual happening, or reports of such an unusual incident by the media. The fundamental safety goal of the public demonstration would be to run the Accelerating Walkway System without an accident. This requires careful attention to all the factors that may have some contributing causal role. However, it should be recognized that it will not be possible to completely eliminate the probability of an accident, particularly since some of these factors are user related and beyond the control of the equipment manufacturer and operator.

Table 1.2 is a topological outline of the factors associated

ACCELERATING WALKWAYS - SAFETY FACTOR TOPOLOGY

USER, SETTING ATTRIBUTES	EQUIPMENT ATTRIBUTES					
	TREADWAY		HANDRAIL		BALUSTRADE	DRIVE
	MOTIONS	FORM	MOTIONS	FORM	FORM	
USERS	EQUIPMENT	EQUIPMENT	EQUIPMENT	EQUIPMENT	PROTRUSIONS	VIBRATION
ALERTNESS	ACCELERATION	PALLETS	MOVEMENT RELATIVE TO TREAD, UNIFORMITY	CONTINUITY	SHAPE	NOISE
AGE & SEX	DECELERATION	BELTS	EMERGENCE FROM AND RETURN INTO BALUSTRADE	HEIGHT	NEWEL EXTENSIONS	HEAT
AGILITY	RATE OF CHANGE ACCELERATION	DIMENSIONS	FAILURE MODE	HANDGRIP OR CONSTRAINT CROSS-SECTION	HAND CLEARANCE	OVERLOAD AND FAILURE MODES
CONFORMITY	UNIFORMITY	FRICTION FACTOR	NOISE & VIBRATION	RETURN TRAP	SMOOTHNESS	BRAKING
STRENGTH	MAXIMUM SPEED	SLIDING	HEAT	COLOR		
HEIGHT	EMERGENCY STOP	MESHING	USER	FRICTION FACTOR		
HANDICAPS	NOISE AND VIBRATION	ROLLING	GRASPING	USER		
PERCEPTION	SURFACE EXPANSION/ CONTRACTION	SHEARING	STRENGTH	HAND HEIGHT		
REACTION	FAILURE MODE	COMBING	PERCEPTION	BODY C OF G		
EXPERIENCE	USER	TOLERANCES	REACTION	CLOTHING		
LEARNING	BOARDING	FINISHES		ACCESSORIES		
ACCESSORIES	STEPPING OFF	USER				
FOOTWEAR	STANDING	FOOTWEAR				
SETTING	WALK ON TREAD	SOLE FRICTION				
LIGHTING	SPEED PERCEPTION	CLOTHING				
COLORS	REACTION	CANES, CRUTCHES				
DISTRACTIONS		CARTS				
TRAFFIC		BAGS				
		ACCESSORIES				

with the safe use of an Accelerating Walkway. This outline includes user, site and equipment attributes. The user must have the basic agility, perception and reactive capabilities to board and subsequently step off of the moving treadway surface. Hand height and strength, as well as perception and reaction are factors relating to the user's ability to grasp the moving handrail and avoid tripping due to a misstep, or perhaps an emergency stop of the walkway. The accessories carried by system users can be an accident factor where bags or packages are placed on the treadway obstructing movement, or possibly caught up by the system to present a tripping or entrapment hazard. Similarly, footwear and certain types of clothing can contribute to the tripping and entrapment hazard. Soft footwear with high friction coefficients such as rubber sneakers can result in a gripping action on equipment shearing surfaces. Pliable footwear of this type may also result in the failure of safety features designed to prevent entrapment or to stop the equipment if it occurs.

Of particular concern in the development of accelerating walkways as a viable means of public transportation is its adaptability to the elderly and handicapped. The basic AMWS development objectives for the elderly and handicapped would be that the system would have equal or better safety and utility for the segment of this population now using conventional escalators and moving walkways, and if possible, that this user population be extended. Templer and Jones in their work on pedestrian mobility developed a classification of the numbers of the handicapped by subgroups shown in Table 1.3. [7] Estimates of the numbers of the handicapped population are complicated by the fact that a

Table 1.3

CLASSIFICATIONS OF THE HANDICAPPED

ATTRIBUTES	HANDICAP	SUBGROUP	NO. PER 1000 POPULATION
Size and maturity	Developmental restrictions.	1. Preschool children	97.50
		2. School-age children	216.57
Agility, stamina, and reaction time	Chronic restrictive conditions related to agility, stamina and reaction time.	3. Persons over 65	103.30
Legs	Lower extremity impairment.	4. Confined to wheelchair	2.07
		5. Walk with special aids	23.49
		6. Walk with difficulty without the use of special aids	10.92
Arms and shoulders	Chronic impairment of upper extremities and shoulders.	7. Chronic impairment of upper extremities and shoulders	12.06
Hearing	Severe auditory impairment.	8. Severe auditory impairment	8.70
Sight	Severe visual impairment.	9. Severe visual impairment	2.25
Mental equilibrium (Comprehension)	Obvious confusion, and/or disorientation	10. Obvious confusion and/or disorientation.	93.19

SOURCE: "Barrier-Free Environments" - J. Bednar Ed., Chap. 2, J. Templer, M. Jones - "Pedestrian Mobility", pp. 17-43. [Ibid. ref. 7] person may have more than one physical or mental impairment.

The setting or environment in which the accelerating walkway is placed could affect system safety. Inadequate or distractive lighting may affect the user tasks of boarding and stepping off the walkway. Unusual color combinations, movements or other distractive features can cause motion illusions which might affect the performance of some users. The volume, density and direction of pedestrian traffic, and waiting and queuing could cause anxiety for some, as well as obscuring system entrances and exit features.

Equipment components affecting user safety include the treadway, handrail, and their driving mechanisms, and the balustrade. The movement characteristics of the treadway, its composition and finishes, means of surface expansion and contraction, and method of combing would be among the factors to be considered. Accelerating walkway handrail designs are less advanced that that of the treadway for most of the candidate systems, so that some prospective safety considerations may not yet be identified. The movement of the handrail relative to the treadway surface, handrail composition and configuration (handgrips, multiple handrails, accordion types), height, clearances and return trap configuration would be important factors. Balustrades are passive elements of the walkway system, but such factors as the clearances between the balustrade and moving handrail, balustrade protrusions into the treadway, and the newel extension treatment at entry and exit must be considered. Drive mechanism characteristics that might influence user safety include vibration, noise, heat, and the overload and failure modes.

Based on the above review, the AMWS safety objectives are summarized as follows:

- The AMWS should be as safe, or safer, than existing escalators and conventional moving walkways;
- The requirements of the handicapped and elderly will be considered in evaluating the design features and operating characteristics of accelerating walkways, so that as a minimum, the segment of this population currently using existing escalators and conventional walkways will be served by the new systems, and if possible, the potential numbers of users from this population will be extended;
- The design of the AMWS, its physical setting, and manner of operation should be such that there is a minimal probability of an accident, and that the potential severity of such an accident is limited.
- The design of the AMWS should meet the revised A17 Code.

2.0 ANALYSIS OF AMWS SAFETY

2.1 General Discussion

Section 1.1 of the report outlined the basic evaluation procedure used to determine the relative safety of a typical human interface situation involving an accident potential. This procedure consists of hazard identification, risk evaluation and a judgment of the acceptability of that risk. A definition of the terms, hazard, risk and exposure are necessary to avoid confusion. Hazard has been defined as the source of a risk which may be capable of inflicting an injury. [8] Risk is the amount of peril, or more precisely a statistical probability or quantitative estimate of the frequency and severity of an injury associated with exposure to the risk. Exposure is the frequency of contact with the hazard in terms of number of uses, or temporally in terms of the period of use in minutes or hours. A hazard can exist, but there may be no risk if there is no exposure. For example, a potentially hazardous motor might be enclosed or shielded in such a manner that there is no exposure, and thus no risk associated with its operation. However, a mechanic might be subjected to an accident risk if the enclosure is removed to repair the motor. Accident severity is another factor that must be considered in evaluating the safety acceptability of the accelerating walkway. Not all injuries are equal. Bruises or skin abrasions are not as serious as an amputation or bone fracture, or the loss of life.

The potential hazards, risks, and accident severity associated with the use of accelerating walkways has been developed from a number of sources including a search of the relevant literature, information received from prospective AMWS developers, an analysis of escalator accident experience, participation in committee meetings of the Special Moving Walk Sub-committee deliberating changes to the A17.1 Safety Code, participation in a Project sponsored Safety Seminar, discussions with special Project consultants retained for this purpose, and the review of reports submitted by these consultants as part of the project. The proceedings of the AMWS Safety Seminar are available as Report G of the Project series.

2.2 System Descriptions

A brief description of Accelerating Walkways is presented in this section to provide general information about system characteristics relating to safety. More detailed system data and information may be found in Report B, "AMWS Technology Assessment", Five prospective AMWS(s) are currently advanced sufficiently in terms of hardware development to be considered as candidates for participation in a general use public demonstration. Additional systems may be further developed subsequent to this report. The current candidates listed in approximate order of development, are the Dunlop Speedaway system; the TRAX system, an operational prototype developed by the Regie Autonome de Transports Parisiens (Paris Transit Authority); the Applied Physics Laboratory prototype developed by Johns Hopkins University; the Boeing system design by the Automated Transportation Division of the aircraft company; and the prototype by Dean Research, an industrial conveyor corporation. All of these systems will have potential hazards in common with each other, and others will have characteristics which are unique to that specific design. The problems of acceleration, deceleration, and higher walkway speed, are, of course, common to all.

The Dunlop Speedaway one directional design resembles the entry characteristics of an escalator, but with a much wider treadway comprised of rectangualr platforms fed at escalator speed at entry and then accelerated laterally in the primary direction of travel to five times the boarding speed. This combination of transverse and longitudinal speeds produces an 'S'-shaped trajectory or path for the roller mounted platforms, which are guided by tracks. The platforms form an endless belt, which is propelled by friction drive supplied by variable speed electric motors. Conventional combplates are provided at the entry and exit. The speed ratio and acceleration/deceleration rate determines the geometric shape of the platforms, the width of guideway tracks and the dimensions of the entry and exit sectors of the system. The 'Speedaway' handrail is designed in seven independent constant speed sections with handrail speed matching walk speed in the constant high speed zone, and averaged to the speed of adjacent walk sections in acceleration and deceleration zones. (see Photo 2.1). The Dunlop system is the only AMWS utilizing a non-changing tread like an escalator, although the direction of the tread changes. Other AMWS's rely on expansion and contraction of the treadway surface in some manner, or rollers to produce walkway acceleration and deceleration. The Speedaway system prototype has undergone considerable engineering testing and demonstration in a laboratory environment and the first production unit is nearing completion.

The Trax variable speed conveyor is a two directional loop system with a continuous treadway comprised of self combing intermeshing grooved sliding plates conventionally combplated at entry and exit. The relative longitudinal sliding motion of grooved plates is obtained by

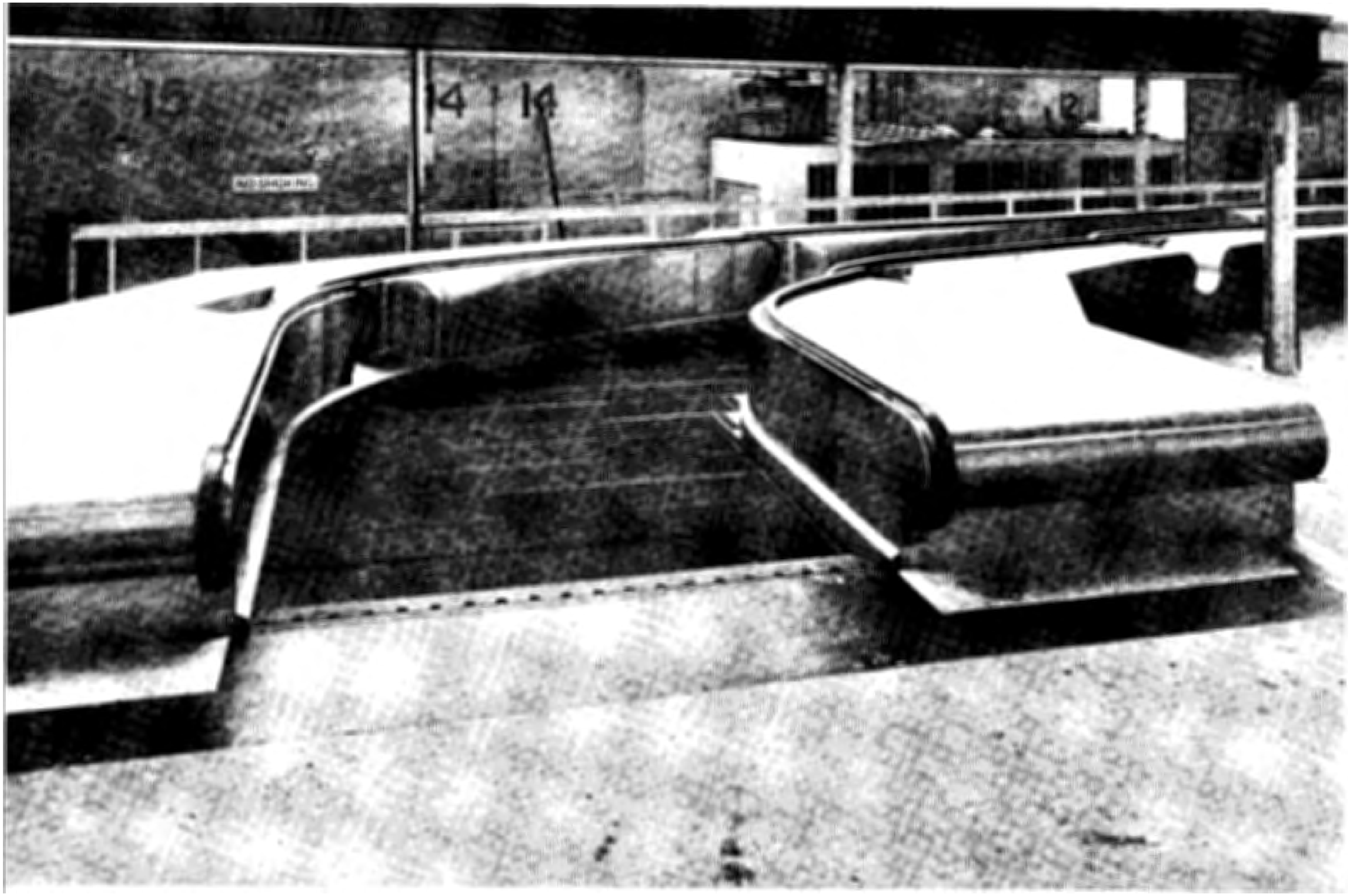


FIGURE 2.1 DUNLOP SPEEDAWAY SYSTEM

interconnecting the underside of each of two successive plates by a moveable chain linkage. The movement of the chain (and plates) is controlled by sprockets and a telescoping tube assembly which runs in variable gauge tracks flanking the undersides of the treadway. The gauge or spacing between rails determines the configuration of the treadway carriage combination of telescoping tubes, sprockets and chains. The rails are spread wider and plates meshed closer together in the walkways' slow speed section, and conversely, the rails are closer and plates spread further apart in the high speed section. Electric motors driving cleated chains power the system (see Photo 2.2). The Trax handrail consists of individual handgrips, and between these a covered chain linkage forming a continuous but less comfortable handhold. The exposed length of the covered chain varies with system speed. At the boarding and discharge zones, the spacing of the individual handgrips would correspond to the minimum desirable distance between passengers, mitigating bunching. The Trax system has undergone user and engineering testing in a laboratory environment.

The Johns Hopkins University, Applied Physics Laboratory (APL) variable speed walkway is a linear, one-directional design using a treadway comprised of overlapping, intermeshing, leaves combing each other and conventionally combplated at entry and exit. The leaves are linked together to form an endless chain, supported by a guiding track. Acceleration and deceleration is accomplished by a variable pitch screw and guiding tracks beneath the treadway which changes the leaf angle to expand or contract the treadway surface. Each of the individual leaves forming the treadway is curved so that the composite surface remains practically level during changes of the leaf angle. The system is electrically driven. The

FIGURE 2.2 RATP TRAX SYSTEM

FIGURE 2.3 APPLIED PHYSICS LABORATORY SYSTEM

handrail concept is a covered coil spring slaved in mean speed to match the leaved walkway speed. A 31 foot (9.5 m) long prototype of the APL Variable Speed Walkway has undergone preliminary engineering testing and demonstration at the Johns Hopkins University Laboratory, Laurel, Maryland (see Photo 2.3).

The Boeing High Speed Moving Walkway proposal is a two directional loop system with a continuous treadway comprised of overlapping, intermeshing, sliding pallets combing each other and conventionally combplated at entry and exit, similar to the Trax system. The sliding pallets would be mounted on rollers running in flanking tracks. Propulsion would be supplied by a linear induction motor. Variable speed performance would be achieved by cam tracks and linkage mechanisms to provide the changing of the overlap of the intermeshing pallets. The spread of the pallets and length of the treadway would be increased in the acceleration section and decreased in the deceleration section. A matching speed handrail is proposed employing overlapping sections to form a telescoping variable speed handrail for the acceleration/deceleration areas. Fabrication of a system prototype is in progress as of the writing of this report (see rendering 2.4).

