A Systematic Review of Railway Trespassing: Problems and Prevention Measures

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Abstract: Railway trespassing is a growing problem in both rail and road transport. A high percentage of rail accidents are a result of the former. Factors that contribute to trespassing accidents range from poor decision-making by the trespasser and general ignorance of rail traffic rules to poor infrastructure (e.g., a lack of fences along tracks to prevent trespassing). The objective of this study was to provide a systematic review of the known literature on the problem of trespassing on railway tracks. The methodology implemented for literature collection was in accordance with the PRISMA method. The literature was searched using keywords: railway trespassing, railway trespassing accidents, trespassing factors, trespassing prevention, railway trespassing detection, and railway trespassing education in the Web of Science Core Collection and an additional search was conducted through other literature databases. The starting point was the collection of \( n = 291 \) studies of which a total of 72 publications were included in the literature review ranging between 1953–2023. The literature review consisted of 73.6% journal papers, 18.1% conference papers, and 8.3% expert reports. The results were the formation of: (1) Factors that influence the occurrence of trespassing accidents: (a) locations of frequent railway trespassing, (b) the temporal frequency of railway trespassing, (c) trespasser profile and behaviour, (d) motivation for and general knowledge of railway trespassing, and (e) other factors and models for railway trespassing accidents; (2) Measures for trespassing prevention: (a) education measures, (b) signalization, technological and infrastructure measures for trespassing prevention, and (c) pilot studies of railway trespassing preventive measures. The main findings were summarised and discussed with considerations for future work.

Keywords: safety; human behaviour; railway trespassing; trespasser behaviour; preventive measures

1. Introduction

Trespassing on railway tracks is considered an extremely dangerous illegal act and is one of the main causes of the occurrence of railway accidents [1]. Definitions vary somewhat from country to country and there are numerous different explanations, which makes the already complex problem even more difficult. According to the Cambridge Dictionary, the definition of trespass is to go onto someone’s land or enter their building without permission [2]. In the context of railways, a trespasser is any person present on railway premises where such presence is forbidden, except legal level crossing users. Therefore, the question of what constitutes trespassing on railway tracks needs to be answered. In Australia, it is considered trespassing for persons to be on tracks, embankments, or other areas [3]. There is a similar definition that states that it is illegal to trespass on private railway property unless it is a designated pedestrian or roadway crossing [4]. In Croatia, by legislation, a person is prohibited from unauthorized access and movement alongside or across the railway infrastructure (bridges, tunnels, and tracks) and endangering the safety of the railway system. Pedestrians and road vehicles are only allowed to enter and move around the railway area in places designated by the infrastructure manager [5]. In academic studies, trespassing has been defined as the illegal entry into railway property by people or places that are only permitted to railway operators, with some exceptions (e.g., railway
stations, level crossings, etc.) [6,7]. Some researchers have also defined illegal crossing at a level crossing as trespassing [8] and there has also been a brief reference to people trespassing on the bridge and their behaviour when they detect an oncoming train [9]. As a result, cases of trespassing can be divided into two groups: the illegal crossing of level crossings and trespassing on non-level crossings [10]. A clear distinction should also be made between rail suicide and trespassing, as in rail suicide people deliberately put themselves in danger [11]. Railway trespassing is therefore defined as persons crossing the railway line at an unmarked location (outside a legal level crossing or pedestrian area), except train passengers, railway staff, level crossing users, or suicide victims [12,13]. Based on the previous definitions, one word is a common occurrence, and that is the illegality of trespassing, which means that the trespassing event is prohibited by law [3,4,14].

In previous literature reviews [15,16], railway trespassing has always been analysed and paired with railway suicides. The latest attempt to identify or conduct a collection of preventive measures was by authors [17] in 2018. This literature review represents up-to-date knowledge on railway trespassing and only includes the collection of publications on the topic of railway trespassing. Therefore, to our knowledge, this is the first attempt to only review the problem of trespassing on railway tracks. Several factors that have contributed to railway trespassing accidents can be directly or partially linked to the presence or absence of a legal level crossing. The complex problem of trespassing on railway tracks is examined in several steps presented in the Methodology section. For this reason, trespassing on railway tracks is divided into several categories, from the factors that influence trespassing to the measures that prevent trespassing. Therefore, it is important to first analyse trespassing accidents and the consequences they have for a better understanding of factors that ultimately led to, in many cases, tragic events. Furthermore, by identifying factors for trespassing occurrence, preventive measures can be developed to mitigate its effects.

The objective of this systematic review is to give an up-to-date answer regarding two research questions: (1) What are the factors that influence the occurrence of railway trespassing accidents? (2) What preventive measures have been developed to reduce trespassing accidents and their severity? On that note, this paper is structured as follows: Section 2 describes the statistics regarding trespassing accidents in Section 2.1 and its consequences in Section 2.2. Section 3 contains the description of the PRISMA methodology implemented for systematic review and Sections 3.1–3.4 are structured to follow that process. The results of the literature collection are presented in Section 4, Section 4.1 refers to trespassing factors and, in Section 4.2, the collection of preventive measures is presented and divided into several categories. The discussion of the main findings (Section 5.1) and the limitations of the collected literature (Section 5.2) are part of Section 5. The conclusion of key elements of the research, the limitations of this paper, and future work are presented in Section 6.

2. Background of Railway Trespassing Accidents

There have been two previously conducted reviews of the problem of railway trespassing. In 2006, Lobb reviewed the trespassing problem by investigating the causality of trespassing (train-pedestrian accidents) and preventive measures [15]. The author also proposed the application of theory to behavioral and cognitive psychology. In 2015, Havranecau et al. used the PRISMA method for an extensive systematic review of the problem of trespassing and railway suicides, but compared to this review, the authors only analysed preventive measures for railway suicides and railway trespassing [16]. Considering the passage of time since these previous reviews, newly published research, and a different approach to data processing, the authors believe that this review of railway trespassing is justified.

