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Assessing Passenger Risks and Impact Incidents at the Platform-Train Interface: Insights from Valparaíso Metro

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Abstract: The study focused on assessing passenger risks specifically at the platform-train interface (PTI). The primary aim of this investigation is to analyze how various factors, including station design, passenger flow, and weather conditions, impact the frequency and types of incidents occurring at this critical interaction point. To achieve this, the study utilized a comprehensive data analysis approach, examining records from the Valparaiso Metro for the period of 2022-2023. During this timeframe, a total of 361 incidents were documented, providing a substantial dataset for evaluating incident patterns and their correlations with different influencing factors. The analysis revealed that incidents are notably influenced by peak hour conditions and weekdays. Specifically, the study found that crowded conditions inside the train during peak hours, which typically occur in the morning and evening rush periods, contribute significantly to the occurrence of incidents. When examining incidents occurring on the platform, the study identified that these are closely related to the type of station and the presence of stairs for station access. Conversely, stations designed with more accessible features might experience fewer such incidents. Future studies will focus on incorporating additional factors and analysing new data to provide a more comprehensive understanding of incident dynamics.

Keywords: passengers; risks; incidents; metro station; platform-train interface; Valparaiso; Chile

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1. Introduction

Passenger safety in urban railways has long been a significant concern for train operators, as it directly impacts both the safety and operational efficiency of the entire transit system. Various factors contribute to these risks, including the presence and behaviour of other passengers, the physical design of the station and trains, the availability of information, and prevailing weather conditions [1]. Each of these elements can influence the likelihood and nature of incidents, particularly at the platform-train interface (PTI), which is often recognized as one of the most complex and hazardous areas within railway stations [2].

The PTI, where passengers interact with both the platform and the train, presents a unique set of challenges and risks. For example, in the Valparaiso Metro system, over 20 million passengers utilize the railway network annually. During peak times, this results in extremely high passenger densities, with up to four passengers per square meter or more at the PTI [3]. Such high crowding levels can exacerbate risks, including falls onto the tracks or slips, due to the confined and often congested space.

Given these challenges, there is a significant opportunity to enhance safety by employing advanced tracking tools and monitoring systems. These tools can provide real-time data on passenger density and movement patterns at the PTI, allowing for timely interventions when the space becomes

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overcrowded. For instance, by identifying periods of high congestion, operators can implement measures to manage crowd flow more effectively, thereby reducing the likelihood of accidents and improving overall safety. These proactive measures could include adjusting train schedules, deploying additional staff to assist passengers, or implementing crowd control strategies to prevent incidents.

Garcia et al. [4] suggest that leveraging such tracking technologies could significantly mitigate risks at the PTI, helping to prevent accidents like passengers falling onto the tracks or slipping. By continuously monitoring and analyzing crowd conditions, transit authorities can make informed decisions to enhance passenger safety and operational efficiency. Figure 1 illustrates these tracking tools and their potential impact on improving safety at the PTI, emphasizing the importance of integrating technology into safety management practices.

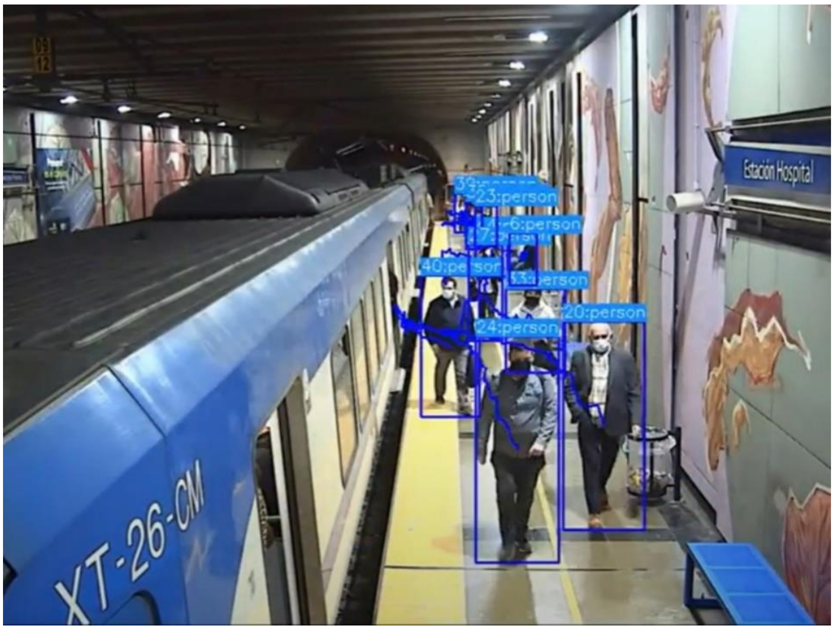

Figure 1. Tracking technologies used at the platform-train interface in Valparaiso Metro.

From a design perspective, the layout of seats inside a train plays a crucial role in shaping passengers' perceptions of safety and comfort. The arrangement of seating can significantly influence personal space, which in turn affects the likelihood of various incidents occurring. For instance, a cramped seating layout may reduce personal space and contribute to uncomfortable conditions, potentially leading to incidents such as suffocation, especially in situations where the train is crowded or poorly ventilated [5]. This impact on personal space is an important consideration in train design, as it directly relates to passenger safety and overall satisfaction.

Seriani et al. [5] also highlight differing passenger preferences based on service type. For long-distance journeys, passengers generally prefer to use seats, valuing the comfort and support they provide for extended travel. However, in urban services where the focus is on shorter trips, passengers often opt to stand near the train doors. This preference is driven by the need for quick boarding and alighting at frequent stops. This behavior is illustrated in Figure 2, which shows the tendency of urban passengers to position themselves close to the doors, facilitating a swift exit at their destination.

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Figure 2. Passengers staying closer to the doors in a crowded train in Valparaiso Metro.