The Dean Research prototype AMWS is a linear one directional system utilizing a treadway surface comprised of a series of abutting steel rollers. The steel rollers in acceleration and deceleration sections are programmed to produce gradually increasing or decreasing speeds. Hydraulic motors were used for the variable roller speeds in an early prototype, but the developer has alternative means of propulsion under consideration. User tests have been performed on a very short length prototype, reportedly without incident. An operational handrail has not yet been

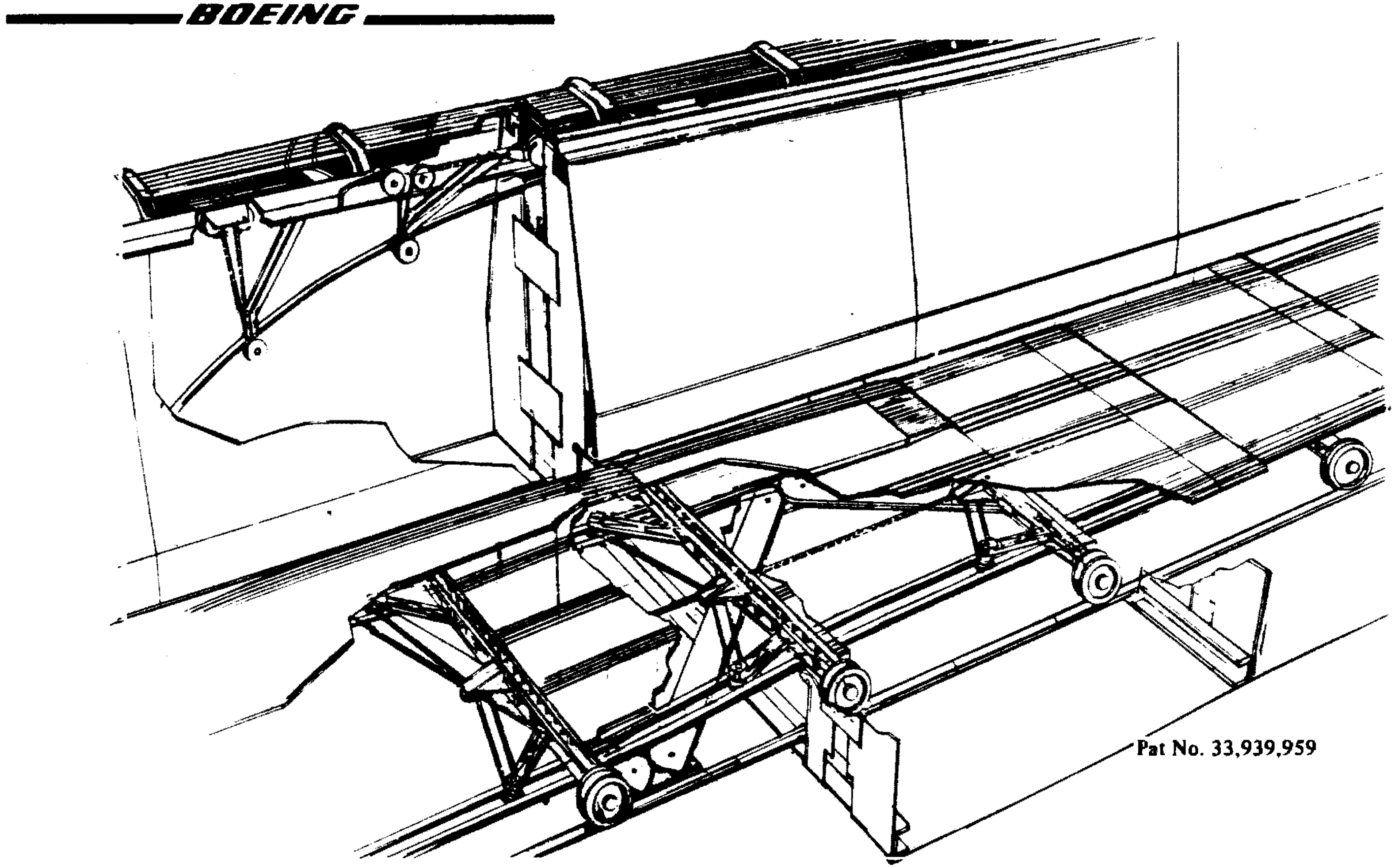


FIGURE 2.4 BOEING SYSTEM

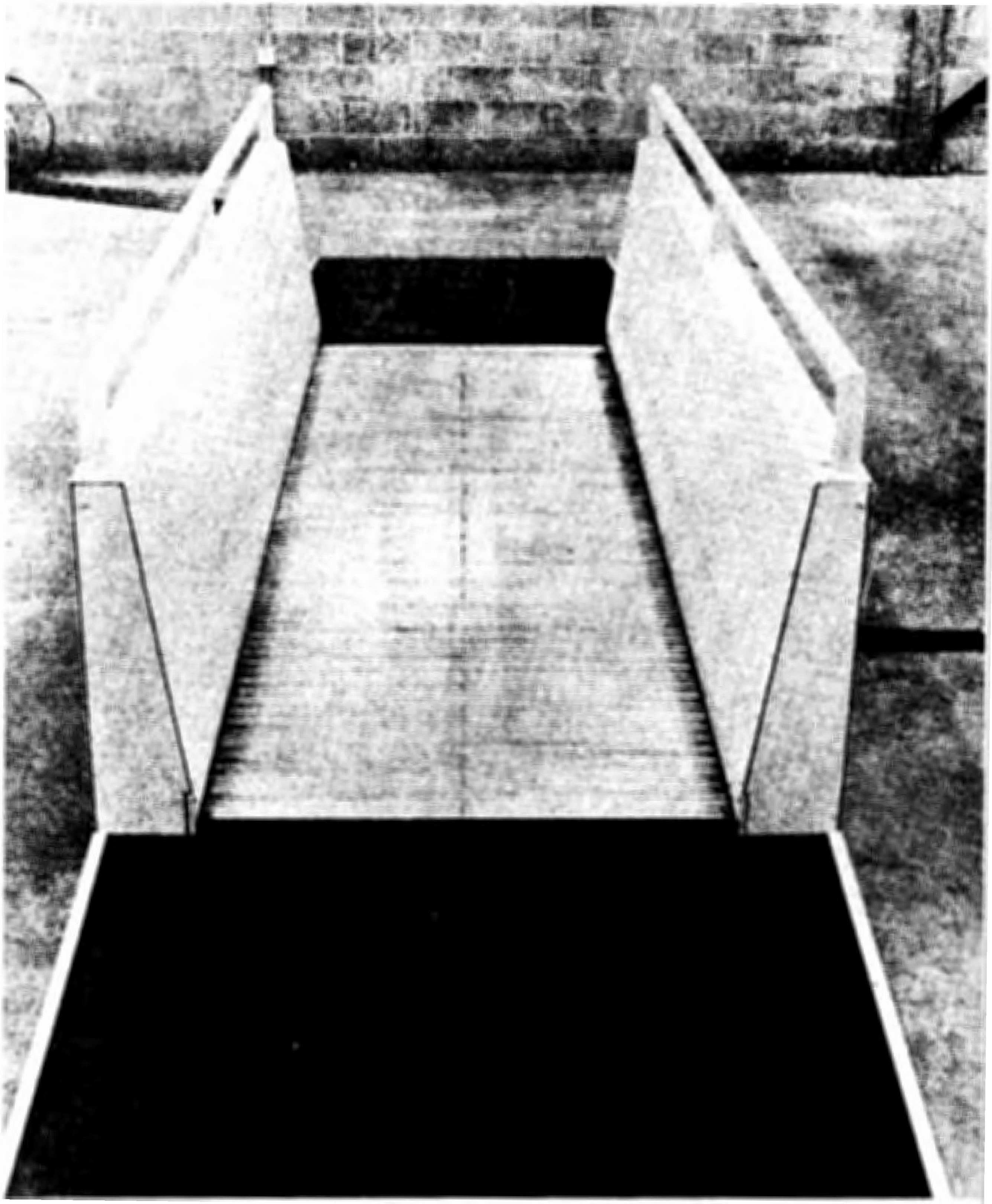


FIGURE 2.5 DEAN RESEARCH SYSTEM

developed, but a solid handgrip running at the speed of the treadway, with the interposition of a variable section between, has been proposed (see Photo 2.5).

2.3 Identification of AMWS Hazards

Based on a review of the current AMWS technology, six potential equipment related accident hazard categories have been identified. An additional general category can be considered encompassing characteristics of the environment which in combination with equipment affects and user responses might be hazardous. The equipment related hazard categories have been termed (1) inertial, (2) entrapment, (3) divergence and surface discontinuity, (4) bunching, (5) post problems, and (6) mechanical failure.

Inertial Hazard

The inertial hazard refers to the movement forces placed on the user by the acceleration, deceleration, the rate of changes of acceleration or deceleration, ("Jerk"), or sudden emergency stopping of the equipment. Coriolis is another force affect that is not associated with the equipment being considered, but would be present in systems using turntables or other devices involving circular movement paths to accelerate or decelerate passengers. Too rapid acceleration or deceleration could cause AMWS passengers to loose their footing and fall, unless the fall is arrested by grasping a handrail.

Linear acceleration or deceleration of a body is defined as the change of its velocity during an interval of time divided by the duration of the interval. (9) Average or uniform acceleration and deceleration is expressed as,

$$\frac{\text{final velocity (vf) - original velocity (vo)}}{\text{time interval (t)}}$$

Acceleration or deceleration can be expressed in terms of the force of gravity (G), with a force of 1G equaling about 32 feet per second, per second, (980 cm/sec^2). Another motion characteristic that has been found to be a factor in upsetting passengers on transit vehicles is the rate of change of acceleration, termed "jerk" by some investigators, and using the initial letters, "rococ" by Hirshfeld. (10) Because of possible misinterpretations or misconceptions of the term "jerk" by the general public, the use of this word is not recommended. In the popular vernacular "jerk" connotates an irregular, uncomfortable movement sensation, whereas a uniform rate of change of acceleration (RCA), represents a smooth transition to the final uniform velocity state, and is not "jerky". The uniform rate of change of acceleration or deceleration is expressed as:

$$\text{RCA} = \frac{\text{acceleration, deceleration (a, d)}}{\text{time interval (t)}}$$

Acceleration and rate of change of acceleration data from transit industry sources compiled in a recent study, are shown on table 2.1. (11) These data show a range for normal acceleration and deceleration of transit vehicles of 0.093 to 0.164 G's, for emergency deceleration rates 0.102 to 0.319 G's, and for the rate of change of acceleration (RCA) 0.084 to 0.300 G's per second. The criteria for seated passengers would necessarily be different than standees. Experiments with unsupported standees, in which the advent of foot movement (not

Typical Transit Vehicle Longitudinal Acceleration, Deceleration Rate of Change Acceleration

Vehicle	Normal Acceleration (m/s^2)	G's	Normal Deceleration (m/s^2)	G's	Emergency Deceleration (m/s^2)	G's	Rate of Change of Acceleration (RCA) (m/s^3)	G's/SEC
Toronto Subway	1.12	0.114	1.25	0.128	1.34	0.137	2.68	0.273
San Francisco BART	1.00	0.102	0.91	0.093	1.00	0.102	0.91	0.093
Washington Metro	0.91	0.093	0.91	0.093	1.00	0.102	0.82	0.084
SOAC	1.20 1.34	0.122 0.137	1.20 1.43	0.122 0.146	1.56	0.159	1.12	0.114
SLRV	1.25	0.128	1.56	0.159	2.68	0.273	1.12	0.114
Amsterdam LRV	1.00	0.102	1.50	0.153	2.70	.276	-	-
Bern LRV	1.20	0.122	1.20	0.122	3.00	0.306	-	-
PCC Streetcar (old)	1.61	0.164	1.61	0.164	3.13	0.319	-	-
Japan Railways	1.27	0.130	1.37	0.140	2.16	0.220	2.94	0.300
Minitram Research (Limit Standing)	1.25 1.50	0.128 0.153	1.25 1.50	0.128 0.153	- -	- -	1.25 1.00	0.128 0.102
AVERAGES	1.22	0.125	1.31	0.133	2.06	0.211	1.48	0.151

NOTES (1) 1 m/s^2 = 3.28 $ft./sec.^2$ (2) G the force of gravity = 32 $ft./sec.^2$, 980 $cm/sec.^2$

SOURCE: Young, J. A. - "Passenger Comfort in Urban Transit Vehicles"

SOA Report Ontario Ministry of Transportation and Communication
Jan. '76 50 pp, bib.

falling) caused by various average rates of acceleration and RCA are shown in Table 2.2. This data is based on the Hirshfeld 1932 PCC car experiments and involved 79 passengers of varying ages and physical conditions for 489 equipment runs. (12)

Browning conducted somewhat similar experiments, but more specifically addressing the problems of accelerating walkways. (13)(14) Browning also concluded that the upsetting effect of acceleration that causes staggering or stumbling depends not only on the level of acceleration but the time taken to reach this level. Very rapid changes of acceleration, attained in less than 1/2 second, give a greater upsetting effect than slower more uniform changes to reach the same level of acceleration. Browning collected considerable film evidence of the reactions of free standing passengers to acceleration and RCA in controlled tests. These films were repeatedly viewed and analyzed in detail and were subjectively classified according to large, moderate, slight or virtually no body movements, by noting the passengers' adaptability to the various accelerations. On the basis of these experiments, Browning developed a relationship combining values of acceleration and rise time for the various passenger movement effects. The relationship is expressed as follows:

$$\text{acceleration level} = a + b\ (t_0 - 1)$$

where t_0 is the rise time in seconds.

Passenger effects for values for a and b at either rise times equal or greater than one second, or less than one second, are shown on Table 2.3. These accelerations and their concomitant rates of change are translatable into the required lengths for the acceleration and

TABLE 2.2

MAINTENANCE OF EQUILIBRIUM UNDER ACCELERATION - PERCENT OF UNSUPPORTED STANDEES WITHOUT FOOT MOVEMENT

(HIRSHFELD'S PCC EXPERIMENTS)

AVERAGE ACCELERATION ATTAINED		RATE OF CHANGE OF ACCELERATION (RCA - ft/s^3)		
(ft/s^2)	G's	2.5 ft/s^3 (.078 G/s)	4.5 ft/s^3 (.141 G/s)	6.5 ft/s^3 (.203 G/s)
1	.031	99%	97%	99%
2	.063	95%	93%	93%
3	.094	87%	81%	85%
4	.125	67%	70%	80%
5	.156	42%	55%	70%
6	.188	12%	30%	60%
7	.219	4%	18%	20%
8	.250	1%	7%	-

Source: References 10, 12.

TABLE 2.3

Maintenance of Equilibrium Under Acceleration - Unsupported Standees

(Browning's Formula)

Passenger Effects (in terms of movement)	Values of (a) in G's	Values of (b) in G's $t_0 \leq 1$	$t_0 > 1$
Large	0.15	0.03G	0.01G
Moderate	0.12	"	"
Slight	0.09	"	"
Virtually none	0.06	"	"

Acceleration level = $a + b\ (t_0 - 1)$
Where to = rise time in seconds

Source: References 13, 14

sections of AMWS, for a given constant velocity in the high speed section of the walk.

The actual transition from the stationary pavement surface to boarding of the moving surface of conventional slow speed moving walkways and escalators may be worse than the rider accelerations and decelerations being considered by AMWS developers. Photographic observation and detailed analysis of the boarding sequences of 142 pedestrians using the 164 fpm (50 m/m), 600 ft. (183m) long walkway at Montparnasse Transit Station, Paris showed that 20 percent were upset by the conveyor motion upon boarding to the extent that body position was noticeably displaced, with passengers either stumbling or temporarily losing balance, but not falling. (15) A follow-up study of 274 pedestrians boarding a 130 fpm (40 mpm), 750 ft. (232m) long walkway at Heathrow Airport, London, showed that 31 pedestrians had difficulties upon boarding ranging from a slight knee bend or sway, to two passengers who fell. This study determined that passengers who had slower approach speeds or stopped at the walkway portal were more likely to lose their balance. A passenger boarding a walkway from a completely stopped position to a treadway speed of 120 fpm (37 mpm) or more is probably undergoing greater shortime acceleration affects than the more gradual transition designed into the acceleration and deceleration modes of the AMWS.

A significant inertial problem associated with AMWS(s) will be the passenger toppling effects resulting from a sudden emergency stop. In an emergency situation, it is desirable to stop the equipment as quickly as possible, particularly where there may be an entrapment

The interface between Stationary and Moving Surfaces causes difficulties for many escalator users.