This systematic review offers a new perspective by analysing up-to-date knowledge of railway trespassing alone (without suicides). To that end, trespassing accidents were analysed for their causality, consequences, and factors that influence railway trespassing.
The authors also searched for preventive measures that are known or have the potential to reduce railway trespassing. A brief analysis of trespassing accidents and their consequences is presented in Sections 2.1 and 2.2.

2.1. Trespassing Accidents

Railway trespassing accidents are often listed and addressed in railway accident reports published by railway operators. Accident reports provided by railway operators are used as input data for different statistical analyses. It is also not uncommon for railway operators to finance studies targeting reducing accidents in railway transport. In most cases, accident reports refer to the previous year. According to the data published by Eurostat from 2021, 59% of all fatalities were unauthorized persons on tracks. The highest percentage of seriously injured unauthorised persons on tracks was recorded in 2011 (41.7%) and in 2021 dropped to 37% (from all recorded railway accidents). There is no clear drop or rise in serious injuries of unauthorised persons on tracks from 2010 to 2021 [1]. In the USA, trespassing accidents are counted by States, generating 606 recorded fatalities (deaths) or 52.3% of all trespassing casualties (fatalities and non-fatalities) in 2022 according to the Federal Railway Administration report [18]. A high number of trespassing cases, nearly 3000, was also reported in Australia from 2021–2022, with special reference concerning the danger of being electrocuted as a consequence of trespassing [14]. In 2022, the railway operator Infrabel in Belgium reported 649 cases (a 10% increase compared to 2021) of trespassing, which in turn caused delays in railway transport by 213,409 min [19]. Croatia Railways accident reports have been published from 2017 to 2021. In the previous period, the percentage of trespassing fatalities, out of all railway fatalities, dropped from 61% in 2017 to 40% in 2021 (5 years) [20].

The numbers and textual data that are found in a railway accident report in turn help researchers with their in-depth studies of the problem. An example of accident report analysis is a 10-year report from the hospital emergency department in Turkey (Adult Emergency Department of Hacettepe University Medical Center), which revealed that out of 44 patients who were admitted, 11.4% still succumbed to injuries. This means that even if victims survive the initial accident there is still a high risk of death [21]. Compared to the previous statement, in the Indian district of Barpeta, Assam, during the years 2015 and 2016, 96.6% of persons died at the scene [22]. Victims of railway trespassing are often pedestrians (84%), as shown in the research conducted in the city of Chicago. By analysing spatial and temporal data from 2004 to 2012, out of 338 accidents, 32% were the result of accidental deaths at other locations along the railway (presumed trespassing fatalities) [23]. In New Zealand, researchers have recognised the importance of analysing the increase or decrease in accidents spanning several years, as the data can be used for further studies. They concluded that the number of trespassing fatalities and serious injuries remained constant from 1994 to 2003 (10 to 20 in total). A major problem was insufficient data on the nature of the accident in the accident report [24]. There is also the possibility that some of the accidents are unreported. An example of this is a study in Cape Town, where up to 20% of fatal accidents go unreported; in comparison, a total of 379 fatal accidents were reported from 1994 to 1996 [25]. The severity of an accident can increase depending on the actions leading to the accident. By using a geographically weighted regression studying non-crossing trespassing accidents from 2005 to 2016 in the USA, researchers determined that a person lying on the tracks has a 60% higher chance of a fatal accident [26]. In Finland, researchers examined the development of railway safety from 1959 to 2008. The average drop in trespassing accidents was 4.4% per year, which is the lowest percentage when compared to other railway accidents [27].

If several accident variables, e.g., time of the day, day of the week or month, are examined, results vary based on the country, region, city, etc. For example, a day with the highest number of trespassing fatalities could be on Thursday, evenly spread across a day in December [24] or half of the trespassing accidents could happen at night [26]. The specific time of the day, i.e., 6 am to 12 am, could also be linked to the highest number
of trespassing fatalities [22] or, in contrast, based on research from New York, Pittsford, between 12 pm and 6 pm [28]. There is also a difference in trespassing in urban and rural areas, with urban areas experiencing more frequent trespassing than rural areas [29–31].

2.2. Consequences of Trespassing Accidents

Trespassing accidents have a high mortality rate or often end with serious injuries, especially in train-pedestrian accidents. The sustained injuries vary based on the impact, the speed of the train, or the behaviour of the trespasser at the time of the accident. Sustained injuries could be lighter injuries such as scratches (33.3%) or serious injuries (head injuries—14.2%, fractures 13.4%) [31]. Based on forensic analysis of victims of railway accidents in the district of Barpeta, Assam (India), there were serious internal injuries due to train accidents, e.g., lung injuries (44.8%), liver injuries (44.8%), and kidney injuries (39.7%), with the highest number of fatal accident due to head injuries (53.5%) [22]. The evidence of head injury being the most common fatal wound is also supported by similar research in India, in which head injuries were found in 69.3% and neck injuries in 28.4% of victims [32]. Insight into the trauma register of a medical center at the University of St. Louis from 1985 to 1992 found statistical significance between the type of amputation of a body part and whether a railway worker or trespasser (66.7% required leg amputation below the knee) was the victim of the trespassing accident [33]. This is further supported by an analysis of the hospital registry from 2012 to 2016, in which, out of 255 patients, 68.3% sustained injuries of the lower extremities, which led to amputation in 90 patients. The location of the accident (on the platform or on the tracks) did not contribute to the difference between the injury severity, mortality, and length of hospital stay [34].