In terms of information management, train delays can have a profound impact on scheduling and operational efficiency, potentially triggering a cascade of risks throughout the railway system. When delays occur, they can lead to longer waiting times at platforms due to a knock-on effect, which in turn increases the potential for incidents. For example, excessive waiting time can cause passengers to become impatient or agitated, heightening the risk of accidents or other safety issues [6]. Therefore, effective communication and timely updates about delays are essential for mitigating these risks and maintaining smooth operations.

Weather conditions also play a critical role in passenger safety and service performance. Adverse weather, such as rain and strong winds, can affect the safety conditions at the platform-train interface (PTI), leading to potential delays and increased risk of incidents. For example, slippery platform surfaces due to rain can cause passengers to slip, while strong winds may affect the stability of train operations or the functioning of station facilities [7]. These weather-related challenges emphasize the need for robust contingency plans and preventive measures to ensure passenger safety and maintain reliable service under varying weather conditions.

Overall, the interplay between design, information management, and weather highlights the multifaceted nature of passenger safety in urban rail systems. Each of these factors must be carefully considered and managed to reduce incident risk and enhance the overall travel experience.

According to Seriani et al. [8], the factors influencing safety and comfort at the platform-train interface (PTI) are indeed crucial from the passengers' perspective. These factors include the design of the train and station, the quality of information provided to passengers, and the impact of weather conditions. However, there remains a critical question regarding how these factors are interrelated and how they contribute to the occurrence of incidents.

Specifically, the relationship between these factors and the incidence of accidents at the PTI needs further investigation. For instance, how do different design elements—such as the type of station or the presence of stairs at the station access —affect the likelihood of incidents under various conditions? Similarly, how does the quality and timeliness of information provided to passengers influence their behaviour and safety, especially comparing weekdays and weekends? Furthermore, how do adverse weather conditions (e.g. winter-autumn or summer-spring seasons) interact with these factors to either exacerbate or mitigate risks?

The challenge in addressing these questions lies in the absence of a comprehensive passenger risk model that can analyse the impact of various factors on incidents at the PTI. Currently, there is no established framework that integrates design, information, and weather conditions to evaluate their combined effect on passenger risk incidents in Valparaiso Metro. This gap in research prevents a clear understanding of how these elements interact and influence the frequency and nature of incidents.

The aim of this paper is to address this issue by developing and proposing a passenger risk model specifically designed to analyse the impact of incidents at the PTI. This model will seek to identify and quantify the relationships between different factors—such as design features, information quality, and weather conditions—and the occurrence of incidents. By creating a structured approach to evaluate these interactions, the paper aims to provide valuable insights into how various factors contribute to safety risks and to suggest effective strategies for mitigating these risks.

The paper is structured in the following sections. Section 2 discusses a literature review to identify the concepts and gaps in knowledge related to risk factors and incidents in railways. Section 3 describes the methodology based on regression techniques to identify the impact of incidents on risks. Then, in section 4 results are presented, followed by the conclusions.

2. Literature Review

Passenger's incidents in metro stations are affected by different factors. According to Lu et al. [9], the hourly distribution of disruptions, location of disruptions, interchange stations, station location, and disruption type are important factors that significantly affect the severity of disruptions from the perspective of society, metro operators, and passengers. The same authors [9] found that the flow and environmental factors do not significantly relate to the severity of disruption in metro stations.

To prevent future disruptions, Wang et al. [10] developed a model to predict disruptions taking as a case study the Shangai metro system, in which factors such as incident reason, disruption location, and the time of disruption factors affected the duration of the incident. The incidents can also be studied during the morning and afternoon peak hours. For instance, according to Abolfazli et al. [11], peak hours reached the highest number of incidents, affecting the train operation. The authors [11] used integration operational records from the Montreal metro system using clusters and incident data to understand the delays and the subsequent knock-on effect.

Incidents can be investigated from a modelling perspective. Some authors [12] reported the effect of disruptions on safety, operation efficiency, and service quality. The authors [12] focused on unplanned disruptions in urban railway systems, taking the Hong Kong metro as a case study. Factors such as the signal control system (moving/fixed block), line types (urban/suburban), line operation direction, disruption location (underground/ground/elevated), and disruption types (e.g., tracing, locomotive and rolling stock, passengers, and operation) were considered significant in the study. Other factors, such as the time of day, weather conditions, and the number of affected stations, presented lesser effects on operation and services. Moreover, Chen et al. [13] studied incident prediction, which affects traffic control and management, using a statistical model that performed better than machine/ensemble models to predict train delays under incidents. The models found that the incident type and affected line type are the most significant factors to be considered.

To prevent incidents, Luo et al. [14] developed a multi-output deep learning model to provide valuable information for passengers and train dispatchers to predict the arrival delays of multiple trains simultaneously. Similarly, Tiong et al. [15] reported a data-driven train delay prediction model, in which a holistic view is needed, as further studies are needed to understand the effect of delays in railways.

From the passenger's perspective, Terabe et al. [16] reported that incidents at the platform are affected by different factors such as the design, the equipment and the profile of the station user. The authors developed regression models to identify the relationship between incidents and these factors, in which the length of the narrow part of a platform, the width of the gap between the platform and train, the curvature of the platform, passenger flow crossing, the number of trains passing and stopping, and the audio and visual announcements concerning approaching trains were considered as determinants to achieve safety conditions at the platform-train interface. For Harding et al. [17] the platform-train interface is the space where most incidents may occur. For instance, the horizontal and

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vertical between the train and the platform presents a direct relationship between risks and incidents. Moreover, Zhou et al., [18] analysed the risk of crowds at metro platforms based on smart card data, which can be used to prevent incidents and manage safety at railway stations.

Despite the important studies reported in the literature, there is still a gap in knowledge to better understand the factors that affect incidents in railways, especially at the platform-train interface. Most studies are focused on train operators or passengers, not on a multidimensional perspective, which is the aim of this study.

