Real-Time People Mover Safety Using Edge Intelligence on Lifts, Escalators and Travellators

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October 22, 2024

Abstract

Life-threatening situations in and around lifts, escalators, and travellators are known to cause severe injury and, in some cases, death. We research the real-time risk and analyse the recent spate of injuries by "people movers". We analyse these critical systems that follow a consistent pattern of catastrophic failure. Our research reviews the technology, its application, and the risks to humans from using these systems with low awareness of the dangers of careless use. The study identifies parameters that warn against impending failures by increasing awareness of the risk, such as the shear force experienced by human joints whilst stepping on or off systems in operation, especially with distracted, unrestricted children. We investigate and discuss the dangers of carrying forbidden items onto these utilities. Our investigation delves into electro-mechanical people mover technologies and suggests behavioural and ML-based edge intelligence to preempt accidents.

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***Index Terms*— Health and Safety, Shear-Risk, Travel Speed, inertial-throw, Accessibility Standards, obstructive pileup.**

I. INTRODUCTION

The research project focuses on people mover technologies used to carry people and their baggage from one point to another, saving customers' physical energy and smoothing the people traffic distribution across a complex. Some multi-floor complexes would have three modes of travel, Lifts, Escalators and Travellators, to optimise traffic flow and operational reliability [1], [2],[3]. The standards developed by standards bodies in each country ensure significant clarity on safety and performance expectations from deployers of people-mover technologies. However, all electro-mechanical systems malfunction without warning and quite dramatically, as is visualised in this link to a disastrous event in Sydney. It will provide some context of the threat to public safety we identify as serious enough to warrant increased awareness.
https://7news.com.au/video/travel/trains/bodies-pile-up-as-escalator-malfunctions-at-high-speed-bc-6288100544001,
Copyright terms, [4],[5] for research.
The three system types have weaknesses listed in Table 1.

Table 1 Attributes of people systems

Attribute	Lifts	Escalators	Travellators
Transitions	Up-Down	Inclinations	Horizontal
gFx	Jerks,stop.start	Jerks,stop.start	Jerks,stop.start
Audio	Squeek clicks	Teeth Clicks	Squeeks

Manuscript submitted July, 2021. *(Corresponding author: Ollencio D'Souza.)*
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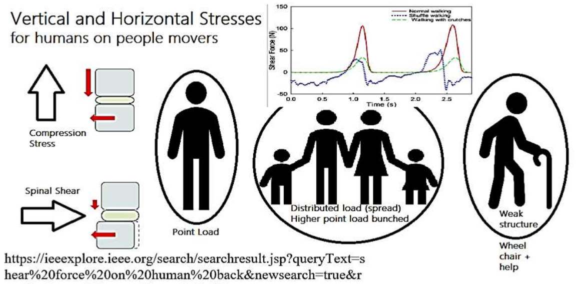
II. LITERATURE REVIEW

The problems with people movers are well documented [6],[7],[8]. Some information is via video clips and news articles because "failures" make sensational news. A couple of clickable links are provided to cover three kinds of incidents;

1. Failure of the escalator (down) mechanism that runs faster than expected does not allow sufficient time for people to get off it – hence, there are pileups, bad accidents and even deaths[8].
2. Travellator (flat surface transport) failure: Two types of incidents – too fast or a sudden stop causing high shear stress on human joints, which results in a severe shock to bone structures and an inertial fall forward, causing severe injury[3].
3. Lifts (vertical) stop, trapping people on a floor or somewhere in the middle of a floor, with a G force that causes severe stress on the human bone structure, nausea, claustrophobia and distress[6].

The People Mover Standards (2021)[1] recently published identify it as a severe issue that cannot be approached after the failure has occurred. It has to be sensed and corrected by constant safety (anomaly) monitoring of the people mover. It is essential to organise the team to respond quickly. The only way to do it is to get information well in advance to manage issues before they become a problem[7],[9]. (**Fig.1**)

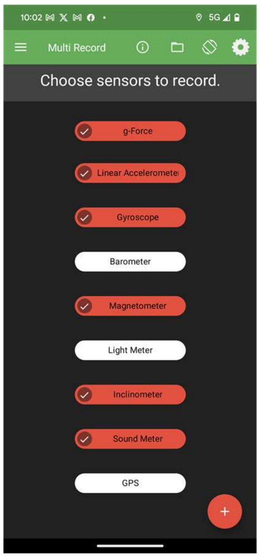
"Edge intelligence" is an effective early warning device, allowing simple "on person safety devices" to become an essential part of your wearable early warning travel kit.