Distinct injuries are related to adults and children. Children are more susceptible to serious injuries because of body and bone development. Children who survived the initial impact of the train require complete amputations or nearly complete amputations. On average, children needed 5.7 surgeries from the moment of hospitalization, with secondary surgical procedures required in 50% of survivors [35]. Another example of the high requirement for operations in victims of train-pedestrian accidents is a clinical report from 2013 to 2019, in which 68% of patients required surgery, in 13% of patients, 14 body parts were amputated and the most common surgical procedure was wound debridement. It has also been noted that patients who arrived at the hospital had a good chance of survival [36]. Some percentage of train-pedestrian accident victims are railway workers, but they are not considered trespassers as it is their job to work on or near railway lines. However, one study objective was to raise awareness of the potential health and safety risks that working in the rail industry brings [37]. The often overlooked consequence of railway trespassing accidents is the psychological effect it can have on train drivers. Stress disorders are present in train drivers for up to one year after an accident, and a train driver is often unable to return to work [38]. The perception of risk and therefore consequences is different between experts and the general public. The general belief is that experts are objective, while the general public is subjective. Although these dangers are real, it is believed that there are no such things as “real risk” or “objective risk” [39].

3. Methodology

The objective of the systematic data collection was to present up-to-date research on the problem of trespassing on tracks. The search was conducted using the PRISMA method. The PRISMA 2020 checklist is presented in Supplementary Materials [40]. The studies for the literature review were included based on several criteria that are explained in the continuation of this chapter [41,42].

3.1. Study Collection Criteria

The investigation into the literature on the topic was conducted based on several criteria: (1) question criteria; (2) publications written in the English language; (3) the
literature was not limited to a specific time period, rather, the first publication by date was used as a starting point.

Publications were excluded for the following reasons: (1) studies in a different language (not English); (2) studies with no applications for railway trespassing \([41,42]\). The outcome of the search was to identify factors and collective preventive measures for railway trespassing spanning a larger time period without including railway suicides.

3.2. Publication Search Methods

The search formulation questions were based on the previous literature review from authors \([15,17]\) without including railway suicides. The questions were as follows: (a) What are the factors that influence the occurrence of trespassing accidents? (b) What are the current measures that exist for railway trespassing prevention?

The intensive search was conducted through the scientific literature database of the Web of Science (WoS) (journal papers and conference proceedings). An additional search was made through other literature databases: ScienceDirect, ResearchGate, Taylor & Francis, and PubMed, with expert reports searched by independent studies financed by railway operators or yearly reports published by the FRA—Federal Railroad Administration, Network Rail, Infrabel, etc. (safety reports, statistical reports, studies, etc.).

Publications were searched by all possible fields offered by the WoS database (e.g., title, publication titles, author, author keywords). The process of the publication search was conducted from 3 April 2023 to 30 April 2023, with the update check taking place during May 2023. No new studies were published after 30 April 2023. Input keywords were combined with the word trespassing (search limitations): “railway trespassing”, “railway trespassing accidents”, “trespassing factors”, “trespassing prevention”, “railway trespassing detection”, and “railway trespassing education”. The search was separately conducted for each keyword mentioned (within quotes).

After the literature was collected, the next step was the process of removing possible duplicates. The collected literature predominantly consisted of journal and conference papers with previously mentioned expert reports also included for relevant data, especially for trespassing factors. After the screening process, the final number of collected instances in the literature on the topic of railway trespassing is presented in chapter results. Figure 1 shows the PRISMA graph that was used for the process of literature collection \([41,42]\). The graph is a modified version of the example on the website PRISMA \([40]\).

![Figure 1](https://example.com/figure1.png)

**Figure 1.** Flow graph of the literature selection process.

The categorisation of different literature by authors was based on the content of each paper, which is presented in later sections. The objective of this categorisation was to
provide a clear overview of trespassing events, from factors influencing trespassing to preventive measures aimed at the reduction of the occurrence of trespassing events and accidents. Possible shortcomings of the research and the need for further research are listed in the discussion.

3.3. Data Collection and Analysis

At the start of the process of the literature collection, the first problem was reducing the number of studies. This was accomplished through the use of a combination of the word trespassing with every set of keywords. The relevant literature was studied in detail because authors often only mention the problem of trespassing in the text (not in keywords or titles).

The selection process was independently conducted: publications were identified by both authors based on the inclusion criteria and a discussion was conducted to reach a consensus on the studies that would be included in the literature review. This was based on the previously mentioned reasons for exclusion in Section 2.1. No automation tools were used in the process.

Eligible outcomes for factors influencing railway trespassing included studies or expert reports that had recorded the following: location of frequent trespassing, temporal frequency of railway trespassing, behavior, and motivation for and knowledge of railway trespassing by traffic participants. However, because numerous publications had recorded these factors, the publications were randomly chosen by the authors. The objective was the formation of cohesive patterns (e.g., males trespass more than females). Similarly, for preventive measures studies that included educational measures and signalization, technological and technical measures for trespassing prevention were analysed to determine whether they included any evidence of their effectiveness in reducing railway trespassing. Pilot studies had to include evidence of testing in a laboratory or real-life situations.

For publications that were included in the review, the universal categories were formed in a Microsoft Excel spreadsheet for data extraction: authors, title, publishing year, type of publications (journal paper, conference paper, or report), internal division (presented in results), description of objectives, methods, the results of each study, and possible shortcomings of the research.

Several changes to category formation in the results were made after the literature was collected. At the start, all factors were grouped together and were not separated by category, as shown in Table 1. As for preventive measures, originally, signalization and technological and technical measures for trespassing prevention were separately presented in the literature review, but due to a lack of publications on each of the measures, a decision was made to analyse them together. Furthermore, a new category of pilot studies was formed after the data collection process.

Table 1. Formation of railway trespassing categories.

