Innovative Technologies that Improve Escalator Passenger Safety

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Abstract. New technologies such as variable frequency drives can greatly improve escalator passenger safety. These technologies and how they work are explained.

Additionally, existing devices and procedures required by the ASME A17.1 code but not required by BS EN 115 that can greatly reduce the frequency of occurrence of entrapments as well as the severity of the harm caused by entrapments are explored.

1 INTRODUCTION

Accidents are a frequent occurrence on escalators [1]. Often these accidents result in passengers being injured. Whilst most injuries are minor, serious injuries occur. Some injuries are life-changing and occasionally life-ending.

The majority of the accidents fall into two general categories as follows [1]:

1. Falls
2. Entrapments

These two categories will be explained and how both the probability of occurrence and the severity of harm of these two categories can significantly be reduced by the application of new technologies.

2 ACCIDENT TYPES

2.1 Falls

Falls most often occur when passengers are boarding an escalator. The transition from walking to standing on an escalator step can be difficult to navigate particularly for older passengers [2].

Falls also occur when the steps make the transition from being level to being inclined. It is during this transition that passengers whose feet are placed on more than one step may fall. Additionally, if a passenger is transporting luggage, the shifting of the luggage may cause the passenger to fall. In locations where passengers routinely carry their luggage onto the escalator, such as airports or transit centres, luggage is involved in the majority of escalator falls [1].

Most escalator falls involve passengers over the age of 65 years [2]. This is attributed to a reduction of cognitive ability [2].

The majority of escalator falls at airports involve women. This makes older women an *at-risk* group [1].

2.2 Entrapments

Entrapments take many forms such as the following:

1. Non-injury. A non-injury entrapment might involve a shoelace or other item of clothing becoming entrapped.

2. Minor injury. A minor injury usually involves a body part becoming entrapped, but the escalator is stopped before the body part impacts the combplate.

3. Major injury. These injuries often begin as minor injury entrapments, which proceed along the escalator until the body part impacts the combplate and causes life-changing injuries. Note: A Life Changing Injury might involve an amputation or a permanent impairment of function.

4. Fatal injury. A very rare form of entrapment that occurs when severe crushing or amputation is caused by the escalator.

3 RISK ASSESSMENT AND REDUCTION

Risk assessment involves assessing the hazards that cause harm to persons, property, or the environment and determining their probability of occurrence and the severity of the harm because of a harmful event.

Risk reduction involves the following:

1. Reducing the probability of occurrence.
2. Reducing the severity of the harm.
3. Reducing both the probability of occurrence and the severity of harm.

ISO 14798 2009-03-01 Lifts (elevators), escalators and moving walks — Risk assessment and reduction methodology, is a standard that describes how to assess hazards in the lift industry [3].

The harm of falls and entrapments can be reduced by applying new technologies and by applying practices required by the ASME A17.1 code that are not required by BS EN 115-1 [4, 5].

4 FALL REDUCTION

4.1 Variable Speed Drives

Variable speed drives can reduce falls because of the following:

1. Brake failure.
2. Harsh stops.
3. Congestion.
4. Boarding and exiting.
5. Speed.

Brake failure: Brake failure occurs when the mechanical brake cannot bring the step band to a stop after an emergency event has caused the brake to be applied and power to be disconnected from the motor. This can happen when a fully loaded escalator travelling in the down direction makes an emergency stop. The result is a pile-up of bodies at the lower landing of the escalator.

The maximum deceleration rate for an escalator braking system is defined by BS EN 115 as 1.0 m/s^2 and 0.91 m/s^2 by ASME A17.1 [5, 4].

The same mechanical brake must stop a fully loaded escalator travelling in both the up and the down direction at the same maximum deceleration rate. The brake must dissipate the kinetic energy of the moving load and the change in potential energy of a load moving in the down direction.

The mechanical brake loses some of its friction material each time the brake is applied. To remove an escalator from service, the stop button may be used in lieu of the on/off switch, causing brake wear.