3. Materials and Methods

This study is focused on railway stations in Valparaíso, which are located in the cities of Valparaiso, Viña del Mar, Quilpue, Villa Alemana and Limache. The population of these cities are around one million. The whole network consists of 20 stations over 5 cities (42 km long). The coastal overground stations are (shown in Figure 3 from 1 to 6): Puerto, Bellavista, Francia, Baron and Portales [3]. The underground stations are (shown in Figure 3 from 7 to10): Miramar, Viña del Mar, Hospital and Chorrillos [3]. The interior overground stations are (shown in Figure 3 from 11 to 20): El Salto, Quilpue, El Sol, El Belloto, Las Amercias, La Concepcion, Villa Alemana, Sargento Aldea, Peñablanca and Limache [3].

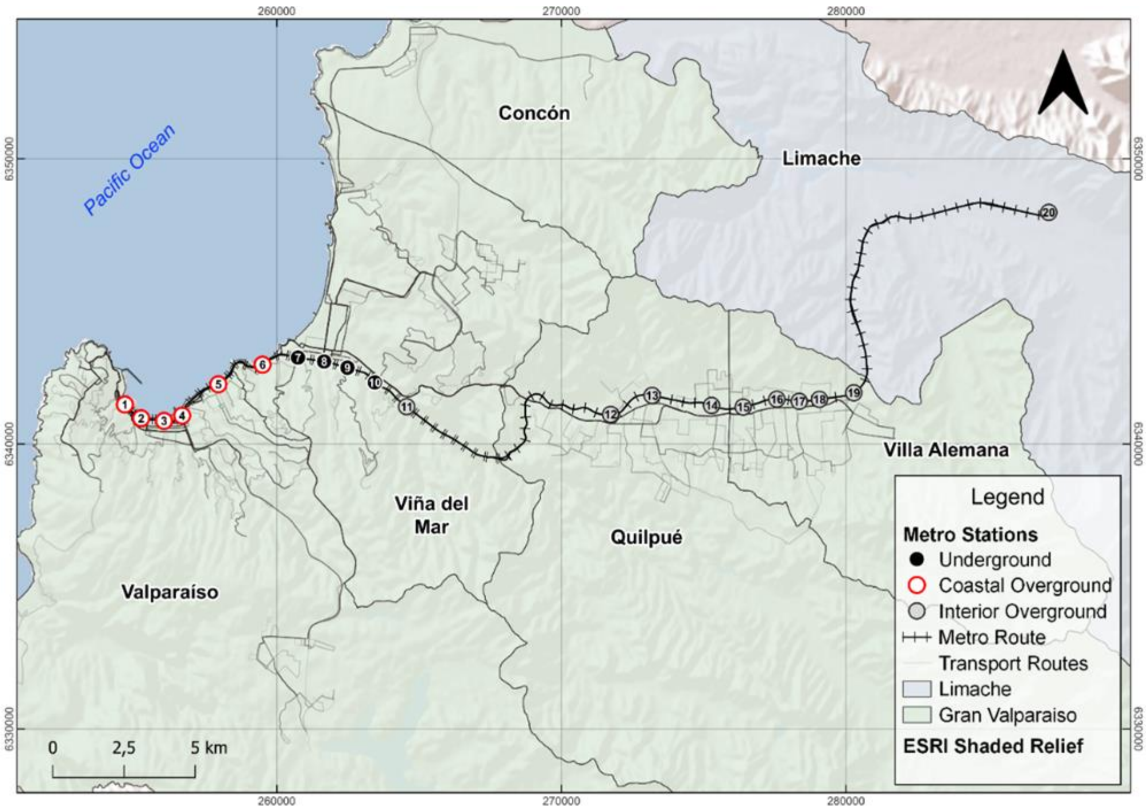

Figure 3. Valparaiso network divided into underground stations (shown in black), coastal overground (shown in red), and interior overground (shown in grey).

Table 1 provides a detailed account of the total passenger flow at the Valparaiso Metro stations for the years 2022 and 2023. This data reveals significant variations in passenger demand across different stations over the two-year period. Notably, the terminal stations, Puerto and Limache, exhibited a remarkably high level of demand compared to other stations on the network. These terminal stations, often serving as major transfer points or end destinations, naturally experience higher passenger volumes, which is reflected in their elevated flow statistics.

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Table 1. Passenger flow at each station during 2022 and 2023.

City	N°	Type	Station	Flow 2022	Flow 2023
Valparaíso	1	Coastal stations	Puerto	670,522	1,603,627
	2		Bellavista	377,082	846,806
	3		Francia	422,688	946,626
	4		Barón	445,037	979,797
	5		Portales	327,125	679,156
Viña del Mar	6		Recreo	143,415	351,271
	7	Underground stations	Miramar	496,920	1,145,845
	8		Viña del Mar	959,060	2,120,708
	9		Hospital	444,337	1,056,273
	10		Chorrillos	502,259	1,129,749
	11	Interior stations	El Salto	112,866	276,089
Quilpué	12		Quilpué	804,916	1,757,348
	13		El Sol	244,204	557,883
	14		El Belloto	438,032	973,951
Villa Alemana	15		Las Américas	392,196	865,072
	16		La Concepción	185,481	425,311
	17		Villa Alemana	601,676	1,303,551
	18		Sargento Aldea	270,934	635,244
	19		Peñablanca	238,552	558,044
Limache	20		Limache	831,550	1,685,339
Total				6,850,075	19,897,690

In particular, Viña del Mar station emerged as the station with the highest passenger flow in 2023. This significant increase is indicative of its critical role within the network, potentially due to factors such as its strategic location, popularity among commuters, or its status as a major commercial or residential area. Following closely, Quilpue station and Villa Alemana station also recorded substantial flows, highlighting their importance in the network's overall passenger distribution and suggesting that they too are key nodes in the transit system.

The overall passenger flow in 2023 experienced a dramatic increase, reaching approximately three times the flow recorded in 2022. This surge is largely attributed to the effects of the COVID-19 pandemic, which had significantly impacted passenger numbers in the preceding years. During the pandemic, various restrictions and changes in travel behavior led to reduced ridership across many transit systems. As restrictions eased and recovery began, passenger numbers rebounded, resulting in a substantial rise in overall flow.