<table>
<thead>
<tr>
<th>Main Trespassing Categories</th>
<th>Trespassing Sub-Categories</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factors influencing the occurrence of trespassing accidents</td>
<td>1. Locations of frequent railway trespassing</td>
<td>(Silla and Luoma, 2012) [43], (Silla and Luoma, 2009) [11], (Skladana et al., 2019) [44], (Skáldánová et al., 2016) [7], (Colonna et al., 2019) [45], (Skaloš et al., 2011) [46], (Rådbo et al., 2005) [47], (Skáldánová et al., 2019) [48], (Dostál et al., 2012) [49], (Alarete et al., 2013) [50], (Beiler and Filion, 2021) [51], (Nunonan, 2005) [52], (Dostál et al., 2018) [53], (Beiler et al., 2019) [54]</td>
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<tr>
<td>2. The temporal frequency of railway trespassing</td>
<td>(Silla and Luoma, 2012) [43], (Silla and Luoma, 2009) [11], (Skladana et al., 2019) [44], (Beiler et al., 2019) [54], (Pelletier, 1997) [13], (Rådbo and Andersson, 2012) [55],</td>
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Table 1. Cont.

<table>
<thead>
<tr>
<th>Main Trespassing Categories</th>
<th>Trespassing Sub-Categories</th>
<th>Authors</th>
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<tbody>
<tr>
<td>Factors influencing the occurrence of trespassing accidents</td>
<td>3. Trespasser profile and behaviour</td>
<td>(Silla and Luoma, 2012) [43], (Silla and Luoma, 2009) [11], (Skladana et al., 2019) [40], (Pelletier, 1997) [13], (Patterson, 2004) [24], (Federal Railroad Administration, 2008) [30], (Davis et al., 1997) [56], (Matzopoulos et al., 2006) [57], (Rådbo et al., 2005) [47], Rådbo and Andersson, 2012) [55], (Ozdoğan et al., 2006) [58], (Beiler et al., 2019) [54], (Zhang, et al., 2018) [10], (Kučerová et al., 2019) [59], (Hua et al., 2019) [60]</td>
</tr>
<tr>
<td>4. Motivation for and general knowledge of railway trespassing</td>
<td></td>
<td>(Silla and Luoma, 2009) [11], (Rådbo and Andersson, 2012) [55], (Silla and Luoma, 2012) [43], (Skladana et al., 2016) [7], (Skladana et al., 2019) [44], (Kučerová et al., 2019) [59], (Freeman and Rakotonirainy, 2017) [61], (Freeman and Rakotonirainy, 2015) [62], (Lobb et al., 2001) [6], (Harris and Napper, 2005) [63]</td>
</tr>
<tr>
<td>5. Other factors and models for railway trespassing accidents</td>
<td></td>
<td>(Kang et al., 2019) [64], (Zha et al., 2019) [65], (Austin and Carson, 2002) [66], (Ghomei et al., 2016) [67], (Rajabalianjad et al., 2019) [68]</td>
</tr>
</tbody>
</table>

Measures for trespassing prevention

| Measures for trespassing prevention | 1. Educational measures | (Waterson et al., 2017) [69], (Havârneanu et al., 2015) [70], (McLaughlin et al., 2014) [71], (Havârneanu et al., 2016) [72], (Havârneanu et al., 2015) [16], (Hoekstra and Wegman, 2011) [73], (Waterson et al., 2015) [74], (DaSilva and Carroll, 2011) [75], (Department of transportation (FRA), 2011) [76], (Edwards, 1953) [77], (Cohen et al., 2003) [78], (Ricketts et al., 2010) [79], (Ricketts, 2015) [80], (Lobb et al., 2003) [81], (Hallewell et al., 2022) [82] |
| 2. Signalization, technological and technical measures for trespassing prevention | | (Silla and Luoma, 2011) [83], (Federal Railroad Administration 2011) [84], (Waterson and Monk, 2014) [85], (Horton and Da Silva) [86], (Oh et al., 2022) [87], (Gao et al., 2021) [88], (Tang et al., 2023) [89], (Bashir et al., 2019) [90], (Zhao, 2021) [91], (Müller and Boos, 2002) [92], (Fayyaz and Johnson) [93], (John and Federal Railroad Administration, 2022) [94], (Zhang et al., 2018) [8], (Havârneanu et al., 2017) [95], (Hallewell et al., 2022) [82], (Lin et al., 2022) [86] |
| 3. Pilot studies of railway trespassing preventive measures | | (Barić et al., 2018) [97], (Haryono and Hidayat, 2022) [98], (Oishi and Shanker, 2016) [99], (Wullems et al., 2014) [100], (Li et al., 2021) [101], (John and Federal Railroad Administration, 2022) [94], (Zaman et al., 2019) [102], (Xue et al., 2022) [103], (Havârneanu et al., 2016) [72], (Lobb et al., 2001) [6], (Lobb et al., 2003) [81], (Silla and Kallberg, 2017) [104], (Silla and Kallberg, 2016) [105], (Catalano et al., 2014) [106] |

3.4. Method of Literature Synthesis

Literature synthesis was conducted in the form of qualitative analysis. The findings of each study that met the inclusion criteria and were therefore eligible for the literature review are presented in Section 3. A summary of the findings is presented in the discussion.

4. Results

This section deals with the results and scientific contributions of individual studies. Trespassing on railway tracks is a very complex problem to study and, in recent years, there has been more focus placed on suicides on railways, with trends slowly changing. The collected literature ranged from 1953 to 2023, or, more accurately, represented 70 years
of the literature in which researchers focused on the problem of railway trespassing. The starting point was $n = 291$ studies, which were reduced to $n = 213$ after removing duplicates. The collected literature was then screened and, after the final assessment, 72 studies were included in the literature review. The literature review consisted of 73.6% journal papers, 18.1% conference papers, and 8.3% expert reports.

The railway trespassing categories were formed based on the content of each scientific paper or expert report. To place the individual literature into a category, an analysis of the goal, method, and results of each study was conducted. The exception was papers in which the authors did not focus just on factors for trespassing occurrence, but also on preventive measures. Many researchers combined suicides and trespassing events, or classified illegal crossings at the level crossing as a form of trespassing. For the former, several studies were included to distinguish between illegal crossings at the level crossing and trespassing on the track (unofficial locations).

The process of literature classification was redefined several times because of the complexity of the problem. Factors for accident occurrence were especially difficult to place into one category, e.g., in category locations, the reasons and motivation for trespassing were initially separate categories but they were then grouped.