https://ieeexplore.ieee.org/search/searchresult.jsp?queryText=shear%20force%20on%20human%20back&newsearch=true&rowsPerPage=52&returnType=IMAGE

Figure 1 Vertical and Horizontal Stresses (American Society of Mechanical Engineers "ASME")

time	gFx	gFy	gFz	ax	ay	az	wx	wy	wz	Bx	By	Bz	Azimuth	Pitch	Roll	Latitude	Longitude	Speed (m/s)
0.137732	0.0335	0.3041	0.9468	0.0065	-0.02	-0.093	-0.0272	-0.0269	0.0113	-19.032	31.0978	40.6504	0	0	0	-33.7541	151.1538	0
0.154432	0.0335	0.3041	0.9468	0.0065	-0.02	-0.093	-0.0272	-0.0269	0.0113	-19.032	31.0978	40.6504	49.7226	-17.7622	1.7341	-33.7541	151.1538	0
0.156168	0.0335	0.3041	0.9468	0.0065	-0.02	-0.093	-0.0272	-0.0269	0.0113	-19.1906	31.0002	40.6626	49.7226	-17.7622	1.7341	-33.7541	151.1538	0
0.170517	0.0335	0.3041	0.9468	0.0065	-0.02	-0.093	-0.0284	-0.0009	0.0166	-19.1906	31.0002	40.6626	49.7226	-17.7622	1.7341	-33.7541	151.1538	0
0.17206	0.0335	0.3041	0.9468	0.0518	-0.0039	0.0097	-0.0284	-0.0009	0.0166	-19.1906	31.0002	40.6626	49.7226	-17.7622	1.7341	-33.7541	151.1538	0
0.187428	0.0345	0.3034	0.9511	0.0518	-0.0039	0.0097	-0.0284	-0.0009	0.0166	-19.1906	31.0002	40.6626	49.7226	-17.7622	1.7341	-33.7541	151.1538	0



Parameters for consideration:

1. gForce (gfx) – this parameter is very important for the kind of force applied in the forward direction
2. Acceleration, (x,y,z) – another critical factor the acceleration contributes to the serious injuries that can occur because of a pull & push force.
3. Gyro, (x,y,z) – angular motion , i.e wobbly along the planar axis. Serious.
4. Magnetometer (x,y,z). Not important by itself but a directional reference.
5. Inclinometer (azimuth, pitch & roll). Extremely important.
6. GPS – for location of trouble spot.
7. Sound meter (in decibels) – with inference model to listen in to anomalies.

The data was collected at the local metro line at a depth of 30m from the ground level, the inclination (gradient) of the escalator was serious enough for a person walking down the stairs to fall forward if there was a jitter in the escalator movement. The fall distance is the length of the escalator estimated at about 30m (Calculations in the results section).

Figure 2 Range of scientific criteria (red) were used to determine efficacy of sensing parameters to deliver a safe environment.

Our data gathering and study[3] of the forces that the people movers inflict on our bodies can be accurately measured so that challenging circumstances are recognised early, the service provider can be advised to correct it, or the person should be advised that travelling by those means would cause them harm (bearing in mind that this could be a personal issue of age, frailty or disability)[10]. The resonance at which humans succumb to personal structural (joint) fatigue is also a determinant of the damage that could occur from a poorly maintained people mover. Wearable sensors pick up this threshold which can be an advisory[11].

How this paper is organised: (I) Introduction provides a broad background to explain the seriousness and complexity of the subject. (II) The literature review exposes the complexity and presents data collected from actual problem locations. (III) Extracts the details from the data to present cautionary warning from results, the intent and a way forward. In (IV) We present a technique to measure the problem empirically, including the devices and inference models created to deliver timely information to commuters. In (V) we present the results and finalised operational diagnostic model; in (VI) we conclude and suggest a way forward to the next level of safety.

III. Methodology

The people mover systems have key parameters that establish the criteria that need to be observed to detect precursors to a malfunction (or anomaly). Collecting different kinds of data was the first step in deciding which parameters best described a typical problem (**Fig.2**).

We adopt thresholds at which warnings will be issued, and whether the device is wearable or installed at the site will be a choice determined for each location[12].

From Fig.2, using a "Physics App" we establish after several trials that a specific set of parameters gave us an optimised result.