The increase in passenger flow in 2023 reflects a recovery phase as normalcy resumed and travel patterns adjusted. This substantial rise underscores the importance of adapting transit operations to accommodate higher volumes of passengers and address the challenges associated with increased demand. Understanding these flow dynamics is crucial for planning and managing station capacity, scheduling, and resource allocation to ensure efficient and safe service for all passengers.

Overall, the data presented in Table 1 highlights significant trends and changes in passenger flow at the Valparaiso Metro stations, providing valuable insights into the system's performance and the impact of external factors such as the pandemic on transit usage patterns.

3.2. Variables Description

The analysis draws upon data from incidents recorded by Valparaiso Metro from April 2022 to October 2023, encompassing approximately 600 incidents across the entire metro network. This comprehensive dataset provides a broad view of safety issues within the system. However, for a more focused examination, the data was specifically concentrated on incidents occurring at the platform-train interface (PTI), narrowing the scope to about 361 incidents.

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The concentration on the PTI is crucial because this area represents a complex and high-risk zone where interactions between passengers and the infrastructure are particularly critical. Within this subset of incidents, the predominant categories identified were decompensations, falls, and contusions. Decompensations, which generally refer to medical emergencies or health-related incidents, were the most frequently recorded type of incident at the PTI. These incidents often involve passengers experiencing health crises, such as fainting or other acute medical conditions, exacerbated by factors such as overcrowding or inadequate ventilation.

Following decompensations, falls were the second most common type of incident, occurring when passengers lost their balance or tripped, often due to crowded conditions or obstacles on the platform or in the train. Contusions, or bruises and injuries resulting from impacts, were also noted as frequent incidents, typically occurring when passengers bumped into objects or other people in the confined space of the PTI.

The analysis also included a category labeled "Others," which encompasses a range of less common incidents such as cuts, physical altercations between passengers, and other miscellaneous events. These were grouped together in Figure 4, providing a summary of incidents that do not fall into the primary categories of decompensations, falls, or contusions. By focusing on the PTI and analyzing these specific types of incidents, the study aims to identify patterns and trends that are critical for improving safety measures. Understanding the frequency and nature of these incidents can help in developing targeted interventions to address the most prevalent safety concerns and enhance overall passenger safety and comfort.

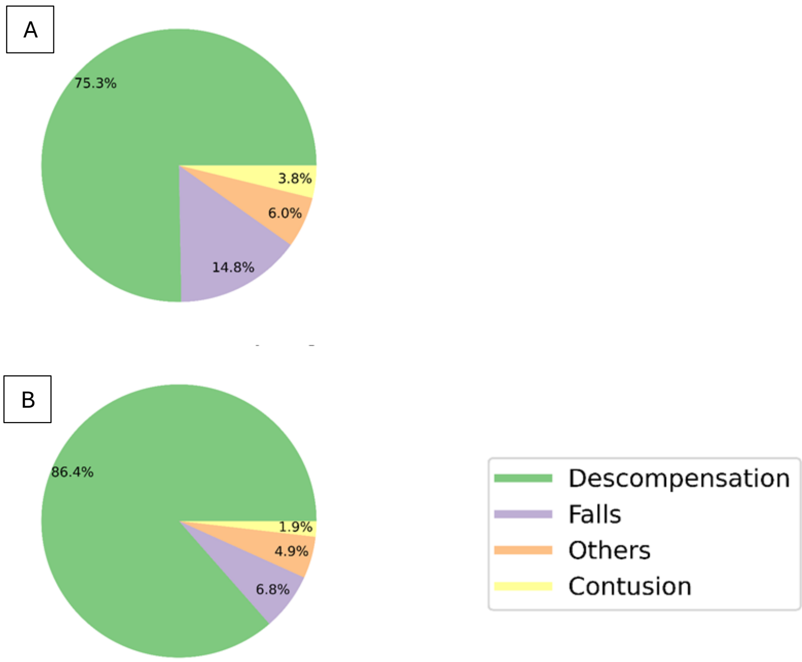

Figure 4. Train and platform incidents in Valparaiso Metro: A) Platform; B) Train.

Two regression models were developed to analyse the binary variables of Train Incidents and Platform Incidents, using the dimensions of Flow, Climate and Design. The Logistic Regression model from the Python 'statsmodels' library was chosen due to its ability to handle binary dependent variables, providing probabilities of occurrence for each class. This choice allows a direct interpretation of the effects of the independent variables on the probability of a Train or Platform Incident.

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To evaluate the performance of the models and compare them, metrics such as Log-Likelihood, Pseudo R-squared, AIC (Akaike Information Criterion) and BIC (Bayesian Information Criterion) were used, in addition to the statistical significance of each variable.

The classification of variables was carried out using Python to process the information on incidents in the Valparaíso metro. In the Flow dimension, peak times for incidents were considered, which cover the period from Monday to Friday between 6:30 and 09:29 hours, and between 17:00 and 19:59 hours. Incidents that occurred outside these times were classified as off-peak. In addition, weekdays were grouped into workdays and weekends.

For the Climate dimension, incidents were grouped according to the seasons of the year, dividing the year into Warm Seasons (spring and summer) and Cold Seasons (autumn and winter).

As for the Design dimension, various aspects of the metro were considered, such as the location of the incident (Platform or Train), the type of station (Underground or Overground), and the use of stairs for access to the metro.

Finally, a correlation matrix was created between the variables to evaluate the possible collinearity between them.

4. Results

4.1. Statistical Data

Figures 5 and 6 provides a detailed distribution of incidents across various railway stations in the Valparaiso Metro system. This visual representation highlights the frequency of incidents at each station, revealing a significant variation in incident counts. Notably, Quilpue station emerges as the station with the highest number of recorded incidents, exceeding 40 incidents. This high frequency indicates that Quilpue station is a critical point of concern, where safety measures may need to be intensified due to the prevalent issues leading to such incidents.