The final categories were formed as follows: (1) Factors influencing the occurrence of trespassing accidents (additional sub-categories divisions: locations of frequent railway trespassing, the temporal frequency of railway trespassing, trespasser profile and behaviour, motivation for and general knowledge of railway trespassing, and other factors and models for railway trespassing accidents); (2) Measures for trespassing prevention (additional sub-categories divisions: education measures, signalization, technological and infrastructure measures for trespassing prevention, and pilot studies of railway trespassing preventive measures). The categories and sub-categories of studies that were included in the review are presented in Table 1, with publications placed into each sub-category by author.

4.1. Factors Influencing the Occurrence of Trespassing Accidents

There are numerous factors that influence an individual’s reasons for trespassing on railway tracks. The objective of this study was to give an overview of several factors often mentioned in the literature. The factors mentioned were as follows: locations of frequent railway trespassing, the temporal frequency of railway trespassing, trespasser profile and behaviour, motivation for and general knowledge of railway trespassing, and other factors and models for railway trespassing accidents.

4.1.1. Locations of Frequent Railway Trespassing

The locations near railway tracks are often classified as places with frequent trespasses compared to places further away from the railway line [43]. The trespassing locations referenced in this section can be formed between two legal crossings, on open tracks, on legal crossing (improved paths), near tracks as recreation or meeting places for people, and in other locations. One of the first attempts to identify locations with frequent trespassing was conducted in Finland. Researchers used a survey directed at engine drivers to determine problematic sites that were then observed. The results showed that trespassing seems to be concentrated near big cities [11]. Similarly, in the Czech Republic, there is a serious problem of trespassing on tracks. The researchers, therefore, referenced the AMELIA project, in which six distinctive locations were mentioned: everyday shortcuts not including stations and stops, hiking trails and recreation areas, destinations of specific interest groups, places to meet and live, and railway crossings [44]. The AMELIA project was referenced in detail in a conference paper in which it was further explained that a level crossing is only considered a trespassing location if improvised paths exist alongside the level crossing or the barriers on the level crossing are lowered [7]. Another factor for the possible formation of trespassing locations is increasing urbanisation [45–47]. Using electronic maps of accidents between trains and pedestrians, interviews with train drivers, infrastructure managers and police, and the use of GIS tools, researchers have
identified 27 locations where trespassing frequently occurs [48]. Similarly, maps from different historical periods can be used to analyse how urbanisation has affected the frequency of trespassing (GIS) [49] or how the construction of railways started the process of urbanisation (impact on demographic differences in regions, between urban and rural areas) [50]. To summarise, GIS tools can be used for different analyses, among which is the geographic analysis of locations of high trespassing frequency (risky locations on the railway tracks) [51]. Although there is no specific reference to trespassing in the study in the USA regarding two different neighbourhoods on different sides of a track, there is a possibility that different socio-economic and environmental characteristics of the two areas may influence the emergence of different trespass locations [52]. In the Czech Republic, given the growing population, the effect of suburbanisation has been identified as one of the factors influencing trespassing. The most trespass-prone locations are high-speed railway lines and high train frequency railway lines. The effect of railways as a barrier between two areas also influences the frequency of trespassing [53]. Surprisingly, in the USA, when researchers studied Amtrak trespassing incident data, the highest number of trespassing incidents was where the population density was lower (55.7%) [54].

4.1.2. The Temporal Frequency of Railway Trespassing

The temporal frequency of trespassing is difficult to determine as it greatly varies depending on the different characteristics of the places along the railway line. In a survey conducted in Finland, trespassers indicated that most trespassing occurred during the day (17.9% in the afternoon hours), with no clear answer as to the month in which most trespassing occurred [43]. Three years earlier, the same researchers also used the survey to identify locations with a high incidence of trespassing. The results showed that 67% of respondents trespassed at least once a week and were aware of a legal crossing. The time with the highest frequency of trespassing is between 11 a.m. and 9 p.m. [11]. A similar survey was conducted in the Czech Republic, where 36.3% of respondents observed trespassing, including 56% annually, 69.3% weekly, and 64.7% every day [44]. However, in a USA study of trespassing factors, trespassing was evenly spread across the seasons and the weekdays, with 51.2% of trespassing incidents occurring in nighttime hours [54]. In another study from the USA, most trespassing accidents occurred between March and August, 57% at weekends, and 82% of trespassing incidents were close to the victim’s place of residence [13], with a high percentage of accidents occurring at night and on weekends confirmed by a Swedish study [55].

4.1.3. Trespasser Profile and Behaviour

The gender profile and age of trespassers are important in developing preventive measures against trespassing. More men illegally trespass, at 73.2%, compared to women, at 64.3%, and the group most likely to trespass are young people under 20 years of age according to a Finnish study [43]. This was also confirmed by an earlier study by the same researchers, where men illegally crossed 63% of the time [11]. In the Czech Republic, the ratio of male (53%) and female trespassers (47%) was reasonably balanced. The local population, dog owners, students, and pupils were identified as the groups most likely to trespass (the highest number of trespasses recorded) [44]. Several studies have also confirmed that alcohol is one of the factors influencing trespassing on railway tracks. In the analysis of data provided by the Office of the Chief Pathologist (North Carolina), trespassers were mostly male, had lower than high school education levels, and were between 20 and 49 years old (100 trespassers had alcohol levels greater than 100 mg/dL) [13]. Alcohol levels were also determined to be high in several trespassers, using 10 years of statistics on railway trespassing accidents [24]. Data on trespassing fatalities (Federal Railroad Administration—USA) can be used to develop a demographic profile of trespassers. According to the data, the average age of trespassers was 38, and they were mostly white males under the influence of alcohol [30]. When comparing a study from 1997 with the former, the average age of male fatality was 39 and the influence of alcohol was also present [56]. Alcohol was identified to
be a risk for unintentional rail injuries during daylight hours [57]. The trespassers were usually lying on railway tracks or walking alongside tracks. In Sweden’s study, which included suicide victims, the age range of males was 20–59 years. Before the accidents, the victims were standing, walking, or lying on the tracks [47] or using a shortcut [55]. In Turkey, on level crossings, males were killed in 77% of cases (age group 25–60 years old) [58]. The analysis of Amtrak data showed that the population aged 17–29 constituted 25.9% of trespassing incidents. Males were predominantly trespassers (75.9%) and walking or running was identified as the most common behaviour before the incident (35.7%) [54].