In Table 1, we "listened" to what was happening, analysing all the sounds that emanated from the people mover. Each of them makes distinct sounds. I suppose a just-installed, brand-new one would not be silent – but would make similar sounds at a much lower threshold[13].

The people mover we selected is less than 5 years old, and relatively new. The recorded audio showed a distinct rhythm of sounds. Trying to understand what causes this rhythm is complicated, But we examined other similar people movers of different vintage and found that almost all had a distinct rhythm. We surmise that this pattern results from wear and tear of specific parts such as gears, drive chains, etc., and will get louder as they age. We studied a recent and a 10-year model to compare the "sound pattern" to establish the basis for the sound and its implications as an active parametric measure.[14] The results of this study are presented in the "results" section. In summary, this observation intends to establish precise, observable characteristics of people movers that distinctly deliver an approximate performance measure. Our methodology targets early signs of fatigue or 0"precursors" to failure. We assume that we can develop an age analysis or condition analysis measure that will reduce the number of incidents of catastrophic failure[8], as is apparent from the literature on statistical records of incidents.

IV. Empirical Measurements to Establish Precursors

Our use of the "Physics app" to establish which parameters help diagnose potential failures provided valuable reference data and analysis options.

We used multiple parameters to understand the potential for discovering a potential failure, as presented in (**Fig.2**). Each parameter adds to the predictability of a failure event. We use a decision tree technique to establish this parametric measure.

The algorithm [15],[16] uses "Entropy" analysis of a multi-set;

$$E = -\sum_{i=1}^{k} Pi \log_2(Pi) \quad (1)$$

The probability P_i (=c_i/n) is the fraction result of elements "*c*" with value "*i*" divided by the total number in the set. The "category" with the highest Entropy (uniqueness) will progress as shown in Fig.5. Parameters selected

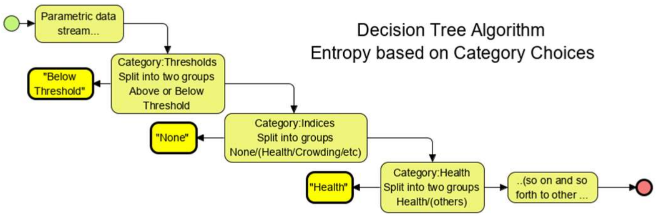


Figure 4 The "selection" Algorithm (Decision Tree)

The results section explains the sensor selection and refinement of the semantic model in this use case. The model is presented in the results section.

V. Results

Developing a model helps in the reasoning behind choices made for this site. The model can be used for other situations if a similar logic is followed[17].

Semantic model for sensor selection

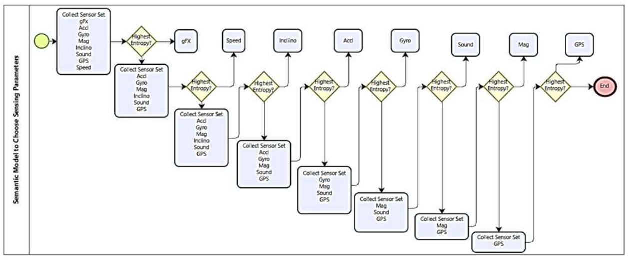


Figure 5: Decision Tree logic to choose sensor priority

The decision tree technique semantically enables the right choice of sensor functionality and priority to be applied to the cluster of sensors on microcontrollers so it delivers the detection outcomes required.

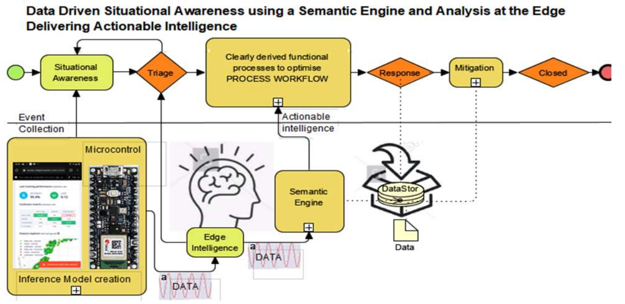
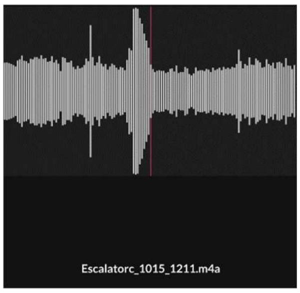


Figure 3 Creation of an inference model (above) and portable sensor

Shows typical workflow and inference model sensor setup

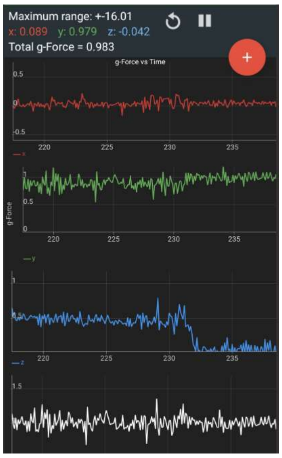
<Device in ruggedised rubber casing and mini powerbank.