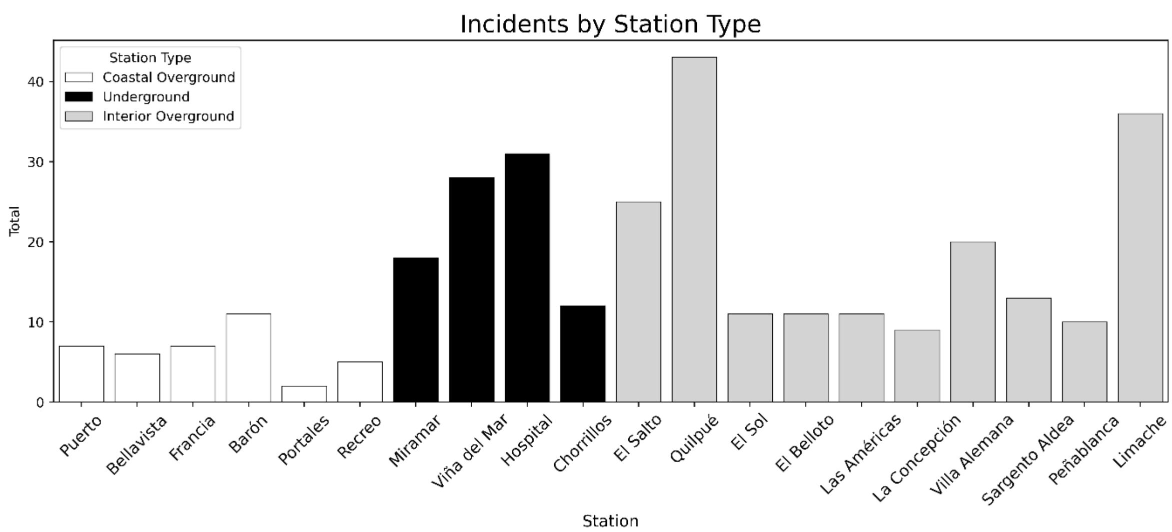

Figure 5. Total incidents in railway stations in Valparaiso Metro during 2022-2023.

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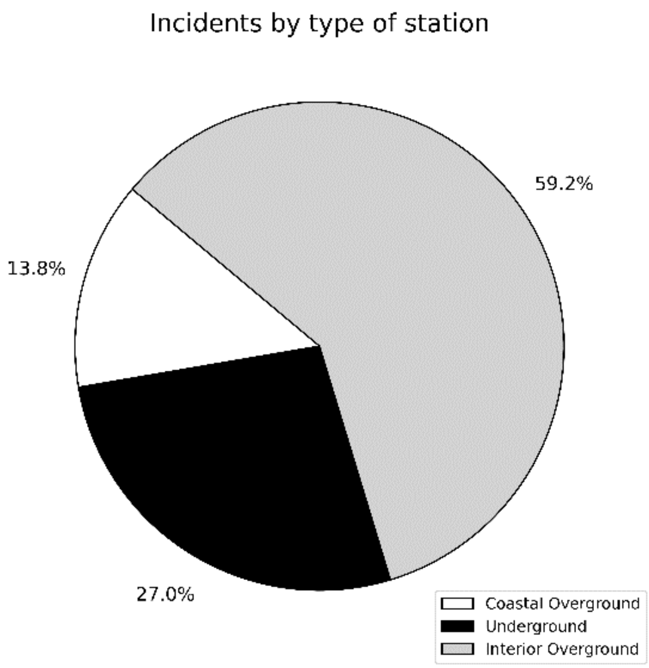

Figure 6. Total incidents by type of railway stations in Valparaiso Metro.

In stark contrast, Portales station is recorded as having the fewest incidents, with only 2 incidents documented. This low number suggests that Portales station may have more effective safety protocols in place or face fewer challenges related to incident occurrence compared to other stations. The significant disparity between the two stations highlights the variability in incident frequencies across the Valparaiso Metro network.

The distribution pattern observed in Figures 5 and 6 underscores the importance of addressing station-specific factors that contribute to incident rates. At Quilpue station, it would be beneficial to conduct a thorough investigation to identify the root causes of the high incident rate. Potential factors could include design flaws, operational issues, or increased passenger flow that might be exacerbating safety risks. Implementing targeted interventions based on these findings could help mitigate the frequency of incidents at Quilpue station.

On the other hand, the relatively low incident rate at Portales station offers a valuable benchmark for understanding what safety measures or operational practices might be contributing to its lower incident frequency. Analyzing the successful strategies in place at Portales could provide insights that could be applied to other stations with higher incident rates.

Overall, Figures 5 and 6 emphasizes the need for a nuanced approach to safety management within the Valparaiso Metro system, focusing on station-specific characteristics and incident frequencies. By understanding and addressing the factors contributing to the higher incident rates at stations like Quilpue, and by leveraging successful practices observed at stations like Portales, the Valparaiso Metro can enhance its overall safety performance and reduce incident occurrences across the network.

Regarding the distribution of incidents throughout different times of the day, Figure 7 provides a clear depiction of temporal patterns in incident frequency. The data reveal a significant concentration of incidents during peak hours, specifically around 08:00 and 09:00, with the number of incidents exceeding 20 during these times. This sharp increase in incidents during peak hours can be attributed to the heightened passenger volume and the resulting overcrowding, which can exacerbate the risk of accidents and health-related issues.