FIGURE 2.6

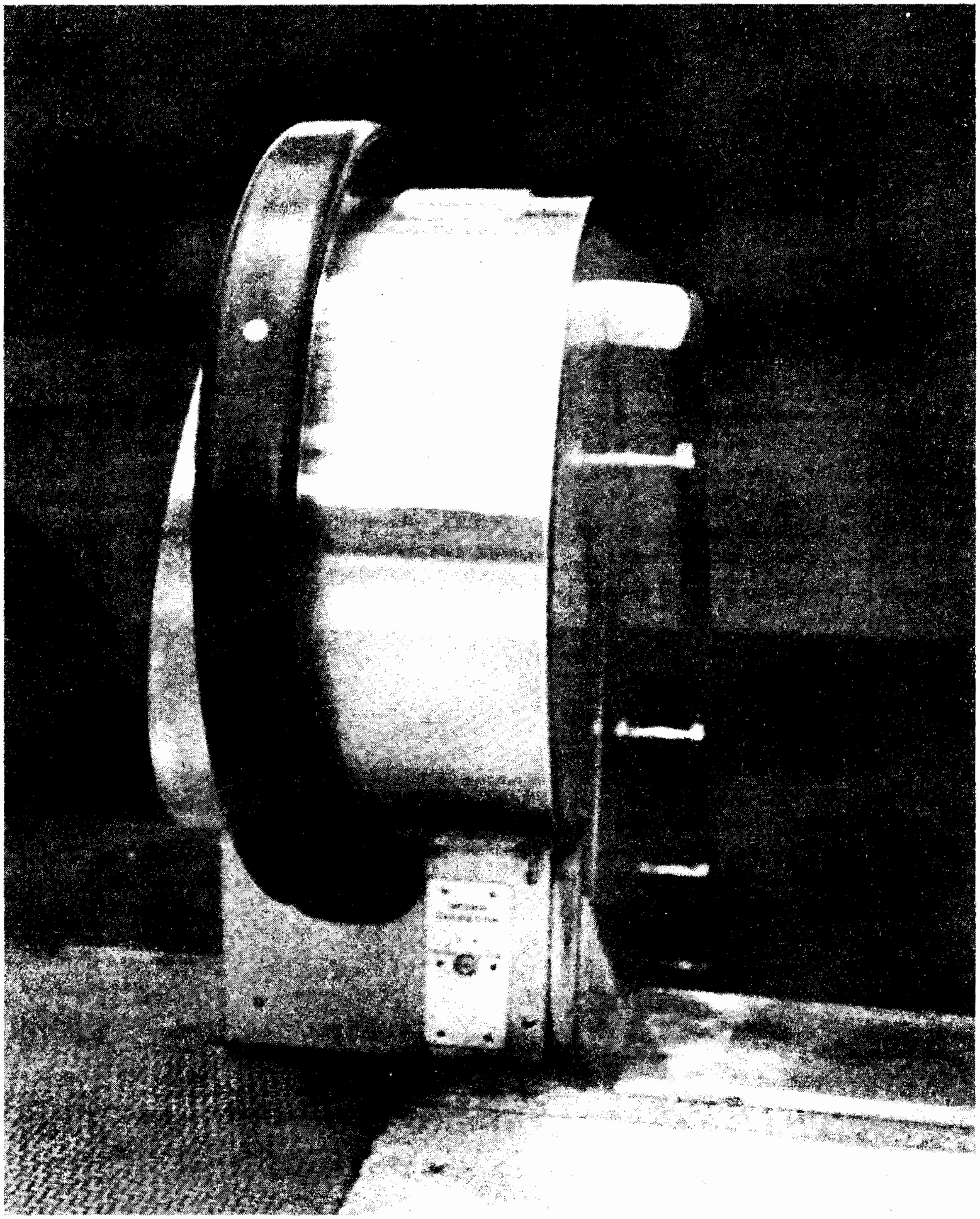
incident. However, stopping the system results in the possibility of toppling riders, subjecting them to the risks of falling. The consequences of falling will depend upon the deceleration rate and its rate of change, whether the fall can be arrested by grasping the handrail, the physical condition of the passenger, the configurations of the area in which the fall occurs, and pedestrian traffic density on the system. In the case of traffic densities, a potentially dangerous fall might be cushioned by a nearby passenger. A fall on an AMWS should have less risk than a fall on a downward moving escalator where the incline and stepped surface edges can increase accident hazard and severity. However, there is the potential for more falls with an emergency stopping of an AMWS because of its greater speed. The high speed mode of the AMWS may be related to the speed of many familiar human activities. An AMWS speed at about twice that of normal walking is slower than that of a beginning jogger, a competitive ("heel and toe") walker, or a skate boarder, and is about half the medium speed of the average cyclist. The consequences of falls at these speeds, on a level regularly shaped surface, with the possibilities for limiting the force of the fall by use of a handrail are not considered to be unacceptable.

AMWS manufacturers have specified emergency stopping decelerations ranging between 0.1 and 0.2 G, sufficient to cause moderate to large body movement for most riders, but below the maximums noted for transit equipment (Ibid Table 2.1). These emergency decelerations are the equivalent of stopping times ranging between 1-1/2 to 3 seconds. While emergency stopping times of this duration are seen as being reasonable to minimize toppling by riders on the system, there is a possibility that this elapsed time may limit the effectiveness of automatic safety devices installed by some manufacturers to detect and stop the equipment for mechanical failures or entrapment situations.

Entrapment Hazard

The entrapment of clothing, footwear or human extremities is an accident hazard common to all moving machinery. Entrapment hazards for both escalators and moving walks exist at the combplates, and for the escalator at the point where the step riser converges near the exit to form a level surface. Additional entrapment hazards exist at the edges of the treadway depending on the clearance between the treadway and balustrade, at the moving handrail, and at the handrail return. A significant reduction in handrail entrapment incidents resulted some years ago when the balustrades were extended beyond the end of the treadway and the handrail return placed more out of reach. The handrail return is the point at which the handrail reenters the covered interior of the equipment. (See Photo Figure 2.7.)

Certain types of footwear are more frequently involved in entrapment incidents. The gripping action of sneakers and rubber overshoes can result in their ingestion into an escalator, if for example, the foot is thrust against the step riser as it converges, held against the stationary balustrade, or caught in the combplates. Loose shoe laces or thongs may also be drawn into the equipment, causing the rider to fall, or in extreme cases causing extremities to be pulled into the equipment. Equipment wear can increase the possibilities for entrapment, if for example sections of the combplate become broken to create openings and prevent combing action, or where clearances between the stationary and moving parts of the system become larger due to wear. Entrapment accident severity on some equipment has been reduced by electrical sensing



Balustrade, Handrail Return and Stop Button - Typical Escalator

FIGURE 2.7

switches which will stop the equipment if the entrapment results in sufficient jamming force to trip the switch.

Possible entrapment hazards with accelerating walkways will exist at combplates and other types of transitional surfaces similar to those of existing conventional walkways, with additional entrapment potential at the intermeshing treadway surfaces characteristic of the APL, Trax and Boeing systems, and where pallet surface edges are retracted beneath the balustrade in the deceleration zone of the Dunlop Speedaway. AMWS handrails may also offer possibilities for entrapment as they converge in deceleration sections or where hand grip designs have features that might catch clothing or purse straps, or where the handrail return configuration is improperly designed or located.

Divergence and Surface Discontinuity Hazard

Divergence is defined as a displacement or differential in treadway or handrail speed or direction. Discontinuities are interruptions in treadway or handrail surfaces. Divergence and discontinuity problems exist at the entrance and exit of conventional excalators and moving walkways where users must adjust to differentials between stationary pavement surfaces and the equipment's moving treadway and handrail. Another divergence and discontinuity situation exists with the emerging stepped riser of the escalator, which can cause loss of balance if the user straddles the line between two emerging steps. The AMWS can present other divergence and discontinuity situations. The Dunlop Speedaway System will require adjusting hand positions for its sequence of seven handrails as well as for a differential in the handrail speed relative to the treadway. Shifting treadway positions, or more accurately, the shift in the facing direction of the rider relative to the direction of movement on the system, may also disorient some users of the Speedaway. Expanding and contracting handrails on other systems will also create differentials between hand location relative to standing position requiring adjustment of user hand and/or body position.

Divergence and discontinuity situations are mainly an accident hazard for inattentive users, those under the influence of alcohol or drugs, or segments of the elderly and handicapped with impaired perception and reaction capabilities. Persons with obscured views of handrail or treadway surfaces due to dense pedestrian traffic or hand carried packages may also experience some difficulty adjusting to divergence and discontinuity situations.

Bunching Hazard

Bunching may be defined as the crowding of pedestrians to such an extent that their free movement is restricted. Bunching is considered to be a potential hazard on linear accelerating walkways where the contraction of the treadway results in a reduction of the surface area available to users. Under certain pedestrian traffic conditions bunching could cause a dangerous jamming or pile up. Bunching has been identified as a significant hazard by some and considered a critical design constraint. (16) Others tend to minimize the probability of bunching incidents on an AMWS if the problem is recognized and appropriate counter-measures instituted. Bunching type accidents occur on existing conventional escalators and moving walkways where their exits or outlet ends are blocked or restricted in some manner, thus forcing following riders into a limited and confined space. Bunching accidents have resulted in fatalities in unusual circumstances generally through negligence when exit routes from landings are blocked. A multiple accident bunching situation occurred at the 1970 Japanese Exposition when a tripping incident at the exit of a walkway resulted in a pedestrian pile up and the injury of 42 persons, but none fatally. (17)

In order for bunching to occur on an AMWS, other than the type of incident described above, it is necessary for a number of riders to walk forward in the high speed zone and to come into close proximity with other users. As the walkway decelerates the treadway surface contracts and standing area is reduced, producing a denser pedestrian grouping. The problem would occur on the contracting surface walkways where a standing area reduction, proportional to the speed ratio of the system would occur in the deceleration zone. Bunching is not considered to be a problem on the Speedaway, although minor treadway reductions occur. Roller systems should not have a bunching affect because the treadway does not contract.

As part of the AMWS project, the Johns Hopkins University Applied Physics Laboratory was retained as a consultant to study the bunching problem. The consultant identified factors involved in bunching problems and conducted bunching experiments on APL's AMWS prototype. A brief summary of the consultant's findings is contained in Section 3.5. As nearly as possible, the experiments on the APL prototype were related to full scale higher speed systems. The study concluded that several aspects of passenger behavior tend to mitigate against bunching. The walkway entrance to an AMWS acts as a funnel which produces relatively wide spacings between entering passengers. The entrance also limits the number of persons on the system at any time and thus the number that could form a bunching critical mass. Additionally, it is a human behavioral characteristic that pedestrians tend to select relatively large personal spaces to avoid contact with each other. This suggests that the contraction of space occurring in deceleration zones might not reach a level critical enough to restrict forward movement off the system. (18) Bunching groups would have to reach extreme densities before forward movement would be stopped sufficiently to block the exit. This is not like the instantaneous outlet blockage situation where passengers are continuously discharged into a fallen rider or confined space. Small groups of riders involved in bunching contact on an AMWS should be able to alter standing locations or move more rapidly off the system to relieve bunching pressures.

Nevertheless, bunching on am AMWS is a recognizable safety hazard with potential risks that should be minimized as much as possible. One strategy suggested by the consultant is to designate walking and standing lanes on the AMWS. Walkers require at least 4 to 5 times the area of standees for locomotion. This would tend to open up pedestrian ranks, providing sufficient area to deal with contraction of the walkway surface in the deceleration zone. A variable speed handrail using individual handgrips spaced at a non-critical pedestrian spacing interval would definitively discourage bunching behavior. Use of this type of handrail would be supplemented by visual and audial instructions to riders to grasp handgrips before entering the deceleration zone. Marked standing positions on the treadway adjacent to the handgrip could also help encourage optimal pedestrian spacing.

Post Hazard

The post problem can be described as a stationary object or design feature along the system or at its outlet which protrudes into the walkway plane from the sides, or from above, situated in such a way that it could come in contact with moving passengers. In a sense the bunching problem is a form of a post problem since the moving rider encounters an immovable mass of pedestrians. Protruding moldings or other irregularities in the balustrade surface can cause post situations by catching packages, shopping carts, etc. and thereby impacting the rider and throwing him off balance. The fact that the balustrade sidewalls on escalators and moving walks are stationary results in a form of post problem for moving passengers that brush against or otherwise come in contact with these surfaces. For example, small children have been observed to be upset by touching this stationary sidewall.

Post problems have been identified more with multi-stage transport systems where a moving way system interface is used as a boarding and exiting stage. When used in this configuration the passenger must make a boarding commitment on or off the higher speed secondary stage before the end of the interfacing moving way system, or potentially be carried into some stationary element. Serious post problems have not been identified with the current AMWS prototypes.

Mechanical Failure

Mechanical components of a system can fail in a manner hazardous to passengers. Although a most unusual occurrence, dislodged or missing treadway pallets have been responsible for several serious escalator accidents. Missing pallet detection devices have been installed on some equipment to reduce the potential consequences of this type of hazard. Sudden failures of mechanical linkages, jamming or failing of treadway support rollers or other elements of the system could also endanger passengers. As part of the AMWS procurement the potential fialure modes of each element of the system should be identified by the supplier, its consequences evaluated, and possible response measures recommended.

Physiological/Pyschological Response

This hazard category includes responses to various elements of the system, possibly in combination with characteristics of the site environment, lighting, equipment finishes, motion or stroboscopic illusions, or other similar effects, which would disorient the user.

2.4 Moving Way System Accident Analysis

Escalator and moving walk accident data is not compiled on the same basis as other forms of transportation. Because these systems are usually free, the numbers of users are not as determinable as systems where a fare is collected. Most minor accidents on moving way systems involve personal carelessness and are generally unreported by the victim, particularly if the injury does not require treatment. The Port Authority follows the policy of reporting all observed incidents on escalators and walkways for the purposes of improving facility safety. A standard accident reporting form is used for this purpose. Currently, the Port Authority has 334 escalators and 10 moving walks at its 3 airport facilities, 3 bus terminals, the PATH Transit System, a passenger ship terminal, and the World Trade Center. The passenger facilities accommodate more than 160 million annual passengers. In addition, many others move through these facilities as employees, visitors, or accompanying passengers. The World Trade Center now houses about 35,000 employees, and estimates of daily visitors run as high as 80,000. Approximately 500 moving way system incidents are reported at Port Authority facilities annually, virtually all on escalators. In the three-year period investigated as part of this study, there were only two recorded incidents on moving walks. Because of the difficulties of establishing accurate estimates of exposure in terms of the number and type of users all of this data is not statistically comparable. However, some generalized conclusions can be drawn from the data. About two thirds of the incidents reported in the analysis occurred over a three-year period at the Port Authority Bus Terminal, located in Midtown Manhattan. This facility averages about 60 million passengers per year, but there are a great many non-passengers moving through the facility as well. This facility has a greater number of infrequent users and a larger proportion of the elderly and handicapped than a typical commuter facility. Additionally, because of its Times Square area location there is extensive police coverage, making it more likely that incidents involving minor injuries would be reported. It is also known that about 15 percent of these incidents reported at this facility are alcohol involved. Based on the known distribution of passengers on the three bus levels in the Terminal, plus allowances for visitors and employees it is estimated that there are approximately 100 million escalator uses at this facility each year. The average annual number of reported incidents on these escalators for a three-year period was 260, or a ratio of about 1 incident in every

385,000 estimated uses. As a point of contrast, the George Washington Bridge Bus Station, a passenger facility used almost exclusively by daily commuters, with lesser police coverage, reports an average of about 12 incidents per year with estimated usage at 15 million annually, or 1 reported incident in every 1.25 million estimated uses.

Location and Reasons

A compilation of data from 1228 escalator accident reports summarized by the subjects stated reason for the incident and the location on the unit are shown on Table 2.4. By direction of movement, downward moving accidents were more predominant (57.1%) than upward moving (42.9%) and in terms of the boarding and alighting interface, the user was more likely to have an accident getting off an escalator (65.6%) than getting on (34.4%). However, more than half of all accidents occur while riding the escalator (53.6%). Although not directly indicated by the classifications shown in Table 2.4, 86% of the accidents involved falls, with loss of balance (31.9%), slipped (11.7%) and tripped (9.4%) accounting for 53% of all accidents.

The remainder of the stated reasons were relatively evenly distributed. Pushing and crowding incidents can be somewhat related to the bunching problem of the AMWS.

Sex and Age

Figure 2.8 following is a graphic illustration of escalator accident frequency classified by sex and age based on 1,247 reported incidents over a three-year period at a number of Port Authority facilities. A small proportion of incidents in which age was not reported are excluded. Incidents involving females accounted for 61 percent of

TABLE 2.4

PORT AUTHORITY ESCALATOR ACCIDENT EXPERIENCE - LOCATION AND STATED REASON FOR INCIDENT

Reason Stated*	Up, Getting On	Up, Getting Off	Down, Getting On	Down, Getting Off	Riding Up	Riding Down	Number Category	Percent
Loss of Balance	40	42	46	45	100	119	392	31.9
Slipped	14	9	18	35	25	42	143	11.7
Tripped	11	26	4	26	25	24	116	9.4
Footwear Entrapment	1	17	4	15	19	28	84	6.9
Luggage or Packages	3	12	6	28	8	21	78	6.4
Mechanical Related	1	1	0	3	32	25	62	5.0
Pushed	1	3	4	7	22	25	62	5.0
Crowding	1	1	1	17	11	11	42	3.4
Clothing Entrapment	0	6	0	11	2	4	23	1.9
Miscellaneous	2	7	9	11	14	19	62	5.0
Unknown	14	21	17	29	36	47	164	13.4
Direction Totals	88	145	109	227	294	365	1228	100.0
PERCENT	7.2	11.8	8.9	18.5	23.9	29.7	100.0	

* Total All Down = 701 - 57.1%
Total All Up = 527 - 42.9
1228 100.0%

Total All Off = 365 - 65.6%
Total All On = 197 - 34.5
572 100.0%

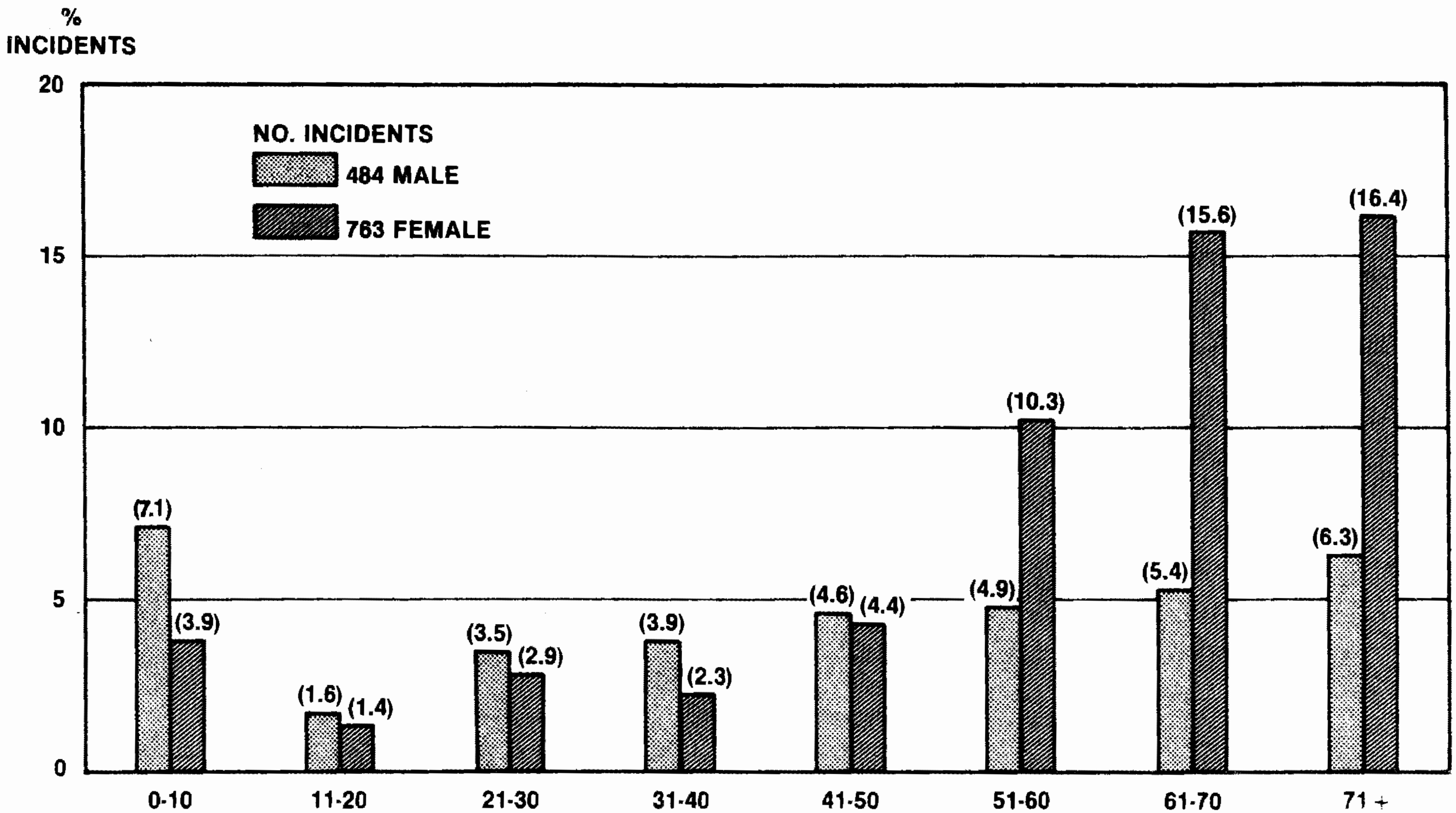


FIGURE 2.8

DISTRIBUTION OF ESCALATOR ACCIDENTS BY AGE AND SEX

(Port Authority Experience)

the total reports and males 39 percent. Persons over age 60 account for almost half of the incidents (43.7%), and women in this age bracket about three quarters of this group or 32 percent of all reported indidents.