Calculation of criticality (how many of the sensor inputs have been analysed) is dependent on the number of sensors in play.



Audio Samples from escalators:
Sound (distinct) over a single run and repeats.
Each side (close to stair) are different.
Likely to change over time due to wear and tear.

Figure 6 Audio recording of sounds made by escalator



Waveform of energy gForce over time
a) gForce x
b) gForce y
c) gForce z

Sensor lying on the stair Distinct nature of the waveform. gForce v/s time clearly shows "integration" of the x, y & z values. Multiple sensors "fused" could produce a reliable reading.

VI. CONCLUSIONS: FUTURE RESEARCH EXPECTATIONS

Our research has focused on why failures occur catastrophically. This paper is not geared to the engineering of the people mover technology but identifies that there are very few real-time sensors using machine learning that look at anomalies that warn against future breakdowns[18].

In the experimentation and data collection, it wasn't easy to qualify the integrity of the data we collected because there should have been sources on the system that delivered outputs of verified values that could help diagnostic teams provide support. Imagine major breakdowns with no "hooks" into the system to verify why or stall the system from operating so a pileup occurs at the end of the journey.

Our intelligent edge devices can be trained to recognise (inference model) regularly identified issues and predict their occurrence using analysis of the various parameters collected for this exercise. We believe that ML & AI-driven solutions would create a failure-free technology base because it will follow the fundamental principle of all safety systems: regular automated tests are the only way to test systems out. Our future research and intention is to build universal sensing devices that can be carried and could analyse many domain outputs such as cries for help, failure "snap, rattle, pop" sounds that signify the start of service failure[19],[20].

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Ancillary Supporting Links and information

PubMed ID: 12450364**DOI:** 10.1109/TBME.2002.804586

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Links to three videos :
https://www.google.com/search?q=obstructive+pileup+on+escalator+failure&sca_esv=fe6507be86e52302&rlz=1C1GCEB_en-GBAU924AU924&ei=upkDZ46CD7m-0-kP9OnGsAo&ved=0ahUKEwiOx8iD6_uIAxU53zQHHfS0EaYQ4dUDCA8&uact=5&oq=obstructive+pileup+on+escalator+failure&gs_lp=Egxnd3Mtd2l6LXNlcnAiJ29ic3RydWN0aXZlIHBpbGV1cCBvbiBlc2NhbGF0b3IgZmFpbHVyZTIIEAAYgAQYogQyCBAAGIAEGKIEMggQABiABBiiBEjTVlDoCljBLnABeAGQAQCYAcwBoAGsE6oBBjAuMTQuMbgBA8gBAPgBAZgCDqACl hHCAgoQABiwAxjWBBhHwgIIEAAYogQYiQXCAgoQIRigARjDBBgKwgIIECEYoAEYwwSYAwCIBgGQBgiSBwYxLjEyLjGgB5A2&sclient=gws-wiz-serp#

https://www.google.com/search?q=obstructive+pileup+on+escalator+failure&sca_esv=fe6507be86e52302&rlz=1C1GCEB_en-GBAU924AU924&ei=upkDZ46CD7m-0-kP9OnGsAo&ved=0ahUKEwiOx8iD6_uIAxU53zQHHfS0EaYQ4dUDCA8&uact=5&oq=obstructive+pileup+on+escalator+failure&gs_lp=Egxnd3Mtd2l6LXNlcnAiJ29ic3RydWN0aXZlIHBpbGV1cCBvbiBlc2NhbGF0b3IgZmFpbHVyZTIIEAAYgAQYogQyCBAAGIAEGKIEMggQABiABBiiBEjTVlDoCljBLnABeAGQAQCYAcwBoAGsE6oBBjAuMTQuMbgBA8gBAPgBAZgCDqAClhHCAgoQABiwAxjWBBhHwgIIEAAYogQYiQXCAgoQIRigARjDBBgKwgIIECEYoAEYwwSYAwCIBgGQBgiSBwYxLjEyLjGgB5A2&sclient=gws-wiz-serp#

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