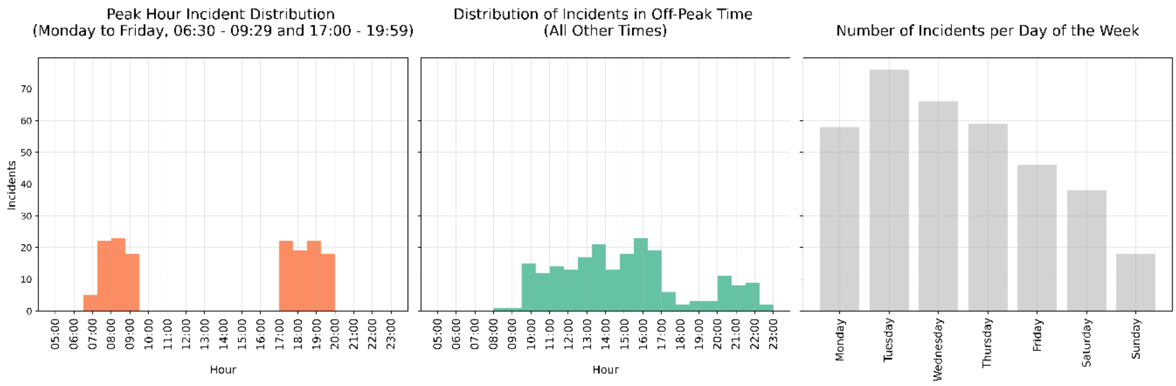

Figure 7. Distribution of incidents at different times of the day and seven days a week. Peak and off-peak hour ranges are defined by Valparaiso Metro [3].

Conversely, the period between 18:00 and 20:00 hours shows a notable decrease in incident frequency, with fewer than 5 incidents recorded. This reduction during the late afternoon and early evening may be due to a decrease in passenger density and a relative easing of the rush-hour congestion.

In contrast to the pronounced peaks observed during peak hours, the analysis of off-peak hours reveals a more consistent and uniform distribution of incidents throughout the day. Despite this more even spread, there are notable upticks at specific times, particularly around 14:00 and 16:00 hours. This increase during mid-afternoon hours could be related to other factors such as changes in passenger flow, routine breaks, or specific activities that occur at these times.

It is also important to recognize that off-peak hours cover a broader range of time compared to peak hours. This extended timeframe means that while incidents may be more evenly distributed, the overall frequency remains lower than during the concentrated peak periods. Additionally, incidents are more frequently observed during workdays, with a particular concentration mid-week, likely due to the regular weekday commuting patterns. On weekends, the number of incidents drops significantly, suggesting that reduced passenger traffic and different activity patterns contribute to fewer incidents.

The seasonal analysis further supports these findings, as most incidents are concentrated during the colder seasons, specifically winter and autumn, as illustrated in Figure 8. This seasonal trend may be related to various factors, including the impact of colder weather on passenger health and behavior, changes in the overall station and train environment, and possibly increased crowding during certain periods of the year. This information underscores the importance of considering both temporal and seasonal factors when analyzing incident patterns and planning for safety measures.

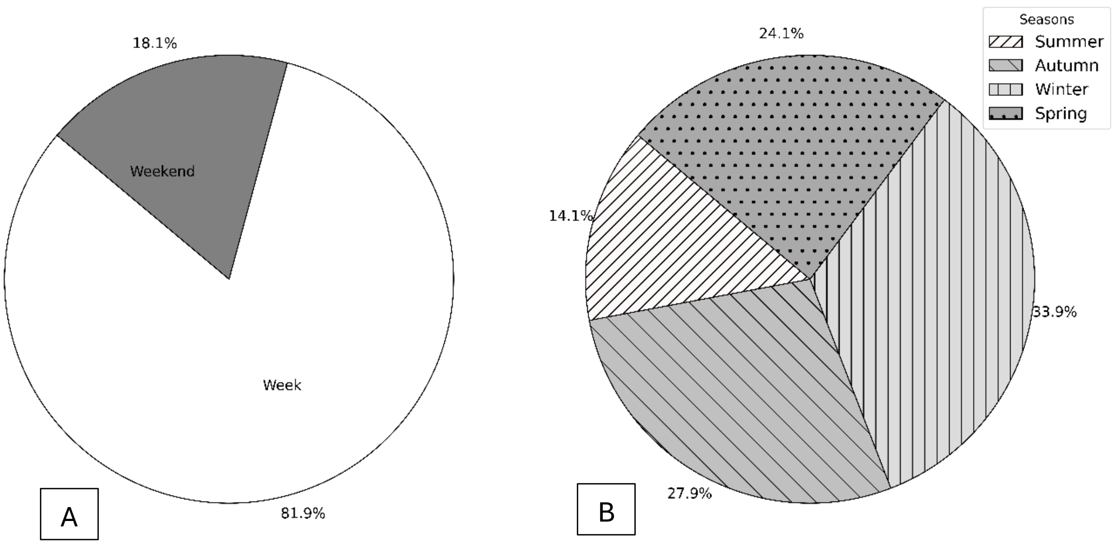

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Figure 8. Distribution of incidents: A) Week vs weekend; B) Seasons.

4.2. Risk Classification

The results presented in Figures 5 and 6 offer a detailed classification based on both the percentage of occurrence and the associated risk of incidents recurring, as adapted from Valparaiso Metro [3]. This classification framework is essential for understanding the likelihood of incidents reoccurring and prioritizing safety interventions.

Table 2 provides a comprehensive overview of the proposed risk probability classification. This table categorizes the stations into various risk levels, reflecting the probability of incidents happening again. According to the classification, the majority of stations are designated as Level 4. This classification indicates a high probability that incidents will reoccur if no effective action plan is put in place by train operators.

Table 2. Proposed classification of risk probabilities associated with the frequency of occurrence of incidents at the PTI.

Risk Probability	**Level 1 (Very unlikely)**	**Level 2 (Unlikely)**	**Level 3 (Moderate)**	**Level 4 (Likely)**	**Level 5 (Very likely)**
Historic probability	No incidents are registered in a longer period of analysis (e.g. the last five years)	At least one incident was registered in a longer period of analysis (e.g. the last five years)	At least two incidents were registered in a shorter period of analysis (e.g. the last two years)	At least five incidents were registered in the last year of analysis	More than 5 incidents were registered in the last year of analysis
Estimated probability	1%-10%	11%-30%	31%-65%	66%-89%	90%-100%

Level 4 stations are those where incidents have been frequent and where the conditions contributing to these incidents persist. This level of risk signifies an urgent need for targeted interventions to address the underlying issues. Without implementing specific corrective measures or preventive strategies, the same problems are likely to arise again, potentially leading to repeated incidents.