While the proportional distribution of the sex and ages of the total user population cannot accurately be determined, it is comprised mostly of commuters, predominantly males in the working age brackets. For example, the passenger population at the Port Authority Bus Terminal where two-thirds of the incidents occur is known to be about 60 percent male. Persons over age 65 represent 3.4 percent of the total Bus Terminal passengers and females in this age bracket only 1.3 percent of all passengers. The largely disproportionate share of accidents related to total use reflects the greater accident propensities for the elderly noted in all aspects of pedestrian safety. Another anomaly in the accident frequency data when related to the user population is the relatively high percentage in the under ten age bracket. Many of these accidents are due to the equipment being used as a "playground" combined with inadequate parental supervision, and the juvenile's lack of knowledge of the use of mechanical systems.

Accident Severity

Many of the escalator accidents reported by police involved minor bruises or soft tissue injuries that required no treatment. Others required minor first aid administered at the facility, with the accident victim choosing to proceed on his way without further treatment, in some cases preferring to be treated by a personal psysician. In other cases an ambulance was summoned by the assisting police officer based on his judgement of accident severity, or in any instance when requested by the victim. It is known that some victims sustaining very minor injuries are cognizant of possible legal claims against the system owner, even in cases involving personal carelessness, and will request an ambulance or otherwise tend to overstate the extent of an injury.

Table 2.5 following summarizes data obtained from escalator accident reports classified by age and accident severity as determined by whether first aid was given, or an ambulance summoned. This summary shows that in the majority of incidents (59.3%) no first aid was required. Less than one quarter (24.3%) of the incidents were serious enough to require the summoning of an ambulance. The classification by use shows that the proportions of accident victims not requiring aid are fairly uniform, and surprisingly do not differ significantly for the elderly, indicating that although the elderly are involved in relatively more incidents, their risk of more severe injury is no greater than the general population.

Figure 2.9 following illustrates another aspect of potential accident severity, and that is the location of the injury. About 80 percent of the recorded injuries involve areas of the body and accident circumstances that are unlikely to lead to fatalities, or severe permanent disability. Head injuries (17.6%) represent the greatest potential for a fatality, and it is therefore necessary to give serious consideration to any equipment detailing which might contribute to the severity of this type of injury. Entrapment of the extremities, the hands or feet represent the next most serious accident risk in terms of potential severity because of the possibility of amputation. About 10 percent of

TABLE 2.5

ESCALATOR ACCIDENT SEVERITY BY AGE *

NUMBERS AND PERCENT IN CLASS

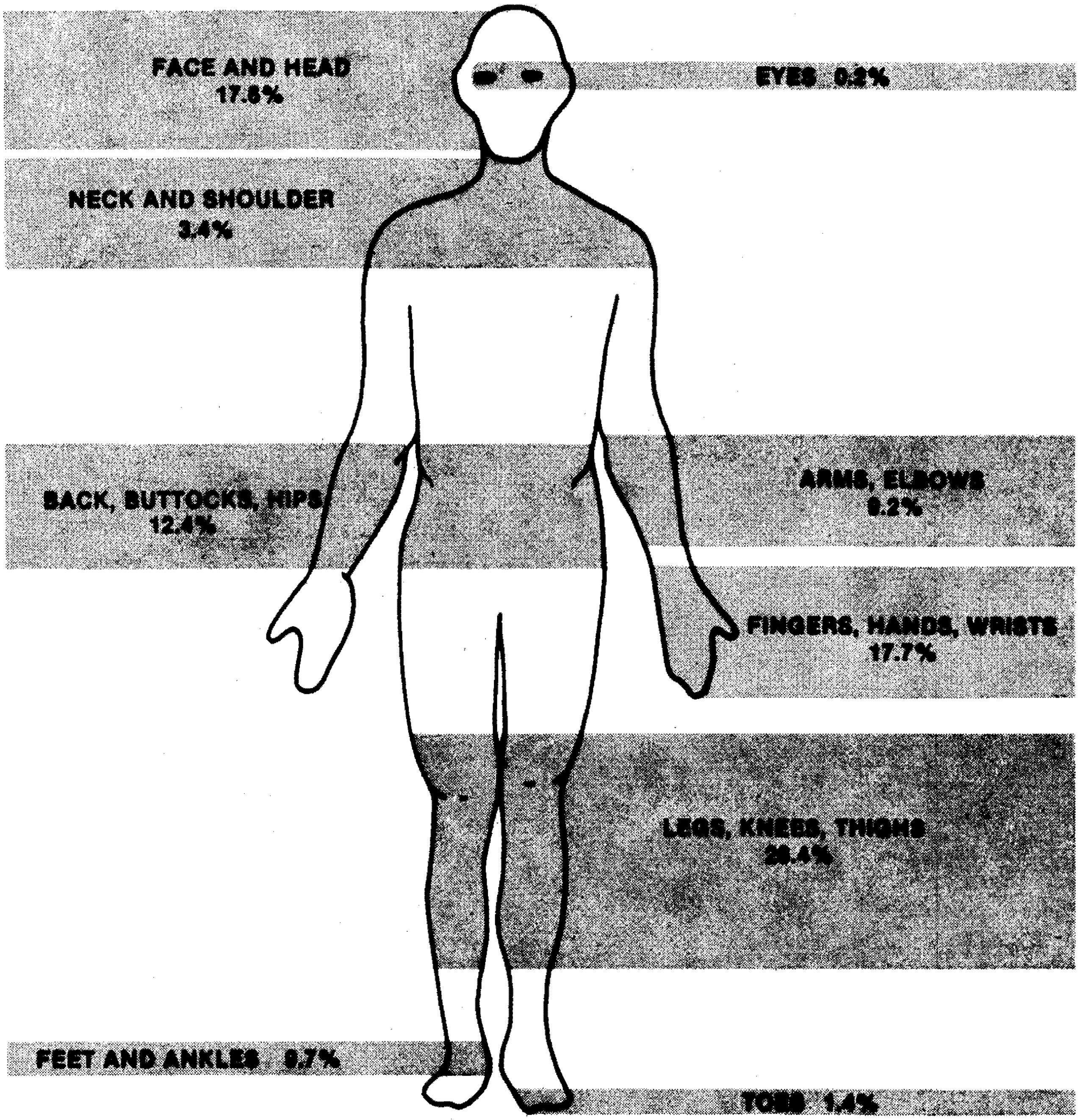
Age Group		No First Aid	First Aid and Release	Ambulance Summoned	Row Total	Row as Percent Total
0-10	No.	60	30	47	137	11.6%
	%	43.8	21.9	34.3	*	
11-20	No.	22	9	6	37	3.1
	%	59.5	24.3	16.2	*	
21-30	No.	47	16	17	80	6.8
	%	58.8	20.0	21.2	*	
31-40	No.	40	11	26	77	6.6
	%	51.9	14.3	33.8	*	
41-50	No.	76	15	21	112	9.5
	%	67.9	13.4	18.7	*	
51-60	No.	125	23	41	189	16.1
	%	66.1	21.7	21.7	*	
61-70	No.	174	29	59	262	22.3
	%	66.4	11.1	22.5	*	
71-90	No.	154	60	69	283	24.0
	%	54.4	21.2	24.4	*	
TOTAL		698	193	286	1177	100.0%
PERCENT		59.3	16.4	24.3		

* Port Authority Experience

* Row Total 100%

ANATOMICAL LOCATION OF ESCALATOR INJURIES

(Port Authority Experience)



NUMBER OF INJURIES · 1417
(SOME MULTIPLE INCLUDED)

FIGURE 2.9

all accidents involve the feet and 17.7 percent the hands. Entrapment and amputation is a rare occurrence, but attention to equipment detailing where there are apertures and shearing or converging surfaces will be necessary to reduce this risk.

General Conclusions of Analysis

- Accidents on moving way systems are relatively rare, occurring at a rate of about 1 incident in every .4 to 1.2 million uses, depending on user population characteristics and the familiarity with and frequency of use of the system; (The higher experience rate stated above is partially related to the degree of surveillance by police and facility personnel, since many unobserved incidents are unreported.)
- Accident locations on the escalator are somewhat evenly balanced between the boarding and alighting interface and those on the escalator itself, but downward moving accidents are more predominant, and two thirds of the interface accidents occur getting off, rather than on, the system;
- More than half of the reported accidents involve minor injuries not requiring medical treatment, with about one quarter involving an ambulance, possible emergency room treatment or hospitalization;
- Persons over 60 were found to be involved in almost half of all incidents whereas the proportion of these persons in the user population is estimated to be less than ten percent;
- Juveniles also show a disproportionate share of accidents when related to the general user population, probably due to lack of experience with the dangers of mechanical systems as well as inadequate parental supervision during use;

- Severe or permanently disabling injuries on escalators are a rare occurrence, with most injuries located in soft tissue areas not requiring medical treatment. Head injuries, the most likely cause of a fatality, were reported in 17 percent of the cases in the analysis. Incidents involving the hands and feet, next most serious in terms of potential severity because of the possibility of amputation, involved 28.8 percent of the reported injuries.

3.0 AMWS SAFETY CONSULTANT STUDIES

3.1 Consultants - Qualifications and Assignments

It was considered desirable as part of the AMWS project to obtain independent opinions from recognized experts in a number of areas relating to user safety. Based on a review of contributions to the literature as well as the canvassing of moving way system consultants specializing in safety problems, three consultants were identified as being expert in areas of specific interest. Additionally, as the project progressed, it became evident that insufficient information was available on the bunching problem on linear accelerating walkways, so that a fourth consultant was retained for a study of this subject. In addition to completing assignments relating to specific aspects of AMWS safety, the consultants participated in a special AMWS Safety Seminar sponsored as part of the project.

Consultant Alan C. Browning of the Royal Aircraft Establishment, Farnborough England, was retained because of his unique research on the human factors problems associated with accelerating moving walkways. (Ibid 13, 14) Mr. Browning's assignment, in addition to participating in the project Safety Seminar, consisted of a human factors evaluation of existing prototype systems, and the development of recommended standards for walkway speed, acceleration and RCA. A brief summary of his report is contained in Section 3.2.

Consultant William Crager is well known in the industry for his almost 50 years of experience in moving way system safety and accident investigation. A Mechanical Engineer and Certified Safety Professional, Mr. Crager also has considerable experience as an expert witness in moving way system litigation. As a long term member and current chairman of the ANSI A-17 Code Committee, he has participated in the development of safety specifications for many of the provisions of the elevator and moving way system model code. In addition to participating in the project Safety Seminar, Mr. Crager's assignment consisted of a review of A-17 Code requirements and their applicability to the AMWS, development of tentative safety specifications for an AMWS and the recommendation of inspection procedures, safety testing and acceptance criteria for an AMWS, and safety procedures during the public demonstration. Section 3.3 is a summary of this consultant's report.

Consultant John A. Miller was retained to review the accident risk and possible accident litigation aspects of accelerating walkways. The consultant is known for his extensive experience in the investigation of escalator and moving walkway accidents, and has testified as an expert witness in many cases that have resulted in litigation. A registered Professional Engineer, Mr. Miller is a member of the National Panel of Arbitrators of the American Arbitration Association, The Institute of Electrical and Electronics Engineers, and The Construction Specifications Institute. He is also an adjunct member of the faculty of the University of Pennsylvania, Graduate School of Architecture and writes a monthly column on elevator and moving way system safety for the trade publication, Elevator World. The consultant also participated in the project Safety Seminar. Section 3.4 is a summary of this consultant's report.

John's Hopkins University, Applied Physics Laboratory was retained as a special project safety consultant to report on the bunching problem associated with linear systems using variable configuration treadways. The University has a well established reputation in bio-engineering research and the Laboratory has the only readily available linear accelerating walkway. The consultant's assignment involved studies of the pedestrian bunching problem on an AMWS using the laboratory prototype to simulate conditions resulting in bunching. The study contract also included review of the available literature related to pedestrian behavior and dense crowding; photographic observation and measurement of bunching behavior on the APL prototype; analysis of pedestrian area occupancies, possible behavior, and potential hazards likely to occur under varying pedestrian densities, AMWS widths, speeds, and speed/area ratios; development and evaluation of potential control procedures to reduce the possibility of bunching on AMWS; and simulation by photography or other illustrative means of the data developed in these studies. Mr. Ralph Blevins and Dr. Jack Gebhard represented the Laboratory at the project Safety Seminar and presented the preliminary findings of the bunching study. Section 3.5 is a summary of the Laboratory report.

3.2 Report Summary - Consultant Alan Browning

Browning's study consists of two reports, the first containing background development of the mathematical relationships of speed, acceleration, rate of change of acceleration and acceleration distance formulae related to AMWSs, as well as graphical illustrations of these relationships, and the second addressing the bunching problem. Browning reviewed the reported motion characteristics of the three operating prototypes available at the time of his study. For purposes of simplification, the systems were designated A, B and C. Table 3.1 following, excerpted from the consultant's report, summarizes these reported characteristics.

TABLE 3.1

COMPARISON OF SYSTEM TYPES

System Characteristic	(DUNLOP) A. Parabolic variable width	(TRAX) B. Linear, constant width	(APL) C. Linear constant width
Entry speed (km/h)	1.44 to 2.16	2.88	1.66 to 3.3
Speed ratio	5 : 1	4 : 1	5 : 1
Line-haul speed (km/h)	7.3 to 11.0	11.52	8 to 17
Acceleration max (normal)	0.041g	0.102g	0.075g
Acceleration rise time (approximate)	1.0 sec	1.7 sec	1.3 sec
Expected need for handrail in normal use	No	Yes	?
Max emergency deceleration	0.102g	0.204g	0.153g
Entry width	3m	2 persons	2 persons ?
Line-haul width	1m	2 persons	2 persons ?
Lost area on decelerator (approximate)	40%	75%	80%
Reversible ?	Yes	No (pair of conveyors, one each way)	Yes

In the absence of definitive information on actual acceleration patterns on these systems, including the rise times to reach the various acceleration levels stated, Browning tentatively concluded the following (single spaced text, as excerpted from the report with minor editing):

> It is immediately clear that system A not only has an entry speed less than 2-1/2 km/h, but the acceleration patterns are well below the tentative acceptance curve.
>
> (Note: as developed in Browning's previous research, see Table 2.3)
>
> This is also true of system C if the line-haul speed is limited to 12-1/2 km/h. The proposed system B has not only the excessive entry speed (2.88 km/h) but the acceleration pattern lies well above the tentative acceptance curve, indicating that handholds may be necessary in normal use as indeed is specifed in the details of that system. For system B to match the tentative acceptance curve (i.e. for the use of handholds to be hardly necessary) it must be run at about 9 km/h.

He concludes that:

> At first sight, gentle accelerations and decelerations would be expected to lead to excessive journey times, but this is not so. The contours of journey time (shown in report, edit.) are both widely spaced and approximately parallel to the contours of equal upsetting effect, so that choosing an acceleration level of 0.03g instead of 0.05g only adds 3 or 4 seconds to the journey time. This additional journey time would of course be less important, in proportion, for longer journeys....and....From human factor considerations only, the use of very low accelerations and decelerations are therefore recommended.

Browning also discusses the use of handrails in the respective systems and comments in detail on the Speedaway system, ("A"), design as partially quoted below. It should be noted that the design details of systems "B" and "C" are not yet available.

> At the other end of the scale of ability, there is no restriction to walking on system A, experienced travellers can be expected to walk in the centre part of the very wide (3m) entry zone, adjusting their walking speed to give an acceptable acceleration and leaning slightly as necessary, leaving the handrails for use by the inexperienced. For comparison with systems B and C however, the availability of the handrail can be made the same by placing barriers at the entry to prevent the centre part being used. These barriers need only be temporary, and easily removed

> if the system were reversed. The barriers, while ensuring that all have a handrail available at entry, will not ensure this at the exit, for if a person stands on the centre of one of the floor plates during the line-haul zone the handrail will recede from him during the deceleration. However, if he stepped on the accelerator near to the handrail, and does not walk at all, he will find himself by the handrail at the decelerator also. This suggests that there should instructions to inexperienced travellers to discourage walking, except for adjustment to handrails, and in particular to encourage the standing on the ends of the floor plates, on the parts which do not disappear at the decelerator. These points could perhaps be designated by a point decoration of some sort, e.g. the manufacturer's trade mark.