There is a difference in the correlation of injury severity between the level crossing and the trespassing location on railway tracks [10]. A study in the Czech Republic has shown that adults can have a negative influence on young people aged 11–16 years when it comes to trespassing. Peer influence also plays a major role, as there are no consequences for bad behaviour [59]. Trespassing on railway tracks is mainly due to human factors [60].

4.1.4. Motivation for and General Knowledge of Railway Trespassing

The problem of trespassing is highlighted by motivation for and general knowledge of railway safety. In a Finnish study, 18.2% of trespassers believed that trespassing is not illegal, suggesting that they base their knowledge on personal perception [43]. In terms of motivation, the most common response from 80% of respondents in the 2009 study was to use a shortcut even though the legal crossing was only 300 m distance from the location [11,56]. In the Czech Republic, trespassing locations appeared because of poor infrastructure at railway stations and less comfortable and convenient legal crossings (long distances to the legal crossing). Fear of using underpasses is also present and people often use improvised paths created alongside underpasses [7]. This was also the case in a 2001 study in Australia where 25% of respondents in a survey stated that their reason for railway trespassing was because the underpass was considered dangerous or too long. Their motivation for trespassing also depended on how limited their time was (in a hurry), on the weather forecast, their mood that day, and, in 20% of responses, it depended on whether they thought it was safe to cross the railroad tracks [6]. A high percentage of respondents in the Finish survey (15%) stated that trespassing must be legal as there are no prohibitive signs [11]. Some respondents trespassed to work (69.3%) or school (42%), while others who did not trespass saw no reason to do so (41%) [44]. The lack of safety knowledge is also present among young people aged 11 to 16. Young people are aware of the dangers of their actions, but they have limited ability to assess the risk and have various misconceptions regarding illegally crossing railway tracks [59]. The question is how many illegal crossings (trespassing) are due to a lack of knowledge and how much is intentional. The 2016 study on level crossings found that 24.5% of respondents intentionally committed traffic violations and 47% were aware of the penalties for illegal crossings [61]. Illegal crossings are often the result of “sensationalism” and pedestrians are more likely to knowingly commit violations [62]. The key element here is self-affirmation in person, which prevents the safety message from having an impact on the targeted group [63].

4.1.5. Other Factors and Models for Railway Trespassing Accidents

It is difficult to separate all of the factors that influence the occurrence of railway trespassing accidents. Therefore, this chapter contains other factors that might increase the occurrence of trespassing on tracks. By using a mixed-effect Negative Binomial Model, researchers have determined that extending a railway line by 8 kilometres is associated with an increase in trespassing accidents from 3.24% to 4.05%, a population density of 100/1.5 km$^2$ leads to an increase in the incidence of trespassing accidents from 4.8% to 8.18%, and 1% more trains per day increases trespassing accidents from 4.47% to 6.23% [64]. The factors for the occurrence of accidents and the severity of accidents can vary at the level crossing. A study using Federal Railway Administration data found that the severity of injuries was directly related to higher train speeds. Other variables included freight trains, a lack of flashing lights at a level crossing and advance warning sounds, rural areas, lack
of visibility, and an increase in the ratio of older pedestrians in the total population [65]. Through the development of an alternative model for accident prediction, several factors have been identified for the occurrence of accidents at level crossings, such as the higher number of night trains, which in turn increases the frequency of accidents, a higher number of railway tracks, and higher train speeds [66]. The same factors can also influence accidents caused by trespassing at level crossings. High train speed was also found to be a key factor in the severity of injuries to vulnerable road users [67]. Ultimately, according to one study, there are three factors that should be considered for successful rail transport: operation excellence, system safety, and human factors [68].

4.2. Measures for Trespassing Prevention

This section contains a collection of preventive measures targeted at the reduction of railway trespassing accidents. The measures are divided into three main railway trespassing prevention categories: education measures, signalization, technological and infrastructure measures for trespassing prevention and pilot studies on railway trespassing preventive measures. It has been five years since, in 2018, researchers tried to identify trespassing prevention measures on an international scale. Some of the preventive measures mentioned in the study are listed in this review with the combination of new research published up until 2023 [17].