Escalators with a rise greater than 6 meters in most cases must be fitted with an auxiliary brake to reduce the probability of occurrence of a brake failure [4, 5].

Dynamic braking using the drive motor and the variable speed drive can bring an escalator to a complete stop electrically. The mechanical brake is then applied as a holding brake. This operation causes no wear to the brake pads or shoes.

If an escalator is fitted with a dynamic braking system, the ASME A17.1 code does not require an auxiliary brake when the rise exceeds 6 meters [4].

Harsh stops: Harsh stops occur when the application of the mechanical brake causes the escalator step band to stop with a high jerk and deceleration rate. These high rates can be caused by a combination of escalator loading and brake adjustment.

A harsh stop often causes passengers to fall in the direction of the escalator travel. If the escalator is travelling downward, a fall by a single person into the passenger in front of them can cause a "domino effect" fall involving several individuals.

Dynamic braking systems use a closed-loop control system to deliver deceleration and jerk rate profiles that are not affected by load or brake adjustments. The acceleration rate can often be set below the code-required maximum. For more detail see ASME A17.1 Figure I-15, Escalator/Moving Walk Dynamic Braking Logic.

Congestion: Congestion can occur at the egress end of an escalator when passengers, after alighting from the escalator, stop in the area in front of the escalator in lieu of moving onward. This often occurs when passengers stop to check their mobile phones for messages.

This type of congestion can cause passengers trying to exit an escalator to collide with other passengers, fall and even become injured.

Artificial Intelligence (AI) pattern recognition devices can detect congestion and cause the variable speed drive to slow down the escalator to reduce the arrival rate at the end of the escalator. An audible alert announcement at the end of the escalator could also be invoked by the AI device. One might think of this as "Escalator Nudging".

Boarding and Exiting: Many falls occur during boarding and exiting escalators due to the extra effort required to transition from walking to standing on an escalator and from standing on a step to walking again [2].

Speed: A study to determine the causes of injury accidents at the Guangzhou Metro found that most fall accidents occurred between the end of the morning rush hour and the beginning of the evening rush hour [6]. At first, this may seem counterintuitive. However, this is the time period when older retired passengers and non-working mothers with children would be using the Metro. The study suggested slowing the speed of the escalators during this lower traffic period to give the older, less agile passengers and those distracted attending to children more time to board. The speed could also be reduced when a passenger requiring a slower speed is detected by AI.

Modulating the speed of an escalator using a Variable Speed Drive is easily accomplished. Additionally, this approach does not negatively affect traffic handling and has a minor positive impact on energy usage and equipment life.

4.2 ASME A17.1 & BS EN 115-1 Code Requirements

Deceleration Rate: The maximum deceleration rate during braking required:

BS EN 115-1:	1.0 m/s²
ASME A17.1:	0.91 m/s².

The lower deceleration rate is less likely to cause falls.

Speed: The maximum step speed permitted for escalators with a 30º inclination:

BS EN 115-1:	0.75 m/s
ASME A17.1:	0.5 m/s

The higher speed makes the transition from walking to riding more challenging, particularly for older passengers. Higher speed causes more falls.

Inclination Angle: The highest inclination angle permitted is:

BS EN 115-1	35º
ASME A17.1:	30º

5 ENTRAPMENTS

5.1 Reduction in Probability of Occurrence

The probability of occurrence of step/skirt entrapments has been found to be proportional to the size of the skirt/step gap and the coefficient of friction of footwear sliding on the skirt panel [7]. The two factors, gap and coefficient of friction are additive.

The index, developed by the consulting firm Arthur D. Little [8], combines these two factors. It establishes the maximum value of this index as 0.25 when Skirt Deflectors are installed. Extensive testing has shown that the probability of occurrence of step/skirt entrapments is significantly reduced when the index value is maintained below 0.25.

The ASME code recommends that this index be tested annually, the gap adjusted, and the surface of the skirt be refinished to maintain this index below 0.25 [4].

5.2 Reducing the Severity of the Harm

Step Guidance: BS EN 115 permits a maximum gap between either side of a step and the skirt of 4 mm and a combined total gap on both sides of the step of 7 mm [5]. These gaps are measured statically.