Browning summarizes his findings on system accelerations/decelerations and the need for handrails as follows:

> As proposed, systems A and C are not likely to cause great upsetting effect on passengers in normal use, even if handrails are not used. Unsteady and inexperienced passengers should be easily catered for by clear instructions to hold the handrail, but whilst the 4-stage handrail of system A theoretically should be satisfactory, it would be reassuring to have some well documented trials of disabled people using the existing prototype. There seems to be no reason why system A cannot be run at the higher line-haul speed of 12-1/2 km/h, still keeping the entry speed below 2-1/2 km/h, but running system C at line haul speeds of 12-1/2 to 17 km/h is not advisable on these grounds. Provided extreme care is taken to ensure that all passengers hold the handrail, system B should also be satisfactory in normal use, but if there are any lapses of attention and they do not hold it, there is likely to be an immediate fall. On grounds of limiting the entry speed, the highest line-haul speed advised for system B is 10 km/h, but to be comparable with systems A and C in terms of upsetting effect if handrails are not used, it must be run at less than 9 km/h.
>
> The emergency deceleration proposed for system A should be satisfactory but those quoted for systems B and C are not likely to be so and they should be reduced because of the high probability of injury to passengers, in the line-haul zone, who are not holding the handrail.
>
> Considering the integral nature of all three systems, it is recommended that consideration be made of the possibility of a reduction of acceleration level, for normal use, for all of them. It seems that for systems A and B reducing the accelerations involves mainly the modification of the curvature of guide rails, and in system A the acceptability of the 4-stage handrail would be increased if the breaks were further apart. However, the choice of acceleration for system C must be made early in the design because changes, for the same line haul speed, will require the manufacture of a new variable pitch screw.

In the second report addressing the bunching problem on the three prototypical systems:

> In the earlier studies, comments on the design of complete systems were based on the assumption of a constant area flow at all points along the conveyor so that any bunching of passengers on the line-haul section would not be hazardous, the subsequent deceleration merely re-orienting the passengers, with no loss of floor area per passenger. All of the candidate systems gain some area during the acceleration zone and lose it at the deceleration zone, the amounts being
>
> | | |
> |---|---|
> | System A | 40% |
> | System B | 75% |
> | System C | 80% |
>
> It is therefore possible, if some of the passengers walk along the line-haul section to form a closely packed bunch, that during the deceleration zone crushing injuries, or at least embarrassment, may occur. Clearly the ranking order of the systems on this criterion is A, B, C simply on the amount of floor area lost, but some consideration of the importance of the lost area must be included in any comparative assessment. The results of the earlier studies can give some insight into this aspect and in this section the relevant results are applied, together with some consideration of a more theoretical nature, considerations which may already have been done by others.
>
> Clearly, if walking is not permitted on the moving conveyor at any point, no bunching can occur. None of the systems incorporate barriers appearing after entry to prevent walking, walking being discouraged only by instructions to the passengers, which may or may not be obeyed. An alternative to verbal instruction, valid even if passengers walk, is to indicate areas of the floor on which it is not recommended to stand during the deceleration. In systems A and B the floor which appears and disappears could easily be coloured differently, but the design of system C, which has the most serious potential problem, is such that indication is more difficult (the floor being made of overlapping leaves). Again however, this ploy only gives information to the passengers, they could disregard it and induce a bunching problem. It is clear that consideration must be made of the probability of bunches occurring and the importance of them when they do. It must be true that if passengers blatently disregard instructions and information, walking or running rapidly once they are on the conveyor, it must be possible for them to form bunches, even on short journeys, unless the passenger flow rate is held to a low value (at the extreme, only one passenger at a time on the conveyor).

System A: Each individual passenger using System A will have to turn through about 90° during the acceleration zone in order to continue to face along the direction of travel. Groups travelling together will remain together but will be reoriented, for example persons initially side-by side will become one-behind-the-other, but no further apart. Extra floor space will appear, and could be used during the line-haul section if required, provided it is not used at the deceleration. Any large close-knit group boarding over the complete width of the entry zone will cause a local flow of some 18000/h which is the worst case for possible bunching, but such rates cannot be sustained for any length of time and continuous loudspeaker announcements discouraging walking could be used at such peak times.

System B: The handholds of System B, for 6000/h flow, are expected to be 3.33 m apart in the line-haul section and 0.83 m apart at entry. The acceleration will merely separate these along the track (either opposite each other, or alternately left and right). Groups of more than 2 persons will be separated, into pairs, 3.33 m apart (or individuals 1.67 m apart) a feature which may make this system unpopular with family groups. There will be the temptation for passengers to walk to maintain social contact with other members of the group, so increasing the local density, possibly above the 67% increase which is necessary for bunching to occur at the deceleration.

System C: The handholds of System C, for 6000/h flow, are expected to be at 3.33 m spacing in the line-haul section and at entry 0.67 m. Acceleration will, as in System B merely separate the handholds, but to 5 times the spacing rather than 4 times, giving even greater spacing of the members of a group. The tendency to walk to maintain the groups could easily increase the flow locally by 33% and lead to embarrassment at the deceleration.

Browning did a number of analyses of potential bunching combinations based on simplified assumptions which showed that bunching requires specific sets of circumstances which are probably susceptible to countermeasure controls. He suggests that computer simulation of variations in pedestrian flow on an AMWS could provide further useful data. The consultant also observes that the possible consequences of bunching is related to system length:

The number of passengers in the bunches is directly proportional to the time spent collecting the bunch together and the potential bunch size is approximately proportional to the length of journey. For example, for a 600 m journey (about 2000 ft.) bunches nearly 7 times as big would be expected to be possible, (ie) bunches of nearly 50 persons. Whilst this does not affect the validity of the above method of estimating the consequences of expanding the bunches at the decelerator, not only are the walking distances and speeds also multiplied by the factor of 7 and the extra deceleration due to walking greatly increased, the walking distances become considerably longer than the decelerator (making anticipation essential) and many persons will be embedded deep in the bunch, unable to see how to avoid being crushed, and may panic. In the Author's opinion, for journeys as long as this only System A is suitable, especially if the entry flow is specifically restricted to a great deal less than the maximum capability, (eg) limiting the flow to 6000/h as suggested.

On bunching and handrail design:

Whilst the safety authority may require a continuous handrail for all systems, the use of Systems B and C without bunching demands that passengers remain separated by discrete handholds. The handrail between these handholds should therefore be both uninviting to use but, at the same time, sufficiently attractive for use in emergency stop. It must be strong enough to support a person during such a stop, but, considering that very few persons will be using them, low comfort and even the potential for damage to the skin during an emergency stop could be acceptable.

Concerning falling passengers:

In the two unexpected falls by adults in the earlier studies, both persons took about 5 seconds to regain their feet, with assistance. There will be ample time for regaining the feet after a fall on the accelerator of any of the three systems, but a fall due to the onset of the built-in deceleration may find the person still trying to rise at the exit point, with fingers pressing hard on the floor and perhaps several other persons trying to help. The possibility of combplate accidents is obvious, and forms yet another reason for designing the low built-in deceleration levels.

Browning summarizes his analyses of the human factors of the three prototypical systems as follows in Table 3.2 (as edited):

COMPARISON SAFETY FACTORS TABLE 3.2

FACTORS	SYSTEM A (DUNLOP)	SYSTEM B (TRAX)	SYSTEM C (APL)
Maximum line-haul speed for entry speed limited to 2 1/2 km/h	12 1/2 km/h	10 km/h	12 1/2 km/h
Specified acceleration, if no handrail used	Below tentative acceptance curve	Well above tentative acceptance curve	Below tentative acceptance curve
Specified acceleration, if handrail used	Acceptable	Acceptable	Acceptable
Handrail	Continuous, 3 changes needed, tests with disabled persons recommended	Handholds needed but safety authority may require continuous handrail	Handholds needed but safety authority may require continuous handrail
Walking by passengers	Easily possible	Possible, but not recommended because of bunching problem	
Emergency deceleration specified	Gentle	Very severe	Severe
Emergency stopping time	Similar, 14 to 18 seconds		
Emergency stopping distance (at comb)	Similar, 4-6 meters		
Effect of accelerator on groups	Slight expansion, but mainly reorientation	Spread out, 4:1	Spread out, 5:1
If a bunch of 6 persons, after deceleration comfortable space for:	3.6 persons	1.5 persons	1.2 persons
Leading member of bunch of 6 must move	1.54 to 0.84 m	1.125-6 m	1.2-7.5 m
Bunch of 50 persons	Could be acceptable, if flow restricted to 6000/h	Probably highly dangerous, because of the possibility of massed crushing accidents	

The amount moved by an expanding bunch, the possible consequences of falls at the start of the decelerator and the effects of walking on decelerators all provide encouragement for the choice of low deceleration values.

3.3 Report Summary - Consultant William Crager

Consultant Crager's report provides background material on the safety aspects of escalator and moving walking equipment including results of accident investigations conducted by him at the 1938 and 1964 New York Worlds Fairs. The Worlds Fair experience is considered significant because of the introduction of innovative moving way systems, some characteristics of which can be related to features of accelerating walkways. The following is excerpted from the consultant's report. (Single spaced text.)

> Moving handrails synchronized with the movement of the treadway, and being readily accessible for grasping by a person's hand for support while riding on a moving walk, no matter what its width or speed may be, have been recognized in my studies of incident experience to be an essential means for minimizing exposures for falls. Such supporting means are particularly needed for the safe use of moving walks by elderly, infirm, nervous and handicapped persons.
>
> The availability of handrails on escalators has resulted in a general expectation of them for use, and in their being used by most persons. In many observation surveys made by me of human behavior on escalators particularly ones located in department stores, and bus and railroad terminals, I recorded the number of persons who maintained a hand on the handrail while riding on the units. It was found in these studies that they constituted 87 percent of the persons using the escalators. These observation surveys also disclosed the fact that having to use both hands to carry bundles and baggage, and in some instances, to hold children were contributing factors in failures to grasp a handrail.
>
> In other observation surveys which were made by me personally of human behavior on moving walk installations not equipped with or not having readily accessible moving handrails at the New York Worlds Fairs, it was noted that many stumbled or displayed need for support, and had to be assisted by assigned attendants to prevent falls. Also, my review of the accident experience in connection with moving walk operations at the Fair, disclosed that most of the falls on these installations were attributable to a moving

handrail not having been readily available for support.

For a handrail installation which would be adequate and accessible for use by persons on a moving walk, I would recommend that:

1. Handrails should be of the moving type so that when grasped by the hand, they will give continuous support of a person along the entire moving walk run they serve. Individual hand grip devices connected to a driving means to produce motion in the same direction of the treadway travel, and so spaced and located as to provide ready accessibility to them for support means required to be used by persons riding on the moving walk, may be used.

2. The moving handrails or hand grips should move at a speed as near as practicable to that of the moving treadway they serve. In an accelerating or decelerating zone of a moving walk, the speed of a moving handrail or handgrip system should be so related to the speed of the treadway that the hand grasping the support is not drawn forward or backward more than 12 inches during the full movement of the person in the zone.

3. Where a handrail is divided into a series of constant speed units, the ends of the handrails should overlap at the points where they meet so that the hand grasping one rail may be readily transferred to the other without causing loss of support.

4. The moving handrail or handgrip device system should be provided on both sides of the moving walk so that the supporting means will be readily available to all persons who may be riding on the treadway.

5. To permit ready grasping of the handrails, the top of the handrails should be located at a height not less than 33 inches or more than 42 inches above the treadway surface.

6. Also, to permit the required accessibility to handrails, the inner surface of the balustrades on which handrails are mounted should not be set back more than 8 inches from the vertical projection of the adjacent edge of the exposed treadway.

7. To permit persons to grasp a handrail before stepping on the moving treadway, and also to retain their grasp on the handrail until after they step off the moving treadway, the moving handrail shall extend at its normal height on the balustrade to a point not less than 12 inches beyond the end of the exposed treadway.

Moving handrails can also be a source of accidents if the necessary protective measures are not taken in the design of balustrades. Many injuries, some of them quite serious, have resulted from the inadequate guarding of the openings through which a moving handrail enters and leaves the interior of the balustrade. In early balustrade designs, a brush-type guard with its bristles projecting toward the handrail's top surface was used to cover the open space between the handrail and balustrade panel. It was,however, found that there was enough flexibility in the bristled construction to permit a child's fingers and in some instances, the entire hand to be drawn forcibly into the opening. To minimize this exposure in department stores where accidents had occurred, it was recommended by me some years ago that these bristled type guards be so set in the balustrade openings that the bristles project towards the face of the opening, and thereby, resist deflection by the insertion of fingers. However, since then, an improvement by using a more rigid material of a plastic type has been made in the construction of such guards. Also, on some escalator installations, micro switches are being installed to provide the required protection to minimize the resultant injuries to a hand drawn into the opening. For the required protection of this exposure which prevails on moving walks as well as escalators, I offer the following recommendation:

> A guard of substantial construction should be installed to cover the open space area between the moving handrail and the edges of the opening through which the handrail enters and leaves the balustrade enclosure.

The balustrade newel should also be designed to eliminate a hazard which may be created by a handrail run extending at an angle towards the floor surface under the extended newel and entering the balustrade opening at a short height above the floor. On installations with such newel designs, there were some serious accidents as a result of children in a crawl position, having the head drawn into a wedge shaped small space under the extended newel.

Balustrades

The balustrades of moving walks should be of a construction having no weakness, flexibility, openings, projections or depressions which can probably cause accidents. In an accelerating moving walk system design which incorporates a series of constant speed moving handrails to match the speed of the zones they serve, the creation of "obstruction" hazards and stationary floor surfaces adjacent to the moving treadway should be avoided.

Where in the moving walk design, a balustrade is set in from the inside line of another balustrade so as to create an obstruction hazard to persons riding on the moving treadway, I recommend the following as a means for minimizing probable accident occurrences from this source:

> The newel of the balustrade forming an obstruction in the path of a person on a moving treadway should be fully covered on the front by a substantial guard which will extend to the inside face of the other balustrade, making an angle of not more than 30 degrees with the latter surface.

Stationary floor or platform surfaces adjacent to a treadway permits a person to step off the high speed moving treadway into the small open space, and be injured in doing so. Also, these stationary surfaces can probably invite children to use them for a "hopping off and on" game which could lead to accidents not only to themselves but also to others on the moving walk. The top surface of the base of escalator balustrades of the glass design which presents a similar stationary surface has been known to be used by some children for stunt performances even though it is beveled for protection.

At the Worlds Fair, the existence of a stationary floor area where transfer was made to a moving walk resulted in a number of persons stepping on it and being injured in falls. The speed of this system was only 125 feet per minute. This exposure was finally eliminated by the erection of a barrier after an experience of over twenty falls which resulted in injuries.

In view of this exposure described as a probable source for accidents, I submit for consideration the following recommendation:

> Any exposed stationary surfaces immediately adjacent to the treadway, on which a person can stand should be covered by a bevel guard.

<u>Clearances between Treadways and Balustrades</u>

An entrapment hazard has always been inherent to clearances which are required to be provided between step treads and the adjacent balustrade skirt guard on escalators. To minimize this hazard, the maximum clearance was limited by a requirement in the 1955 ASA A17.1 Code to 3/16 inch on either side of the escalator. In 1965, this rule was revised to provide an exception to the requirement for a maximum clearance when a device is installed to stop the escalator in the event an object should become caught between a step and skirt panel as the step approached the lower combplate.

Experience continued to indicate a high frequency of accidents resulting from light type footwear being seized in small spaces where no skirt obstruction had been installed. Not only have foot injuries and falls resulted from entrapment occurrences, serious finger injuries have been sustained particularly by children. In the latter type of incidents, many of which were investigated by me, the person was in a sitting position or was attempting to pick up something which had been dropped, and in doing so, had fingers caught in the open spaces.

To further control this cause for accidents, it was felt necessary to revise this rule in 1971 to require skirt obstruction devices to be provided on all future installations, and to increase the maximum allowable clearance to 3/8 inch so as to minimize the entrapment hazard presented by a smaller clearance space.

Most of the accidents resulting from the running clearance exposure on escalators involved children. Test runs on an experimental escalator, and an analysis of accidents brought to light that children's sneakers, fingers and soft flesh on the forearm could be drawn into a space of 1/8 inch between a step and balustrade skirt panel. It was further found in these tests that a very small clearance made it extremely difficult if not impossible to extricate the caught object before the step reached the combplate.

The findings in these tests led to the following conclusions:

1. The relative motion between the moving step and the stationary balustrade skirt panel can draw some objects into very small clearances. It is virtually impossible to prevent the drawing-in action under all conditions.

2. It is believed that larger clearances are safer than very tight clearances. Safety is not served if the caught object cannot be withdrawn before the step reaches the combplate. Furthermore, children may be readily injured when small clearances exist, as a result of a squeezing action.

The accident statistics indicate that the serious accidents resulting from entrapment between steps and skirt panels invariably occurred after the step reached the combplate.

In these cases, the shearing and pinching actions at the combplates resulted in serious toe injuries including amputations. It was found in studies of accidents that there was no evidence of entrapment type accidents of serious nature resulting in persons losing their balance and falling on the steps.

Spaces between the treadway and balustrades on moving walk installations also create entrapment hazards. To minimize such entrapment exposures for probable accidents such as those which have occurred on escalators, the 1971 ANSI A17.1 Code specifies that the maximum clearances on moving walks be limited to:

a. 1/4 inch between the underside of the balustrade and the top treadway surface where a balustrade covers the edge of the treadway.

and

b. 1/4 inch between the edge of the treadway and the adjacent balustrade skirt panel where a balustrade does not cover the edge of the treadway.