4.2.1. Educational Measures

Education is considered a powerful preventive measure for railway trespassing reduction. Education measures are developed by institutions as part of the curriculum, railway operators, communities, safety organizations, and all stakeholders in railway transport. Education-based measures can be part of a study, project, campaign, workshops, guidelines, etc. Examples of the former are presented in this chapter. In the United Kingdom, education measures were directed at young groups aged 16 to 25 years old. Researchers also included professionals that worked with children, railway stakeholders, social workers, and police. To educate young people, four sets of video recordings were presented to them. The results showed that education should be realistic, accurate, and clear to understand for all involved with the use of social networks to reach a wider audience. Furthermore, education can start as early as 6 to 7 years old, and be incorporated into the school curriculum [69]. The same was suggested in another study, but for children aged 8 to 11 years old, in that trespassing can be reduced by implementing railway safety into the school curriculum using different teaching materials, educating parents, and combining education measures with other preventive measures [70]. Based on statistics, elderly people are less likely to be fatalities in trespassing accidents; however, the severity of their injuries is often higher than in other cases. A proposal for developing communication measures aimed at elderly people can be constructed in three steps: analysis of the characteristics of a targeted group, analysis of the environment in which the measures will be implemented, and testing the measures in the environment [71]. An overview of the RESTRAIL project highlights campaign awareness, the development of new education measures, and cooperation with different institutions directed towards trespassing prevention [16,72]. For the former, campaigns must not be solely focused on intimidation effects on the targeted group [73]. To make the message clear, the emotional impact on young people and teenagers is very important for successful communication with both groups [74]. Using a system CARE guide (developed by Transport Canada), which consists of four steps, identifying key trespassing factors, the analysis of data, implementation, and the evaluation of the most effective measure, one of the measures proposed to prevent railway trespassing is education (billboards, public communication, Operation Lifesaver, etc.) [75]. Similarly, the Federal Railroad Administration developed a community guide to identify the trespassing problem in a detailed analysis, with surveys conducted in schools and the general population. The data can be used to develop preventive measures for specific groups [76]. When compiling the formation of educational measures, it is recommended that the preventive measure is accepted from a
psychological perspective, meaning that the message is accepted by the majority of people [77]. When considering education measures, all of the stakeholders, public services, and the community should work together on the development of preventive measures [78]. An effective way to transmit public safety messages is by conveying messages through storytelling, which in one case led to a 19% improvement in message reception [79]. However, not every story is as effective and a careful selection of stories must be made [80]. Enforcement measures are also very effective when combined with education, as shown in research conducted in Auckland, New Zealand [81], where education alone was not as effective in the reduction of railway trespassing. However, education on safety has been proven to change the mindset of people, which is why the railway stakeholders in one study suggested that education on the dangers of electrification is needed at schools (alongside “normal” trespassing education) [82].

4.2.2. Signalization, Technological and Technical Measures for Trespassing Prevention

Trespassing prevention measures that are based on access prevention, warning, or technological measures are highly effective in trespassing prevention. Often, these measures are implemented in combination with other measures (e.g., education measures, enforcement measures, etc.). The measures that are referenced in this chapter are access prevention measures (fence alongside the railway line, landscaping, and other infrastructural measures) and deterrent measures, prohibitive signs (design and implementation), and monitoring and trespassing detection measures. One example of such measures is a study conducted in Finland where researchers tested three measures for trespassing prevention: prohibited signs, fencing, and landscaping. The effect of the measures was tested using a camera: 10 days for landscaping, 11 days for fencing, and 17 days for prohibited signs. The fence reduced trespassing by 94.6%, landscaping by 91.3%, and prohibitive signs by 30.7% [83]. In their report, the Federal Railroad Administration proposed similar measures for trespassing prevention, e.g., deterrent measures, prohibitive signs, fencing, landscaping, and dedicated pedestrian/bicycle paths, though with no data on the effectiveness of each measure [84]. Warning signs can be developed based on the targeted group. In that regard, researchers have developed guidelines for the design and evaluation of warning signs and other visual materials for children. The study included interviews and a focus group with the parents of small children, teachers, professional book illustrators, and authors (n = 38). Methods for testing measures can be conducted through simulated environments, role-playing, classroom discussions, focus groups, and interviews [85]. Some measures can be implemented on both the legal and illegal crossings on railway tracks. An example of this is better visibility of the locomotive, visibility of the tracks, and sound warning systems installed at critical locations [86]. With the development of technology, there is a growing need for new methods to improve railway safety. To accomplish this, researchers conducted a review of the application of deep learning in railway safety. One of the areas of application can certainly be railway trespassing detection and prevention, but there is a need for further research [87]. LiDAR and cameras can also be integrated into train systems to detect objects on railway tracks. For LiDAR, the ground has to be straight and inclined to reduce errors, but by implementing a camera, the distance calculation to an object error is greatly reduced [88]. To improve the convolution neural network (CNN), researchers developed RC-SAFE (railroad crossing surveillance and foreground extraction). The objective of the experiment was to limit the reliance on a manually labelled image with weakly supervised learning, which in turn reduces the load of image labelling. The results were more accurate and effective in the detection of moving and still objects on railway tracks [89]. The surveillance data system, ARTS, for trespassing detection also uses CNN deep learning architecture in two steps: (1) the detection of trespassing activity and (2) high-reliability classification using a deep neural network. This reduces computational expenses and time for data processing [90]. Another study used the improvements in AI technology to develop a video analytic system for monitoring pedestrian and vehicle crossings. An experiment on the YouTube rail crossing dataset revealed 56 out of 58 annotated events and,
on the private dataset, 58 out of 62 [91]. As previously mentioned, trespassing can occur at railway stations and a good detection tool can be a CCTV system, as presented by a study at Zurich railway station. Researchers presented a topology of different uses for CCTV systems, e.g., access control, behaviour control, evidence collection, and traffic control. CCTV systems can be used to monitor and prevent trespassing at railway stations [92]. Systems can also be improved through integration with deep learning technology to increase the detection of objects at the level crossing. The system object detection accuracy was 88% [93]. In 2022, the Federal Railroad Administration conducted a study to develop a detection system based on deep learning. The process of detection consisted of five steps: detection, the definition of the region of interest, classification of a scene, object detection, and trespassing prediction [94]. Often overlooked are the near-miss accidents in railway transport. In the USA, researchers developed a detection algorithm, “Computer Vision”, for the automatic detection of near-miss accidents based on video recordings. The objective was to use this data to better understand trespassers’ behaviour [8]. A better understanding of data can, in turn, be used to develop preventive measures or models, such as the Restrail Problem-Solving Model developed as a part of project RESTRAIL. The model is used as a tool in identifying, analysing, and ultimately solving the problem of railway trespassing [95]. Furthermore, often overlooked measures for trespassing prevention are lightning measures. One study tried to highlight the possibilities of implementation by gathering a group of railway stakeholders. The results were a recommendation of potential measures: LED lights at the station to indicate the arrival of a train, the improvement of illumination of the railway areas, and an interesting measure of playing classical music at the railway station to deter youths from socialising around the train station as the former type of music is considered “uncool” [82]. Overall, railway transportation is rapidly growing, which in turn requires increasing tools in managing its safety. Therefore, researchers from China developed the improved 5M (Management-Machine-Man-Media-Mission) in order to develop safer and more sustainable railway transportation [96]. This chapter mostly offered theoretical knowledge aimed at solving the problem of railway trespassing, but every measure eventually needs to be implemented in real-life situations in the form of pilot studies to test its effectiveness.