The high concentration of Level 4 classifications suggests that there are systemic issues at these stations that need to be addressed. These could include factors such as design flaws, operational procedures, or environmental conditions that contribute to the recurrence of incidents. By analysing the risk levels and understanding the reasons behind these classifications, the Valparaiso Metro can develop more effective safety measures and action plans. Such measures might include infrastructure improvements, enhanced staff training, or changes in operational protocols to mitigate the risk and prevent future incidents.

In summary, the classification system outlined in Table 2 highlights the critical need for intervention at most stations classified as Level 4. It underscores the importance of proactive measures to address and rectify the conditions leading to frequent incidents, thereby improving overall safety and reducing the risk of future occurrences.

Similarly, from Figures 5 and 6, a classification system can be derived to assess the potential impact of various incidents on passenger safety within the PTI (see Table 3). The incidents are categorised based on their severity and potential consequences. For example, if the impact of an incident is determined to be very low, it is classified as a situation where passengers are simply exchanging verbal insults. Such interactions, while disruptive and unpleasant, generally pose minimal risk to overall safety. In contrast, if the impact is assessed as very high, the incident could involve more severe scenarios such as physical altercations leading to arrest or, in the most extreme

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cases, a fatal accident. This classification framework helps prioritize responses and safety measures based on the level of risk associated with different types of incidents, ensuring that appropriate actions are taken to safeguard passengers and maintain safety standards.

Table 3. Proposed classification of risk impacts associated with the type of incidents at the PTI.

Risk Impact	Level 1 (Very low)	Level 2 (Low)	Level 3 (Medium)	Level 4 (High)	Level 5 (Very high)
Passengers' incidents	-Passengers exchange verbal insults	-Threats between passengers. -Theft or robbery of passengers. -Physical assaults on passengers that do not require medical attention.	-Physical assault on passengers with minor injuries. -Brawl between passengers with minor injuries. -Passenger accident with minor injuries. -Attacks with minor injuries.	-Physical assault on passengers with serious injuries. -Brawl between passengers with serious injuries. -Passenger accident with serious injuries. -Attacks with serious injuries. -Verbal and non-verbal sexual harassment of passengers.	-Physical assault on passengers resulting in death. -Passengers with illnesses at stations/on board suffer decompensation resulting in death. -Passenger accident resulting in death. -Attacks resulting in death of passengers. -Physical sexual harassment of passengers.

4.3. Correlation Model

The results from the correlation models, as detailed in Figure 9 and Table 4, reveal several important insights into the factors influencing incidents both inside the train and at the platform. For incidents occurring inside the train, a positive correlation was identified with the Flow and Season factors. Specifically, incidents are more likely to occur during peak hours or on weekdays when passenger flow is at its highest. This increased likelihood can be attributed to the greater density of passengers during these times, which elevates the risk of accidents or health-related issues within the train.

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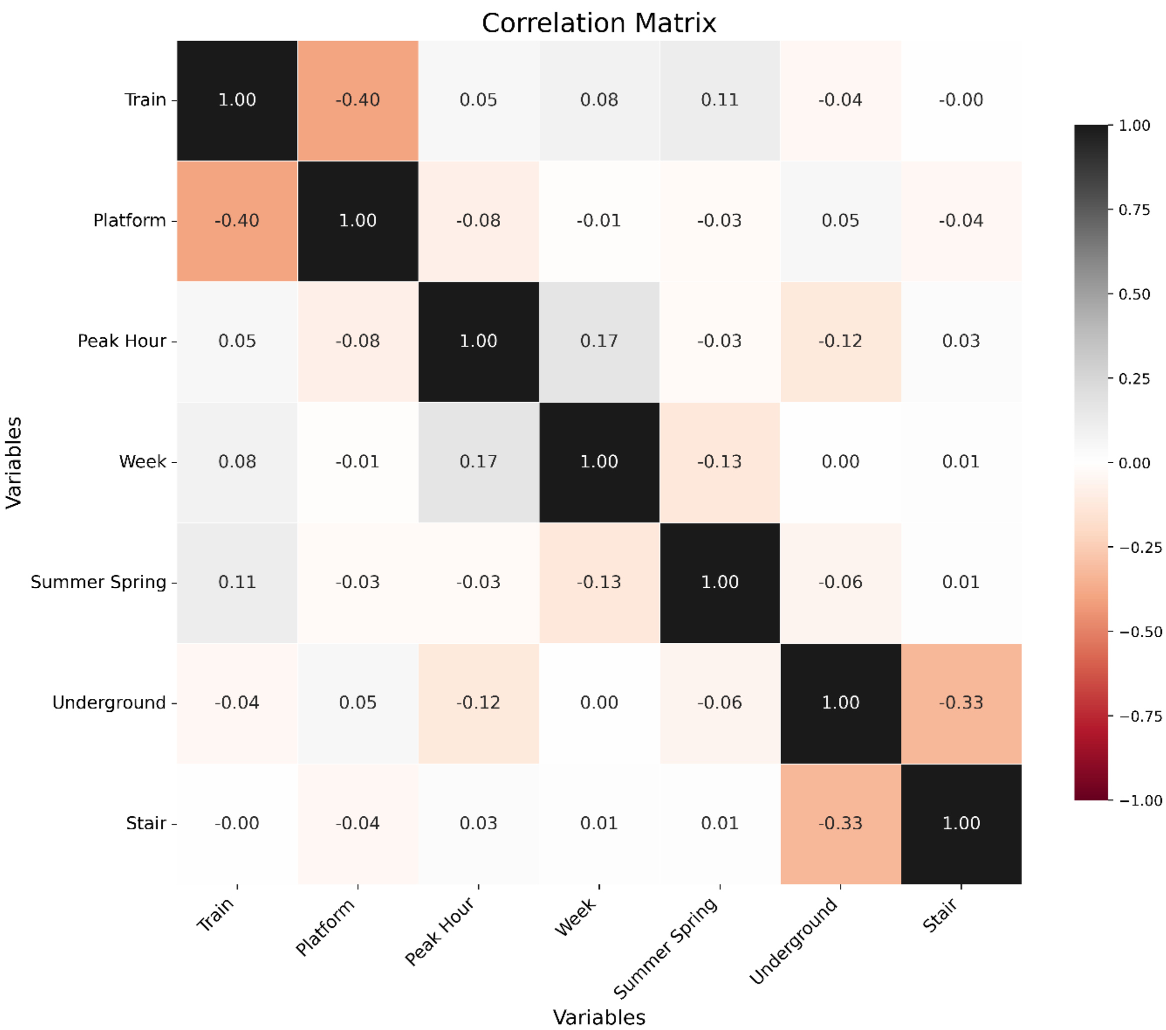