Open clearance spaces under balustrade sections which extend across a treadway or along a curved run of a treadway present greater exposures for the entrapment of fingers as well as toes. In addition to limiting the height of such openings to a maximum of 1/4 inch as specified in the ANSI A17.1 Code, I would also recommend:

> To minimize the hazard inherent to open spaces between the underside of balustrades and the top treadway surface where the balustrade section extends across the treadway or along a curved run of the treadway, further protection in the form of skirt obstruction safety devices should be provided.

Where a threshold combplate at the inrunning location of the moving treadway presents a serious injury hazard for an entrapment exposure, I would recommend:

> Skirt obstruction safety devices should be installed at a point not less than 30 inches and not more than 48 inches from the front edge of the threshold combplate.

Threshold Plates

To prevent falls and foot entrapment occurrences at landings of moving walks as well as escalators, a safe design, construction and installation of threshold plates are essential. On one moving walk installation which was of concern to me in a loss control program, a threshold plate design incidentally one of a combtooth type resulted in a high daily frequency of as many as 12 heel entrapment occurrences, a number of which led to falls and injuries. To control this exposure for such incidents, a redesign of the combteeth was found to be necessary.

On moving walk installations in the 60's, threshold plates with straight line leading edges were a source for many serious accident occurrences. In some of these occurrences, the person's arm was drawn as far as the shoulder underneath the plate. One of these occurrences resulted in a fatality when a child's arm was fully drawn under the threshold plate causing her dress to be pulled so tightly around her body as to result in a collapse of her chest. This accident experience which also included threshold plates of this design where safety lift limit devices had also been installed, resulted in the adoption of a standard requiring treadway surfaces of a grooved design to mesh with combtooth type threshold plates.

To minimize exposures for probable accidents at the landings, it is recommended that the threshold plates conform to the following requirements:

1. They should be provided with a combtooth edge which will mesh with the grooving in the treadway surface.

2. The combteeth of the plate should be so set into the treadway surface grooves that the points of the teeth are always below the upper surface of the treadway.

3. The clearance between the bottom of the combteeth points and the bottom of the treadway grooves should not exceed 1/8 inch.

4. The surface of the threshold plate should provide a secure foothold. Also, the plate surface should be smooth from the line where the upper treadway surface meets the top surface of the teeth for a distance not less than 1 inch or more than 4 inches.

5. If the threshold plate is of a floating type i.e., movable and resting on the bottom of the grooves, a switch should be installed on each side to operate and stop the moving treadway if the

front edge of the plate should rise above the top of the treadway grooves.

Treadways

Plain surfaces, i.e., without grooving were provided in the design of the earlier moving walk treadways. For use with such treadways, the threshold plates at entrances were of the straight line edge design which rested by its weight on the treadway surface. However, as previously stated, the threshold plates of this design were found to present a definite entrapment exposure for serious accidents.

In view of this accident experience, it was the general opinion that for safety, treadways should be of a grooved surface design which would minimize entrapment and also tripping hazards. It is,therefore, recommended that the treadway surfaces of moving walks conform to the following:

1. They should be designed with grooves or component spacings which will mesh with the combteeth of the threshold plates and conform to the following dimension requirements:

    a. In width: not more than 1/4 inch
    b. In span (c/c) between adjoining grooves or spaces: not more than 1/2 inch.

2. The spacings between the ends of adjacent treadway surface members or extensions should not exceed 1/4 inch in any operational position of the members.

Treadway connecting means which consist of part of the propelling system should have a factor of safety of not less than 10 based on the ultimate strength. Means should be provided to prevent separation of the treadway if the normal connecting means at any point should fail. In addition to these means, there should be provided a device which will stop the treadway upon failure or slackening of a chain.

The width of a treadway should be limited to permit ready accessibility to a handrail and also to control any need for a person to walk at an angle across the moving walk. At the Worlds Fair in 1964, moving walk installations ranged from 42 inches to 96 inches in width. On one of these installations which was 66 inches in width, and required side boarding of another moving conveyor unit, it was noted that many persons experienced difficulty in crossing over the moving treadway, and had to be assisted by attendants whose duties required them to continuously tread against the direction of the moving treadway to protect the visitors from falling. The experience in the operation of these wide moving walks indicated that there were a number of fall accidents attributable to some persons having to walk unassisted across a moving walk. In my opinion, based on the experience described, the exposed treadway of a moving walk should be not more than 40 inches in width.

The slope of a treadway must be limited for the required sure footing of passengers to prevent slipping and falls on a normal or emergency stop of the moving walk from the speed at which the treadway is moving. The treadway slope must be one which provides comfort to the passengers and does not create a disturbing reaction to nervous, timid or handicapped who use the moving walk.

The maximum speed of a treadway which depends on the maximum slope of the treadway, should not exceed that indicated as the maximum speeds established below for the various treadway slope ranges:

At the Entrance or Exit of the Moving Walk

Treadway Slope (degrees)	Max. Treadway Speed (f.p.m.)
0 to 3	180
above 3 to 5	160
above 5 to 8	140
above 8 to 12	130
above 12 to 15	125

At Any Other Point of the Moving Walk

Treadway Slope (degrees)	Max. Treadway Speed (f.p.m.)
0 to 4	700
above 4 to 8	180
above 8 to 15	140

In an accelerating moving walk operation, the accelerating and decelerating action in the treadway movement can cause passengers to stagger or stumble. The effect of this action is related to the rate of the acceleration change as well as the acceleration rate. In a public accelerating moving walk operation, consideration should be given to the fact that the infirm, elderly and handicapped persons will use the moving walk as well as physically fit persons.

The results of the tests and studies of human behavior and reactions on accelerating moving walks made by the Royal Aircraft Establishment were reviewed by me.

For controlling the upsetting effect to a slight relative movement to a general public passenger group, the maximum acceleration level was found in the tests to be 0.055 g in a rise time of 1 second. It is my opinion that this value is a reasonable one to be established as a maximum normal acceleration and deceleration rate. However, for an emergency stopping of the moving treadway, I would recommend that 0.070g applied in a 1/2 to 1 second be established as the maximum deceleration rate."

The consultant also recommended formulae as developed by Browning for AMWS acceleration and deceleration lengths which are omitted in this report summary. Also, other sections regarding obstruction hazards above or adjacent to the walkway, as well as relating to mechanical design features have been omitted.

3.4 Report Summary - Consultant John Miller

Consultant Miller's report deals mainly with his experience as an expert witness and, therefore, covers accidents going to litigation, representative of the small proportion of more serious moving way system accidents resulting in permanent injury. The probability of such occurrences is on the order or about one in ten or more millions of uses. The consultant reviewed over three hundred cases from his files and summarized this investigation as follows (single spaced text):

For the purpose of the AMWS study, we have separated the files in two categories, one dealing only in step and riser formation or entrapment accidents, and the second those accidents where level tread, combplate, bunching, inertia or physiological factors were involved, as well as entrapment at the ends.

We have found that the major cause of accidents is in the entrapment category. Forty-eight of the accidents in our files come under this listing. They generally involve children wearing sneakers or other soft-soled shoes getting caught in the combplates at the end of the escalator. A number involve fingers of children who have fallen on the steps or were sitting on the steps and the fingers were trapped under the combplates. In most cases it was found that some fingers were caught because a tooth was broken off of the combplate, leaving an exposed area of the plate without the combing action of the teeth. The sneaker accidents usually involved worn or torn sneakers that had portions get under the normal comb teeth and would break off teeth and cause the entrapment. We have had several cases where older people following on would attempt to pull the child out and have their own toes caught under the broken section of the combplate with amputation of the toes. Two cases resulted in the amputation of the front half of the foot.

A total of twelve cases involved physiological factors. These consist of passengers who would not hold the handrail, would not watch their step getting on or off and would fall because they did not realize that the steps were moving or that the steps came to an end at the combplate requiring them to step off and keep moving, fell on walking on escalator that had been out of service and stopped, were drinking and not aware of the moving steps and fell, walking on an escalator moving in the opposite direction, or became dizzy on looking down the slope of the escalator.

However, it is possible that handrails will slow down or stop and start. This has caused some twelve accidents in our files, usually on the part of older ladies. Other handrail accidents involve clothing getting caught under the handrail or at the end where the handrail enters the balustrade.

The next factor was inertia. We only have eight cases that actually resulted in court action. These generally were the result of the escalator stopping while the passengers were riding, causing upset or fall. There have been numberless requests upon us to investigate accidents where the passenger claimed that the escalator "jerked." Since the absence of any damage or the escalator stopping due to the operation of a safety switch or the emergency button, the claim of the escalator "jerking" is practically impossible. This idea is usually pressed by people who have fallen due to their own failure to watch their step or hold the handrail or otherwise not paying any attention to the fact that they are on a moving stairway. We receive requests from attorneys to investigate accidents where a "jerk" is claimed on the average of four or five times a month. Most are turned down simply on the statements of the accident victims.

Bunching accidents are relatively rare on escalators. Most involve the failure of people to move away from the end of the escalator after getting off. This can be due to a narrow exit area, rain immediately outside the exit area where people hesitate before going out, or crowding at the end due to people being able to not move into some area that is temporarily closed off. Mothers have been observed stumbling over their own children who were sitting on the steps and stopped at the combplate.

Bunching on an AMWS during the decelerating motion will take place when people walk forward during the steady speed portion and stand behind the person in front. This should not present any major problem if the decelerating rate and distance is sufficient to allow people to adjust their position relative to the person in front.

To summarize the escalator accidents that we have been involved with that went to trial or were settled for substantial sums, we have found a total of 72 accidents that could be considered serious, that is more than casual medical attention was needed.

48	Entrapment cases	67%
12	Physiological	17%
8	Inertia	11%
2	Bunching	3%
2	Mechanical	2%
		100%

From the above it should be recognized that two-thirds of the accidents have happened in the entrapment category on escalators. When the AMWS prototype unit is completed the additional items of surface discontinuities, divergence and barriers that will be added to an AMWS may for the most part be spread over the five items listed above in about the same proportion.

Consultant Miller reviewed the characteristics of the current AMWS systems under development, and commented on prospective hazards which might contribute to accidents. His initial remarks are directed toward the Dunlop System which is the most developed and tested, and whose features can, therefore, be readily critiqued. Naturally, as the details of other AMWS systems become further developed, their potential hazards will be more easily identified and evaluated. The consultant's discussion is excerpted as follows:

> Additional sources of accidents on an AMWS will be speed changes, causing tripping forward or backward, handrail speed changes, and combing action or side sliding action of step treads. Each of the proposed systems has some additional sources of accident potential that are unique to the system.
>
> (regarding Dunlop Speedaway)
>
> On entering this device, the passenger will be in the same position as entering an escalator, and would not find the experience any different. But immediately he will find that the handrail starts to curve to the side. He then must let go the handrail and take hold of the next handrail, which is running at a faster speed. This speed will be different than the speed that his body is moving. In addition, there is a substantial barrier created by the need to offset the two handrails. Since the step treads turn under the balustrade, the entrapment of shoes and sneakers can become a real problem, since there is no combing action. As wear takes place on the tread support rollers, the clearance between the top of the step surface and the underside of the balustrade will increase the potential of entrapment.
>
> In addition to the passenger need to adjust to the acceleration effect on his body, it will be found that most people will turn to the direction of travel, which means shuffling the feet. Since the two changes in handrail grip are required, some may not use the handrail at all during entering and only hold it after obtaining full speed.
>
> The shearing action of the adjacent step tread surfaces will create problems with people who do not watch their step and place the toe on one step tread and the heel on the next following tread. This will cause the foot to turn in the direction of the shear. The rubber edges between treads will not help this problem. However, this should not be as serious as the problem with escalators where people tip forward or backward when they span two treads on an escalator step and the steps start to form.

In the opinion of Consultant Miller, the TRAX system has advantages over the Dunlop Speedaway because of its straight alignment, and because of the provision of a handrail comprised of individual handgrips rather than multiple conventional handrail sections.

(with regard to the TRAX system)

> It does have the advantage in that the handhold travels at the same speed as the adjacent step tread. The combing action on this system may present some problems since there must be some slippage of the shoe sole during acceleration and deceleration portions of the tread motion. There would be no more problem here with a stationary balustrade than there would be with the Dunlop system. Both systems will have a problem with people who want to walk ahead while riding the moving walk. Obviously this will result in unusual crowding at the end. During heavy traffic periods this might prove to be a dangerous condition. One way that this might be avoided would be to have the system designed in such a way that the entering and full speed areas would only accommodate one person at a time and open up the width at the exit end by widening the balustrades. This would require wide step treads for the entire length of travel, which would only be usable at the terminals. The Dunlop system does have this advantage where the TRAX system does not. With this feature, neither system would be reversible.
>
> The Johns Hopkins system and the Boeing system are modifications of the TRAX design, and have about the same passenger problems. The Johns Hopkins system would appear to be limited by the length of the screw drive system and possible torsion or twisting on a screw of any length. This problem is eliminated when the system is long enough to require transfer from screw to chain drive in the center area. The Boeing system does have a handrail that will expand at the same rate as the steps. There might be some hand pinching problems on this handrail.

Regarding litigation concerns with acceleration walkways, Consultant Miller concluded the following (as excerpted from his report):

> The dollar amount of claims that have been awarded by juries or settled without jury verdicts has varied substantially. They of course depend on the age of the victim, sex, earning capacity, and life expectancy. Juries have been well educated by frequent newspaper accounts of accident case awards. Most will find for the plaintiff even where there is substantial contribution on the part of the accident victim. Most believe that the owner of the escalator can well afford to pay and

will find accordingly. The manufacturers are usually brought in as a third party defendant along with the maintenance company, if another company. The recent decisions of many courts that find that the escalator owner is at law a common carrier, that is that the owner owes the highest degree of care to the business invitees, rather than ordinary and reasonable care, has placed a substantial burden on owners. The doctrine of Strict Liability is applied and this means that the mere happening of an accident is enough to get a case to a jury. Children under age seven are considered non-contributory to an escalator accident, and to age fourteen must be shown to lack understanding of the inherent danger of their actions while riding. We have no cases where physically handicapped people have been injured on escalators. Apparently most recognize their limitations and use other means such as elevators to get to their floors.

Certainly appropriate warning signs, lights, and public address systems should be used with the AMWS system throughout its life. Attendants will be needed for the first month or so until most people get used to the new idea. Closed circuit television might substitute thereafter. Emergency stop buttons must be unobtrusive or they will become an attractive nuisance. On this basis the highest degree of care obligation may well be satisfied.

Warning signs should be suspended over the entrance, just above the center of the walk and perhaps seven feet to the bottom to clear the average tall persons head. Sample wording might be:

"High Speed Moving Walk"
"Please watch your step"
"Hold Children's Hands"
"Do Not Run on Walk"

The entrance area should be brightly lighted with spot lights on the handrails. Lights of red color under joints of step treads will help people see the joint and not step on it. A flashing light on the sign would help attract attention to it.

Recorded announcements on a public address system might state the following: "This walk speeds up after you enter. Please be careful. Observe change in handrail speed and watch your hand hold." Approaching the terminal - "You are nearing the end of the walk and the walk will slow down. Be prepared to step off at the end."

An additional sign over the walk should provide the same message for people hard of hearing. Extra lighting at the end will also alert people to the change.

> The one major item that must be included in the location is that the moving walk must be off to the side of the regular hallway so that it will not be presented as the only means to travel the distance. Ample walking space must be provided for people to walk the distance who might not want to use the AMWS. The entrance should be such that a change from a straight line of walking must be made to enter the AMWS.
>
> If the above is carried out, any claim of "lack of warning" by an attorney for an injured person would be hard to sustain. This is frequently the basis for court action on escalator accidents, and becomes the first part of the negligence claim against the owners.

Based on his review of AMWS safety, Consultant Miller concluded the following:

> Of course an accelerating moving walk has one major advantage in that there are no steps to form and retract to a level position and second that it moves horizontally. Most escalator accidents occur due to these two inherent designs. Of course, the same problems exist on the stationary steps in the home, that is,stumbling on steps and falling down the slope. Consequently, the major source of moving walk accidents is eliminated, when compared to escalators. With careful maintenance and attention to combplates, balustrades and handrails, there is no reason to expect more accidents on an accelerating moving walk than on an escalator. If the rate of change of acceleration and deceleration is held to reasonable limits, that is well below that of a subway train or bus, there should be few problems.

3.5 Report Summary - APL Bunching Study

The problem of bunching on linear accelerating moving walkways was addressed by the Applied Physics Laboratory of John Hopkins University and the results of their studies contained in a report entitled "Rider Behavior on an In-Line Accelerating Walkway" (No. TPR-040). [19] Because the APL laboratory prototype is a short (3:1 speed ratio system compared to 5:1 ratio systems that will be considered for a public demonstration, the consultant had to devise experimental procedures which would simulate the larger ratio. (Excerpts from report single spaced.)

The report defines bunching as follows:

> Bunching may be defined as the crowding of pedestrians to such an extent that free movement is severely restricted. The step-on speeds of accelerating walkways will likely be the same as those of constant-speed walkways -- about one to one-and-a-half miles per hour. Passengers who board such a walkway will be accelerated to between three and five times the step-on speed. On an in-line walkway, this speed increase is accomplished by a longitudinal increase in the treadway surface. The surface increase, of course, results in a like increase in the distance between static passengers. For example, riders spaced at two-foot intervals at step-on will be six feet apart after acceleration in a 3:1 system. If they maintain their positions, they will again close to two feet during deceleration at the end of the trip. However, a gap of six feet between riders on the constant-speed section may be an invitation to close ranks, and if a walking lane is provided, walkers may step too close to a rider ahead before deceleration begins. Since deceleration reduces the standing area, some riders may be pushed uncomfortably close together. This is the bunching problem on in-line systems, felt by some to be a potential source of accidents at the end of a walkway.