Steps can be forced to move slightly from side to side. Steps can move in what is known as the “step deadband”. A static gap measurement does not consider the step deadband.

Skirt panels are not totally rigid. When a force is applied to a skirt panel, it deflects.

ASME A17.1-2022 defines the maximum gap between the step and skirt to be no more than 5 mm when a 110 N force is applied between the skirt and step. This measurement is referred to as “Loaded Gap” measurement [4]. This is a more aggressive measurement than the measurement required by BS EN 115 because it considers both the movement of the steps into the deadband and deflection of the skirt.

Skirt Obstruction Devices: The ASME A17.1-2022 code, Section 6.1.6.3.6 requires the installation of skirt obstruction devices [4]. These devices are switches located at the point where the step becomes flat as it approaches the comb plate.

If these switches detect an object, such as a foot or hand, entrapped between the step and the side skirt, they will bring the escalator to a stop before the object impacts the comb plate. When an entrapment occurs, if the escalator stops before the entrapped hand or foot impacts the comb plate the injuries are usually minor. If, however, the hand or foot impacts the comb plate, the injuries are often life-changing. A variable speed drive with dynamic braking can develop the minimum deceleration rate necessary to bring the step band to a stop before the entrapped hand or foot impacts the comb plate.

The Hong Kong Code of Practice on The Design and Construction of Lifts and Escalators 2021 Edition Section E Part 4 5.5.3.4 e requires similar components called Detection Devices [9]. This code also calls for Detection Devices along the inclined portion of the escalator.

The BS EN 115-1 standard does *not* require Skirt Obstruction Devices [5].

Step Upthrust Device: The ASME A17.1-2022 code, Section 6.1.6.3.9, requires the installation of a Step Upthrust Device [4].

When an object such as a shoe or boot becomes entrapped between a step and the adjacent step riser, the object causes one of the steps to either rise above its normal position or causes one of the steps to be forced below its normal position.

A Step Upthrust Device is a switch that will bring the escalator to a stop before the raised step and the entrapped object impact the comb plate. As with skirt/sidestep entrapments, stopping the escalator before the object, footwear, or body part, impacts the comb plate reduces the severity of harm.

BS EN 115-1 does not require Step Upthrust Devices [5].

A Step Level Device, a switch that stops the escalator if a step is forced downwards because of an entrapment, is required by both BS EN 115 and ASME A17.1 [4, 5].

The Step Level Device and the Step Upthrust Device both prevent a displaced step from colliding with the comb plate. Such a collision, commonly known as a “step pile-up” can cause considerable damage to the escalator and often causes injuries to passengers.

6 CONCLUSIONS

The frequency of occurrence and the severity of harm of escalator incidents can be reduced by providing escalators with closed loop variable speed drives and adopting parts of the ASME A17.1:2022 code.

Closed loop variable speed drives should perform the following functions:

1. Dynamic braking.
2. Step velocity based on traffic level.
3. Velocity reduction when landing congestion occurs.

The following sections of the ASME A17.1:2022 code should be incorporated into the BS EN 115-1 standard:

1. 6.1.3.3.5 Loaded Gap Between Skirt and Step.
2. 6.1.3.3.9 Step/Skirt Performance Index.
3. 6.1.6.3.6 Escalator Skirt Obstruction Device.
4. 6.1.6.3.9 Step Upthrust Device.
5. 6.1.4.1 Limits of Speed.
6. 6.1.5.3.1.c Escalator Driving-Machine Brake.
7. 6.1.3.1 Angle of Inclination

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BIOGRAPHICAL DETAILS

Rory Smith is Visiting Professor in Engineering/Lift Engineering at the University of Northampton and a Consultant at Peters Research Ltd. He has over 55 years of lift industry experience during which he held positions in research and development, manufacturing, installation, service, modernization, and sales. His areas of special interest are Machine Learning, Traffic Analysis, dispatching algorithms, and ride quality. Numerous patents have been awarded for his work.