Figure 9. Correlation matrix considering different factors at the PTI.

Table 4. Risk model considering different factors at the PTI.

Model	Predictor		Coef.
Train	Constant		-1.42***
	Flow	Peak Hour	0.09
		Week	0.7**
	Weather	Summer Spring	0.64**
	Design	Platform	-24.47
		Underground	-0.07
		Stair	-0.19
	Metrics		
	Log-Likelihood		-203.15
	Pseudo R-squared		0.24
	AIC		420.3
	BIC		449.77
Platform	Constant		-0.2
	Flow	Peak Hour	-0.29
		Week	0.21

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	Weather	Summer Spring	0.1
	Design	Train	-37.59
		Underground	0.08
		Stair	-0.22
	Metrics		
	Log-Likelihood		0
	Pseudo R-squared		1
	AIC		12
	BIC		37.26
Significance codes: ***p <0.01**P < 0.05; *P <0.1.			

Seasonal variations also play a significant role in the frequency of incidents inside the train. The data indicate a higher probability of incidents during the summer and spring months. This seasonal pattern is likely linked to the weather conditions experienced inside the train. For example, warmer temperatures in these seasons, combined with limited ventilation, can create uncomfortable and potentially hazardous conditions that may contribute to a higher incidence of medical issues or other types of incidents.

In contrast, the design factor, which includes variables such as the type of station (overground vs. underground) and the presence of stairs for station access, does not show a positive correlation with incidents occurring inside the train. This suggests that the physical design of the station does not significantly impact the likelihood of incidents occurring within the train itself. Instead, these design factors seem to have more relevance to incidents occurring on the platform.

Moreover, it is important to note that incidents occurring inside the train do not appear to correlate with incidents at the platform. This indicates a separation in the factors influencing incidents in these two areas; an incident inside the train does not necessarily increase the likelihood of an incident on the platform, and vice versa.

Regarding platform incidents, the data show that the type of station (overground versus underground) is a significant factor. Incidents at the platform are more likely to occur due to differences in station types. For instance, overground stations might present different risks compared to underground stations, such as differences in accessibility or passenger behavior. On the other hand, Flow and Season factors do not exhibit the same correlation for platform incidents as they do for incidents inside the train. This suggests that while passenger flow and seasonal conditions significantly impact incidents within the train, their effect on incidents at the platform may be less pronounced or different in nature.

5. Conclusions

This study conducted a thorough analysis to identify various factors that may influence the occurrence and types of incidents, such as descompensations, falls, and contusions, at the Valparaiso Metro. The incidents were specifically measured at the platform-train interface (PTI) over the period of 2022-2023. This period of observation was chosen to capture a comprehensive view of the incident landscape, encompassing different times of the day, varying crowd densities, and seasonal changes. By focusing on the PTI, the study aimed to understand how incidents related to the interaction between passengers and the train, including the moments of boarding, alighting, and waiting on the platform.

The analysis revealed a notable relationship between various factors and the frequency of incidents, particularly during peak hours and weekdays. This correlation is largely attributed to the increased crowding experienced during these times, which can lead to more frequent and severe incidents due to the higher density of passengers. For instance, during peak hours, the limited space can exacerbate situations where passengers may experience difficulties in maintaining balance or managing sudden movements. Additionally, weather conditions emerged as a significant factor influencing incident types. Specifically, warmer conditions inside the train were found to potentially increase the occurrence of decompensations, as elevated temperatures may affect passengers' health and well-being, leading to incidents related to medical conditions or physical stress.

Regarding station design, the study found that while the internal design of the station does not significantly impact the type of incidents occurring within the train itself, certain design features do correlate with the incidence of events at the platform. Notably, the presence of stairs for accessing the station and the specific type of station—whether overground or underground—are linked to the frequency of incidents on the platform. For example, stations with multiple flights of stairs may present additional hazards that contribute to a higher risk of falls or other incidents during boarding or alighting.

The distribution of incidents showed that decompensations were the most common, followed by falls and contusions. Among the various stations analysed, Quilpue station, characterized as an interior overground station, demonstrated a higher risk of incidents compared to other stations. This elevated risk could be attributed to factors specific to the station's location, design, or passenger demographics. Conversely, Portales station, a coastal overground station, exhibited the lowest risk of incidents, which might be linked to its design, location, or perhaps more effective safety measures in place.

The insights gained from this analysis are valuable for practitioners and safety managers within the Valparaiso Metro system. Understanding the trends in incident occurrences and their relationship with factors such as time of day, station design, and environmental conditions can help in developing targeted safety measures.

However, it is important to acknowledge the limitations of this study, particularly due to the period during which it was conducted. The data collected from 2022 and 2023 may be influenced by the unique conditions of the post-pandemic period, which could affect passenger behavior, station operations, and overall incident rates. Therefore, it is recommended that future analyses be conducted to revisit and update the incident data. Such updates would provide a more current understanding of incident trends and their contributing factors, helping to refine safety measures and strategies for mitigating risks in the Valparaiso Metro system.

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