Since acceptable personal spacing and pedestrian behavior are factors in forming the critical area mass of standing pedestrians in a "bunch" the report reviewed this subject as follows:

> An understanding of normal pedestrian occupancy areas and spacing, compared to the abnormal or jam-up spacing, will aid in assessing the likelihood of bunching. Table 3.2 lists these areas as defined in various sources. Horonjeff and Hoch [20] observed passengers on a constant-speed walkway for a 20-minute period after a 747 and 727 aircraft had landed at the San Francisco International Airport. They found that the overall usage resulted in a density of 24.8 square feet per person. This produces a spacing of 5.6 feet. The maximum usage observed on the walkway was seven square feet per person and a separation of three feet. It is important to note that seven square feet is essentially the same as the area reported by both Kinzell [21] and Horowitz, et al. [22] for the "body-buffer zone"

that people tend to maintain about themselves in their approach to other persons. Fruin [18] has indicated a seven to ten square foot range of occupancy as that which people require when comfort in public places is sought. This allows pedestrians standing in queues adequate separation from each other and room for limited lateral circulation between standees. Nevertheless, an average area of occupancy of four square feet has been observed for escalator queues and people waiting at crosswalks [23]. This still allows nearly two and one-half feet between persons. These areas and spacing indicate that people normally stand off from each other if the situation permits. In walking on public streets, movement and readjustment of position are observed when a pedestrian's personal space is encroached upon [24]. It may be assumed that similar behavior will serve to maintain wide spacing in the use of accelerating moving walkways.

An area occupancy of three square feet is the "touch" zone limit. Contact between people cannot be avoided at spacings closer than that defined by a 12-inch radius circle, and involuntary contact is reported to occur in elevators at areas of 2.75 square feet per person [Ibid 23]. Serious crowding occurs when the area available to each person is decreased to one and one-half square feet. With people in close physical contact, the adverse movements of one person will be imparted to his neighbors and a pile-up could occur if someone should trip or fall.

The APL conducted a number of bunching experiments using the Laboratory's linear walkway prototype, subjects involved in the experiments were first instructed to board at random as they would normally and in subsequent experimental sequences to stand as close to the person in front as "comfortable", and then in measured spacings of 18 and 15 inches (457 and 381 mm) respectively. Rider behavior was photographed in each of these sequences. The results of these experiments were described as follows:

TABLE 3.3

PEDESTRIAN OCCUPANCY AREAS AND SPACINGS

Definition	Area (Ft^2 per Person)	Spacing* (Ft.)	Source
Normal Moving Walk Usage	24.8	5.6	Horonjeff & Hoch (2)
Personal Comfort Zone	9.6	3.5	Fruin (5)
Maximum Moving Walk Usage	7.0	3.0	Horonjeff & Hoch (2)
Body-Buffer Zone	7.0	3.0	Kinzell (3)
Body-Buffer Zone	6.8	2.9	Horowitz, et al. (4)
Escalator Queue	4.0	2.3	Fruin (6)
Touch Zone Limit	3.0	2.0	Fruin (5)
Involuntary Contact	2.7	1.8	Fruin (5,6)
Jamming Condition	1.5	1.4	Fruin (5)

* Spacing is the diameter of a circle of the area shown.

Random boarding and spacing. Riders normally entered the walkway at intervals that placed them from 24 to 108 inches apart when on the constant-speed section. The mean spacing selected was 60 inches and 50 percent of the riders rode at a spacing of 60 inches or more. As would be expected with this degree of separation, observation of rider behavior in stepping from the walkway revealed complete freedom of action.

Minimum acceptable spacing. When riders were instructed to step forward and stand as close to the person in front of them as they normally would care to be behind a stranger, separation distances ranged from 18 to 120 inches. Mean spacing was 42 inches and 50 percent of the riders rode at a spacing of 60 inches or more. Observation of rider behavior at the end of the walkway indicated no difficulty in stepping off, even for the passengers that had moved up to an 18-inch separation on the constant-speed section.

Crowding - 18-inch spacing. The instruction for all riders to space themselves 18 inches apart on the constant-speed section of the walkway was observed to produce bunching at deceleration in which riders were in physical contact with each other. Some stepping back and rearranging of the feet were noted, but stepping off without difficulty was accomplished in all cases. The foremost rider invariably stepped off promptly before reaching the end of the walkway at the comb plate, usually by taking a long stride. This relieved the pressure on following riders who also stepped off promptly.

Crowding - 15-inch spacing. The instruction to step up to 15-inch separation on the constant-speed section compressed the riders more markedly on deceleration. Close-up photography of the feet showed that the shoes were in close contact and partially interleaved. It was observed that shuffling and rearrangement of the feet occurred and the riders at the end of the group tended to step back to relieve the pressure. Nevertheless, the foremost rider usually stepped off with a long stride and the rest of the riders were seen to follow suit. In no case was there any mishap. An attempt to aggravate the situation by asking the leader to delay stepping off as long as possible still failed to produce a bunching problem that was not adequately handled.

On the basis of an evaluation of walkway speeds, deceleration values and deceleration distances, and the bunching experiments described above, the consultant concluded the following:

> It is readily seen, then, that bunching on an accelerating moving walkway requires a specialized set of conditions that would not commonly occur, particularly if the condition is recognized and pedestrian controls are introduced to limit bunching behavior. The demonstration offered further evidence that the situation is handled readily.
>
> It was found in the demonstration that riders approaching an in-line accelerating walkway in a group boarded at intervals that spaced them at least 24 inches apart. If the riders did not move forward during the trip, they would be at this safe spacing when they left the walkway. While high speed on the constant-speed section may limit the tendency to walk, a significant number of people - perhaps half - will probably prefer to walk on a walkway if they can. Even so, the walkers will approach no closer than 18 inches to the person ahead of them as was shown in the minimum acceptance condition of the demonstration. This is consistent with the behavior of people seeking to maintain a body-buffer zone about themselves. Eighteen-inch spacing on the constant-speed section was found to be enough to allow room to maneuver when deceleration brought riders in contact. In neither the random nor the minimum acceptance conditions was any difficulty observed in adjusting to the deceleration section of the walkway.
>
> The deliberately induced bunching caused by the 15-inch separation condition of the demonstration is highly unlikely to occur during normal travel on the constant-speed section of the walkway. Such spacing would violate the "touch zone" and quickly be countered by a change of position. Nevertheless, riders still handled the bunching produced by this condition without mishap.
>
> If only a few persons are involved in the bunching cohort, either the persons in front of the cohort can step forward, or those in the rear step backward to relieve the condition. In wider walkways, side-stepping behavior could also be used to relieve the bunching condition. If, on a wider walkway, standing and walking lanes were designated and properly used in this manner, it is unlikely that serious bunching would occur since the walkers in the walking lane would require much more space for locomotion than standees. If a bunching cohort occurred in the standee lane in the converging deceleration section, the cohort could be readily dispersed into the walking lane. It should be emphasized that walkway users will rapidly learn what to expect on different parts of the trip after a few rides. They will also learn the effect of close spacing at deceleration and what must be done to avoid such situations or handle them when they occur.

Although the results of APL's bunching experiments tended to minimize the probable safety problems associated with this operating characteristic of linear accelerating walkways, the consultant suggests and evaluates several countermeasures that could be introduced to reduce the bunching risks.

> The ANSI A17.1 Code specified 16 to 44 inches for the width of moving walkways. Since many pedestrians will want to walk while riding, the maximum width provided by the Code is preferable. This will allow a standee lane to the right and a walking lane to the left with room for passing. The advantage of having space for sidestepping should tandem riders get too close to each other during deceleration is obvious. A stripe down the center to delineate the two lanes will also serve to encourage passengers to keep to the mode of riding selected -- standing or walking.
>
> Some provision for each rider to steady himself by the use of his hands is mandatory, a fact recognized by the Code. On an in-line accelerating walk this should be an accelerating hand-grip system should be synchronized with that of the floor. If handrails are used, safe-spacing marks should be clearly indicated to encourage people to stand only at the marked positions. The use of the hand-holds is a positive message for riders to use them, thus assuring safe spacing at the termination of the trip. Hand-holds are recommended for the right, or standee, lane, but it may be desirable to install a continuous handrail on the left, or walker, side in some installations. Walkers may need to grasp a support at any time, and should not have to seek a hand-hold that may be too far away when needed. Even so, the left side handrail should also contain the specifically indicated safe-spacing markings recommended above. Marked positions on the pavement at the same positions as the hand-holds, is a further measure that can be taken to ensure correct spacing of passengers.
>
> Signs at the entrance to the walkway admonishing passengers to use the hand-holds and stand by the spacers marked on the handrails should be considered. Printed advice could be repeated on signs during the trip and warnings that the pavement will slow down undoubtedly should be posted before deceleration begins. The inability to read signs for children, foreigners and those with vision deficiencies is a problem. Perhaps a pictorial representation of correct standing positions might be devised to instruct foreigners and older children.

Oral announcements carrying the same information as signs may also be considered. The redundancy may be useful, but will not completely solve the problem of advising passengers how best to behave on the walkway, particularly for the hard-of-hearing. Also, there will still be a number of persons who will not understand the language or the intent of the instructions. Nevertheless, between visual and auditory messages, advice to the majority of the riding public would be assured.

It is reasonable to assume that a highly crowded walkway would increase the potential for bunching, or at least the severity of a bunching accident. However, experience with escalators suggests that the number of people on an accelerating walkway at any one time will be kept well below full capacity by the entrance behavior of the pedestrians themselves. Under the heaviest traffic conditions, escalators are used only at 75 to 80 percent of capacity and vacant steps are frequently seen. Therefore, it is not deemed necessary to incorporate specific volume control measures such as turnstiles as a means for limiting usage.

Another device that has been suggested is a bunching detector that automatically shuts down the walkway if bunching occurs. The difficulties of developing a fool-proof device, not susceptible to pranksters, mitigates against its usage. Frequent stops of the walkway, each requiring an operator to resume start-up, should be discouraged.

It is expected that the introduction of accelerating walkways will involve an educational process for the public, just as with any new device. This will occur naturally, as the riders gain experience, but can be enhanced greatly by the use of attendants in the introductory phase. It may be useful to have an attendant at the entrance of the system, but it would be highly desirable to have one at the exit. Properly stationed, the latter could do much to advise passengers on the safe spacing at the deceleration end of the run and assist people off at the comb-plate if necessary. It is fully expected, however, that after the public has obtained experience with accelerating walkways, the attendants can be removed.

The pedestrian controls discussed above are all straightforward and do not require design changes to proposed accelerating walkways. However, the inclusion of such controls can be expected to enhance the introduction and use of these devices by the general public.

4.0 AMWS SAFETY SEMINAR

As part of the study contract it was determined that a seminar specifically addressing AMWS safety would be useful in providing a forum for discussion of the potential problems associated with the public use of these systems. The Seminar was held on April 18, 1977 at the New York World Trade Center. In attendance at the meeting were more than 50 persons including representatives of the escalator and moving walk industry, AMWS developers, human factors and safety professionals, physically handicapped persons and government agency representatives participating in the AMWS Program. The Proceedings of the Seminar are contained in Report G of the Project Series. The Seminar included movies and photographic slides providing illustrative details about several of the AMWSs under development, presentations by the four project consultants dealing with various aspects of AMWS safety, and workshops in which all seminar attendees participated. The presentations by Project consultants basically covered aspects of their studies which were summarized in the preceding report section. Perhaps the most useful output of the conference were the workshop discussions and written comments submitted by conference participants, both on the consultants' talks and workshop discussions.

4.1 Comments on Speakers' Presentations

Consultant Alan C. Browning -- AMWS Human Factors

Comments:

Annonymous - "Interesting, but key factor is jerk not acceleration (in films shown)."

Handicapped Person - "Imperative that a range of handicapped individuals experience the use of the system in order to determine the problems and possible solutions."

Human Factors Researcher - "Little heard from anyone raising serious questions about Human Factors in its design of walkways. One raised concern about the effect on some riders of putting walkways in tunnels. Possible vertigo effects of the sidewalk design mentioned."

Operations Research Professional - "Most useful. Would like to see a report on statistics for all speeds and boarding conditions, also figures on falls, bumps, etc. for test groups."

Handicapped Person - "Changing handrails may cause loss of balance."

Consultants Ralph Belvins, Dr. Jack Gebhard APL Bunching Study

Comments:

Handicapped Person - "Auditory sound announcements - must consider alternative method for hard-of-hearing and deaf persons. Tactile notices for blind people must be devised."

Operations Research Professional - "Interesting, but limited since walkway width was narrow. Also needed figures on capacity."

Anonymous - "Seems a theoretical rather than practical problem."

Consultant John Miller -- Accidents and Litigation

Human Factors Research - "I would have liked Miller to have given us accidents rates per number of rides after he had made escalator accidents as comparable as possible to what might happen on walkways. He led up to this, but didn't do it."

Operations Research Professional - "Needed more detail as to Groups with highest accident proneness and frequencies of types of accidents."

Consultant William Crager - The ANSI A17 Code

N.J. D.O.T. Representative - "...obviously an important consideration with project and future development of AMWS's."

Human Factors Researcher - "Very good account by Crager."

4.2 Seminar Workshops

Workshop No. 1 - "AMWS and the Handicapped"

Participants in this workshop included handicapped persons representing the New York City Mayor's Office of the Handicapped and the Cerebral Palsy Association as well as human factors researchers and representatives of government agencies interested in this subject. The proceedings and conclusions of the work shop are as follows.

The Chairperson opened the workshop by stating its charge: To discuss the possible problems that various types of handicapped persons might encounter on the AMWS and to make suggestions as to how these problems might be solved. The discussion included an enumeration of the various types of handicapped persons and the unique problems each would encounter in negotiating the AMWS.

The handicaps considered were: those with mobility problems that are required to use canes, crutches, walkers or wheelchairs; the blind, the deaf, the low mental comprehensive, and the aged. The aged are included in the category of the handicapped because of possible balance and/or mobility deficiencies. Included in the discussion were the following salient points:

- It is highly improbable that an AMWS on which all handicapped persons could travel can be designed. However, the system should be designed to accommodate as many types of handicapped as is possible, and provide an alternate mode of transportation for those that cannot use the AMWS.
- Persons in wheelchairs present a special problem because there are different types of wheelchairs, i.e. those with caster wheels in the front and those with caster wheels in the rear of the chair.
- Signs and/or audio instructions should be used to inform the general public concerning the precautions to be taken while travelling on the AMWS, but the signs cannot be seen by the blind and the audio instructions cannot be heard by the deaf.
- Precaution must be taken that the AMWS not be over-designed for the use of the handicapped and thereby not provide an adequate benefit for the general public.

Conclusions reached in the workshop are:

- In contrast to past policies, the handicapped must be taken into consideration at the very onset of the design stage.
- An alternate means of transportation must be provided for those handicapped who find it impossible to use the AMWS.
- Both signs and audio instructions must be provided for the deaf and the blind, respectively.
- Longer handrails and balustrades than are presently provided on existing escalators and moving walks should precede the leading edge of the AMWS and succeed the trailing edge.
- Sharply contrasting color differentiation should be used between both ends of the AMWS and the stationary floor or pavement it meets.
- Training of the handicapped in the use of the AMWS should be provided, if necessary.

Written Comment on Workshop No. 1

UMTA Representative - "While I am not for burdening new technology so much with design requirements that we make it out of reach financially or impossible to meet in terms of design, at the same time, we need to approach these new systems with the mentality of can-do with regards to making them accessible to the elderly and handicapped. To me an unhealthy (and probably fallacious) amount of attention is put on how "impossible" it is to include the elderly and handicapped. I feel we must emphasize more research to try to make AMWS systems accessible, in order to avoid appearing to introduce a new system that has not taken the elderly and handicapped into account in its design."

<u>Workshop No. 2 - "AMWS and the A17.1 Code"</u>

Participants in this session consisted mostly of representatives of the industry and members of the ANSI A-17.1 Code Committee.

The workshop opened with a discussion relating to the status and authority of the A 17.1 Code. It was explained that the Code, as promulgated by the A 17 Standards Committee, and published by the American Society of Mechanical Engineers (ASME), was purely advisory. However, many legal jurisdictions throughout the United States, on the State, County, and Municipal levels, have adopted the A 17.1 Code and in those jurisdictions the code is mandatory. Furthermore, the United States Government's Occupational Safety and Health Administration does use the A 17.1 Code as a guide, has referenced it many times, and has cited it in legal proceedings as a guide that should be followed. It was further pointed out that the code is used by owners of elevators, escalators, and related equipment as a reference specification. A New international code is being drawn up in Europe, to be called the CEN Code, which upon completion will be mandatory in all Common Market countries. The CEN will not only include safety requirements but also specify standard sizes of various equipment components which must be adhered to. Its purpose will be to promote international trade through standardization and interchangeability.

The question was raised as to whether, at this point in time, when there is so little hardware available and none in public use, standards for an AMWS can be written. It was pointed out that while it may not be possible to write standards, certain safety limitations are mandatory. However, until such time as experience is developed with AMWS equipment, any safety code will be necessarily be limited.

A discussion ensued regarding specific hazards in the various systems. In one of the systems there appeared to be a shearing hazard where portions of step treads disappear under the balustrade. Although appearing bad, the situation is considered analogous to that experienced with escalators at their combplates and at the step leveling area. It was stated that on the Dunlop system, the portion that slides under the balustrade is smooth with no grooving and therefore any hazard is reduced. It was also added that the Moving Walks Sub-Committee is considering the recommendation to require micro-switch shut-off protection at points where the tread disappears and combing is not possible.

A workshop participant pointed out that there may be problems with teeth breaking in the Trax system. It was observed by others that the teeth in the Trax system have a larger cross section and are more substantial than typical combplate teeth.

Information was requested regarding the emergency stop acceleration and jerk on the high speed sections of an AMWS. The Dunlop representative replied that in emergency stop, the deceleration in the high speed section of that walk is 0.1G.

The next discussion related to the desirability of floating combplates with micro-switches vs. fixed combplates. The Dunlop system uses a sectional combplate, with each section floating and any section being able to stop the machine when it (the combplate section) is tilted. It was reported that the Trax system also uses a floating combplate. The Dunlop representative was asked about how many members of the general public have ridden the Speedaway and how many accidents were experienced. It was stated that no members of the general public have ridden the Speedaway. The only persons who have ridden it thus far were invitees. No accidents have been experienced.

The question of establishing a code for the AMWS at this time was again taken up. It was agreed that there are very limited areas which could be covered by the code. Some of the details present in the elevator and constant speed moving walk code could not be applied to the AMWS at this time because of lack of experience. It was also agreed that there were many limiting parameters which could be specified. These include: treadway slope, maximum speed, maximum acceleration (and deceleration), maximum rate of change of acceleration, the general treatment of shearing points, general limitations on balustrades, and handrail requirements.

Written Comment on Workshop No. 2

Safety Engineer - "Accelerated moving walks 'emergency stopping' consideration might best be given to 'resilient' or variable deceleration stoppings, e.g. at the low speed section, particularly at the combplate, the deceleration should be the same as now experienced on unloaded escalators or constant speed moving walks, but at the maximum speed section, the deceleration should be lower or that means that the stop or '0' speed, would occur some time after the stop occurred at the combplate. This concept might be accommodated by possible (?) modification of the mechanical design."

Workshop No. 3 - "AMWS Safety and General Public Use"

Participants in this workshop represented mostly representatives of agencies interested in the problems associated with the public demonstration and use of the AMWS.

The workshop opened with a discussion of public information requirements for an AMWS demonstration. The various aspects of signing were discussed in detail. 1) Signs should be few, visible and understandable. 2) Excessive signing may be ignored or distract users. 3) Signs should emphasize safe behavior, and warn of potential hazards. Signing needs may be reduced by other control measures such as T.V. monitoring of crowds. Psychologists should be engaged to determine most effective way of getting the message across to people, particularly aspects of AMWS use that are different, such as its acceleration, directional change, or handrail segmentation. Initially, attendants should be provided to assist and direct users. Training films might be employed to explain safe use of the AMWS. Legal precedents should be considered in that anything provided for the demonstration might be required in later production models for regular use. Negative signs should be used whenever possible; they are easier to understand. Public address announcements given at intervals along warning users to keep spaced apart, to hold hand rails, watch steps, etc. are likely to satisfy most legal requirements.

In a discussion on equipment speed it was stated that the environment in which the equipment is deployed must be considered, different speeds will be appropriate in different environments, in open locations wind effects may be a consideration. It is important to consider user awareness of treadway and hand rail movements, including the illumination of treadway surfaces. Through the treadway lighting as in new escalators, or demarcation of some sort, is a near necessity to make people aware of movements and transitions to and from stationary surfaces. Some of the proposed systems will alert the user by the movements felt under the feet, but lighting should be designed to give additional warning, since the elderly may not perceive movement and be able to react as needed. Perceptions of handrail movement is also a consideration. Perhaps handrails should be marked with color strips, dots, diamonds or other markings. Similar markings on the treadway may also help, but alternating dark-light finishes have been shown to be ineffective.

In emergency braking, there is need to stop in the shortest time and distance, but the higher the speed, the more difficult this will be. If there is an entrapment of an extremity, there is need to stop very fast. A loaded down going escalator cannot be stopped in a short distance. Going up, the weight of the people helps to shorten the stop distance. Legal precedents have recognized this problem. For example, to stop in 1-1/2 steps, the user must grip the handrail very hard in order not to fall in a downgoing escalator with the added pull of gravity. Once a limb is caught, every slight additional movement may shear it. In this case, the longer it takes to stop the machinery the more severe the injury will be. An escalator going up can stop in one step length, five or six going down. An AMWS, although horizontal, will have considerable mass and this must also be taken into account in setting maximum speeds and decelerations. The more serious entrapment dangers in escalators are at the combplates and risers, some accidents have been caused by entrapments at combplates and by children or others pressing feet against step risers. AMWS have no risers, only horizontal actions except where there is rotation under a balustrade where there is the possibility of a drawing in action where garments, sneakers, or fingers, may be caught in. This possibility may exist even with clearances as small as 1/16 in. Microswitches have been provided at combplates so that if anything begins to lift it, it will stop the equipment, limiting potential accident severity. The advantages of providing the emergency stop buttons on an AMWS outweight the disadvantages. The problem with emergency stops is the temptation to tamper with them. They should be made accessible but placed out of reach of small children.

Written Comment on Workshop No. 3

Tri-State Regional Planning Comm. Rep. - "Did spend a bit too much time discussion signage problem. All that's needed is 'Hold Handrail' and 'Watch Step.' Did not discuss linear system bunching hazard or multiple combs. Might consider channelized stripes to guide people to handrails on Dunlop (wide entry) system."

U.S. D.O.T. Representative - "Walkways are designed to stop in a certain length of time if an emergency switch is activated. The deceleration experienced by people on the high speed will be greater than that experienced on the acceleration or deceleration sections. The higher speed will require longer stopping times to assure low accelerations. What impact will the longer stopping times of accelerating walkways have on safety?"

Workshop No. 4 - "AMWS -- Possible Future Research and Development

Several possible areas of future research and development activity were discussed by the participants of Workshop 4. The general areas of discussion, and pertinent points relevant to each, were the following:

Handrail Technology

There presently is no adequate variable speed handrail available for accelerating walkways. Early AMWS efforts have concentrated their work on problems of the walkway itself, neglecting handrail development work. Specific areas of research should investigate the adequacy of segmented handrails, the possibility of utilizing overhead subway-type straps, handrail vs. walkway, the pinching problem, expandable handrails, the problem of speed differential, and code compliance. It was the general concensus of the group that a demonstration project would do much to answer many of the questions concerning handrail design.

Side Loading and Intermediate Exits

The existing combplate design is a relatively troublesome point on operating escalator and moving walkway units. It might be desirable to eliminate the comb by emphasizing side loading systems. This emphasis could also consider the possibility of introducing intermediate on-line stations to provide "local" service on especially long conveyors (to increase access and to eliminate barrier effect). This side boarding concept would probably dictate additional research in human psychological and physiological factors (similar to the RAE work), and the post problem.

The desirability of several short section walkways, with intermediate stations, as opposed to one long walkway was questioned, as was the possibility of utilizing AMWS designs as purely boarding mechanisms to long, high speed conventional design walkways (as opposed to one long AMWS.)

Optimal Design - Economic Considerations

The AMWS is largely an untried mechanism, and designers generally have little concept of the optimal design constraints of the unit (most efficient length, speed, applications, space requirements, etc.). More detailed "real world" information should be compiled to develop a designers' manual for utilizing AMWS. Also, economic criteria of AMWS installation and operations must be developed to demonstrate the ultimate applications of the units. Where would AMWS be appropriate?

Again, a demonstration installation would be a valuable testbed to investigate many of these questions.

Safety and Human Reaction

How will the general public "feel" about riding AMWS? What top speed is acceptable for persons moving on unenclosed pallets? Should the walkway be enclosed? Will the public react adversely to enclosed or tunneled AMWS (example: Will sense of movement adjacent to a tunnel wall cause disequilibrium and dizziness)? What visual treatment of nearby surfaces will lessen this impact? What special user protective measures are necessary?

Other Areas of Study

How will AMWS service the elderly and handicapped? What subgroups of this population will be served or excluded, and for what reason? How could mobility be improved?

AMWS vertical curves are necessary to negotiate highway overpasses, one of the most promising applications for the moving walkway system. Designs that negotiate vertical curves must be developed, and then tested from all aspects.

Efforts must be undertaken to adapt AMWS design to the available space, rather than adapting the space to AMWS.

Questions concerning the applicability of AMWS to new town planning and its role in the new town were raised.

The meeting closed on the note that most of the above raised problems and/or questions are solvable, should sufficient efforts be devoted to their study. It was again agreed that the proposed demonstration project would be a valuable asset to the development of an acceptable AMWS research program.

Written Comments on Workshop No. 4

Operations Research Professional - "Panel had wide range of experience and viewpoints. Suggestions involved refinements and alternative walkway designs. The main thrust of future R & D is to be directed towards public acceptance refinements. Tendency is to wait and see the results of the P.A. Hoboken test."

Transportation Systems Analyst - "Too dominated by one person."

Industrial Psychologist - "Very little new of an engineering nature discussed. The main concern of the participants appeared to be on the need for and the uses of moving walkways in general. Much talk on the economic aspects of the systems - where to put systems, who would use them, 'value capture' problems, etc." - "Some interest in pursuing Browning's work on side-loading if riders want to get off walkway at way stations along the way." - "The handrail/handhold design problem needs attention was the consensus." - "My opinion of discussion is that some form of demonstration is required as the step that should soon be taken to settle (or provide light on) current questions and to raise new ones that would lead to the next generation of both systems and their uses, acceptability, etc."

Transportation Planner - "For the most part the areas identified for future possible R & D were important and pertinent to the overall problems of public acceptance and usage of AMWS installations."

Transportation Systems Researcher - "Would like to see future research on 'post-problem' to determine side loading intermediate stops. Would like to see acceptability studies to determine user requirements in terms of distance between stops and speed. What R & D for elderly and handicapped?"

Transportation Planner - "Areas for further research: (1) overhead handgrips vs. handrails, (2) optimal length and speed of accelerating walkway for inter-terminal and new city planning, (3) handrail problem of pinching, (4) vigorous research as to what would happen if a person falls on a moving walkway having a speed in excess of 5 mph and over 600 ft. length, (5) effect of visual confinement in this system, (6) what is the potential use expected by handicapped individuals including visually and motor handicapped individuals?"

5.0 RISK EVALUATION - AMWS PUBLIC USE

5.1 General Discussion

Based on the overview of transportation safety experience including the accident data of pedestrians using stairs developed by the National Bureau of Standards, the identification of the potential hazards connected with AMWS use, the review of known equipment characteristics, the analysis of moving way system accidents on escalators, and the reported experience of the limited use of the available operating AMWS prototypes, there appears to be no apriori reason why an Accelerating Moving Walkway System cannot be operated in an experimental or demonstration mode at levels of safety considered acceptable by the general public. This assumes that a basic safety program is followed that addresses equipment design, the methods of operating and maintaining the equipment, the instruction of users in the operating characteristics of the system and its correct use, and appropriate precautions and controls are taken to assure there are no adverse environmental factors or misuse of the system.

5.2 Equipment Design and Operation

The equipment should be designed and operated in such a manner that the prospective hazards of inertial affects, entrapment, divergence or surface discontinuity, bunching and post problems, or mechanical failure will be minimized. Inertial hazard - Motion effects represent potentially the greatest risk on accelerating moving walkways because of the possibility of toppling passengers, with the associated risk of head injuries.

Minimization of the motion effects will require that the upsetting forces due to acceleration, deceleration, the rate of change (RCA) of acceleration and deceleration, and emergency stopping be at acceptable levels. The project consulting report by Browning, (Section 3.2) as well as other data, (Section 2.3), indicate that accelerations and decelerations below 3 ft./sec.^{3} (.91 m/sec.^{2}-0.095 G) are desirable. Browning recommends even further that accelerations/decelerations as low as 0.03 G might be considered since it would only add a few seconds to journey times which would be inconsequential for longer systems. However, these lower accelerations/decelerations are an equipment cost factor since they result in the lengthening of entry and exit transition sections. As reported by project consultant Crager (Section 3.3), the A 17 Code committee is considering a code provision specifying a maximum allowable treadway acceleration (or deceleration), with an adjustment for possible treadway slope according to the following formula:

$$a_{max} = (.095 - \sin x)\ G$$

where a = maximum allowable acceleration (ft/sec^2)

x = slope of the treadway in acceleration zone

G = acceleration due to gravity = 32.2 ft./sec.^{2}

Project consultant Browning recommends that the rate of change of acceleration be uniform and that rise times of more than one second are preferable to reach a given level of acceleration. Consultant Crager reports that the A 17 Code committee has under consideration a code provision specifying that the RCA shall not exceed 5 ft./sec.^{3} (1.5 m sec.^{3}, .16 G/s), and the product of acceleration cubed, times the RCA shall be equal or less than 25.6.

$$(a)^3 \times RCA = 25.6$$

This is a formula developed by Blevins based on Browning's and Hirshfeld's experiments. [25] [Ibid 9,12,1] Emergency stopping decelerations should be of that magnitude that persons grasping the system handrail will not fall, and that possible falling by those not grasping the handrail is minimized. Indicated maximums for emergency stopping based on transit industry values as well as Browning's experiments are about .15 G. Attention should be given, to the extent possible, to minimizing sudden stopping on the system so that it is only used for appropriate emergencies.

Entrapment hazards - Can be minimized by combing of the treadway at exits and entry to the AMWS and by protective sensing switches at potential pinch points which will stop the AMWS in the event that an entrapment occurs. Equipment detailing between the moving handrail and stationary balustrade surfaces, as well as at the handrail return or point where the handrail enters the balustrade must be designed to minimize the entrapment of fingers, hands, clothing and carried accessories. The entrapment potential of contracting treadway surfaces must be considered, and these surfaces should be designed to comb out, or otherwise prevent, the ingestion of toes, feet and footwear, laces, thongs, or other accessories. In all instances attention should be given to the potential affects of equipment wear, or failure modes of elements of the system which may increase the entrapment hazard during the useful life of the system.

Divergence and Discontinuity Hazards - The expansion and construction of treadway and handrail surfaces, multiple handrails in sequence, and laterally shifting treadway pallets all present divergence and discontinuity interfaces that passengers must adapt to. The effective human reach, based on anthropometric data has been used to develop handrail-treadway speed differential relationships on the Speedaway system. Expanding handrails will also require adjustment for changes in arm reach. While it has been observed that pedestrians normally make frequent hand position changes while shifting position and grasping the handrail in stair locomotion, identifying the specific problems associated with divergence and discontinuity on an AMWS, will require extensive operating experience. This is not considered a significant risk based on the potentially small proportion of users who may have this type of adjustment difficulty. The discontinuity between stationary and moving surfaces that exists at entry and exits similar to existing escalators should be differentiated by contrasting colors as suggested by handicapped participants in the project Safety Seminar. Bunching hazards on a linear accelerating walkway are a recognized problem but are not considered to be a significant accident risk providing that the proper precautions are instituted. These precautions would include audio and visual advisories via public address announcements and signs, markings on handrail and the walkway designating desirable pedestrian spacing distances. Possible designation of walking and standing lanes on the AMWS, and other similar controls should minimize the probability of bunching on the walkway itself. The problem of bunching while exiting at outlet ends of linear AMWS will be comparable to that of existing escalators and moving walks. Post problem hazards - The possibility of the moving passenger encountering stationary features on an AMWS which would cause post effects is minimal. The multiple handrail design of the Speedaway, which results in a series of identations in the balustrade at the transition from one handrail to the next, potentially could produce some post effects under unusual conditions, but the balustrade has been specifically shaped at these transitions to minimize this possibility. The other potential "post" hazard, that of body contact with the stationary sidewalls of the balustrade in high speed sections of the AMWS, is considered to be a low risk, but should be carefully monitored in the public demonstration.

Mechanical failure - As part of the AMWS development and selection process, AMWS manufacturers will be required to identify and describe the prospective failure modes of pallets, handrails, mechanical linkages, motors and other system elements, and also to identify and describe the possible consequences of such a failure on passenger safety. Where feasible the manufacturer will introduce appropriate counter-measures to eliminate, or substantially reduce possible safety risks associated with an equipment failure. In addition, the manufacturer will be required to identify the possible safety consequences of equipment wear, and develop recommended replacement and/or maintenance procedures to reduce safety risk associated with such wear.

5.3 User Information and Control

It is expected as the public demonstration of the AMWS progresses different levels of user information and controls will be required. An incremental approach to user safety has been developed for the demonstration, as described in Project Report "F".

5.4 AMWS EQUIPMENT HAZARD SUMMARY

Table 5.1 following is a summary review of potential hazard considerations for the Dunlop Speedaway, Trax, Applied Physics Laboratory, Boeing, and Dean Research accelerating Moving Walkway Systems.

AMWS EQUIPMENT HAZARD SUMMARY

TABLE 5.1

HAZARD CATEGORY

SYSTEM	INERTIAL	ENTRAPMENT	DIVERGENCE	BUNCHING	POST PROBLEM	MECHANICAL FAILURE	HANDICAPPED CONSIDERATIONS
DUNLOP SPEEDAWAY	Design objective is to meet motion criteria. Handrail proximity is factor at entry and exit.	Equipment tolerances standard, conventional combing at ends, shearing concern for pallet beneath balustrade at deceleration section, multiple handrail detailing may increase entrapment probability.	Segmented handrail/ treadway speed differentials, transverse displacement adjacent treads.	Minor, minimized by expanded area deceleration section.	Handrail transition may have affect in some circumstances	No abnormal hazard identified - missing pallet protection desirable	Multiple handrail grasp and release, handrail proximity, transverse movement treads, handrail and tread speed differences.
TRAX	Design objective is to meet motion criteria.	Conventional combing at ends and at intermeshing treadway, surfaces, handrail detailing unknown.	Synchronicity of handrail and treadway expansion and contraction, shifting of intermeshing treads.	Decrease in treadway area in deceleration zone proportional to speed ratio.	Not identified. Complete equipment detailing unknown.	No abnormal hazard identified missing pallet, protection desirable	Expanding contracting handrail and treadways will require foot and hand position adjustments.
APL	Same as above.	Same as above, plus rotative action of leaves during accel. and decel. may entrap.	Synchronicity of handrail and treadway expansion and contraction.	Same as above.	Same as above.	Same as above.	Same as above.
BOEING	Same as above.	Same as TRAX.	Same as TRAX.	Same as above.	Same as above.	Same as above.	Same as above.
DEAN RESEARCH	Same as above.	Combing detail unknown, rollers are of torque limit design, potentially reducing entrapment hazard. Handrail detailing unknown. Rollers may build up friction coating film in use increasing entrapment.	Treadway does not contract, speed differential adjacent rollers. Handrail contractions.	Treadway does not contract, speed differential of rollers will potentially contribute to some bunching.	Same as above.	Roller seizure could cause tripping hazard	Handrail same as above, rotating rippled treadway surface possible problem.

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