4.2.3. Pilot Studies of Railway Trespassing Preventive Measures

In recent years, general knowledge and research on trespassing on railway tracks have increased, but there are still many questions and insufficient research studies regarding this problem. In 2016, researchers from Croatia conducted a case study on the analysis of road user behaviour at a railway area of the Republike Austrije level crossing in Croatia as part of a wider study. This was the first study in Croatia to use surveys and video recordings to analyse road user behaviour at an area of the level crossing. By understanding road user behaviour, preventive measures can be developed based on this behaviour [97].

It is necessary to improve current methods for trespassing detection and regulation to ultimately develop a better understanding of trespassing events and prevention measures. To this end, to detect trespassing at the railway station, researchers used the existing platform VIANA, a YoloV5, as a model for detection, and DeepSort as a model for trespassing tracking. Two experiments were conducted, one in a simulation environment and one in a real environment [98]. It is important to understand the previous factors for railway accident occurrence for the development of any preventive measures. By using the Modified Checkpoint Apriori Algorithm and several factors (the road connecting/crossing the railway, the time of the day, weather conditions, etc.) researchers have tried to determine which factors are the most influential for accident occurrence [99]. Another example of this is a study that implemented a system for recording and data processing, which also included high-resolution video from the locomotive cabin, which could ultimately result in the better development of measures for accident prevention [100]. To prevent traffic accidents, critical factors must be addressed. In China, Beijing, researchers based their model on a controllability analysis of hazards (critical factors) and identified a weighted
direction accident causality network considering its length as the method with the best results for accident prevention [101]. For trespassing detection, researchers used deep learning-based computer vision to develop six steps for a better understanding of trespassing events [94]. Another example of trespassing detection is a study of trespassing events on level crossings in the USA. Trespassing was detected by using an AI algorithm on three video recordings. It could automatically detect all road users without returning false positive readings [102]. Using the same concept, but a different method, Yolov4 and Deep SORT, the railway detection system could easily record trespassing events and process them and save them for later analysis [103]. For the duration of the project RESTRAIL, pilot tests were conducted in several countries during 2013–2014. Countries participating in trespassing prevention were Spain, Finland, and Turkey (near stations, on open tracks, near schools, stadiums, hospitals, and shopping centers) [16].

To evaluate the education programme for trespassing prevention, researchers used the methods of observation and survey for adults and children (before, two weeks after, and three months after the programme and in schools). The results showed that, out of 438 respondents, 60% noticed prohibitive signs, 51% saw the billboards, 49% noticed a new fence, 38% read about the programme in newspapers, and 60% remembered the conversation at the school assembly [6]. The same researchers also evaluated four railway preventive programmes at Auckland railway station by methods of observation and survey after and before the implementation of each measure (communication measure, communications (public)/increasing awareness, education, continuous punishment and occasional enforcement, and occasional punishment and occasional enforcement). The number of respondents who did not know trespassing was illegal dropped from 54% to 42%. The most effective measure was a combination of education and continuous punishment [81]. In Finland, the automated sound warning system was tested at two locations. The number of trespassers was reduced by 44% at location A and 18% at location B, with a 95% level of confidence. The measures could be more efficient if they were combined with other preventive measures and at the location where the trespassing is concentrated [104]. In Finland, a 45-min lesson was held for children aged 8–11 years old in four schools. The children filled out a short survey immediately after and then again 2 to 3 months after the lesson. The children’s answers improved in all but one question, suggesting that education can have a positive impact on trespassing accident prevention [105]. To quickly react to an unauthorized entry onto railway tracks, an intrusion detection system can be used. One study demonstrated the possibilities of fibre Bragg gratings sensors by conducting experiments in a laboratory and at a freight station in Italy. This system can detect trespassing on railway tracks and can be integrated with other railway systems [106].

5. Discussion

This literature review shows the complexity of the trespassing problem. An overview of causes and consequences and possible prevention measures is given with a focus on factors influencing the occurrence of trespassing accidents and measures for trespassing prevention. The factors associated with the occurrence of trespassing accidents are often found in statistical reports and scientific literature. The factors are divided into five categories: (a) locations of frequent railway trespassing; (b) the temporal frequency of railway trespassing; (c) trespasser profile and behavior; (d) motivation for and general knowledge of railway trespassing; (e) other factors and models for railway trespassing accidents. The aim is to build a complete profile of the railway trespasser. This includes behaviour prior to the accident, from the decision to enter the tracks to the accident itself. The literature on preventive measures is divided into three main groups: (a) education measures; (b) signalization, technological and infrastructure measures for trespassing prevention; (c) pilot studies of railway trespassing preventive measures.
5.1. Summary of Results

A summary of key results or main findings is shown in Table 2 (factors influencing the occurrence of trespassing accidents) and Table 3 (measures for trespassing prevention).

Table 2. Summary of key findings—Trespassing Factors.

<table>
<thead>
<tr>
<th>Authors</th>
<th>Trespassing Sub-Categories</th>
<th>Main Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Silla and Luoma, 2012) [43], (Silla and Luoma, 2009) [11], (Skladana et al., 2019) [44], (Colonna et al., 2019) [45], (Skaloš et al., 2011) [46], (Rådbo et al., 2005) [47], (Skladaná et al., 2019) [48], (Skokanová et al., 2012) [49], (Alarez et al., 2013) [50], (Beiler and Filion, 2021) [51], (Noonan, 2005) [52], (Dosiál et al., 2018) [53], (Beiler et al., 2019) [54]</td>
<td>Locations of frequent railway trespassing</td>
<td>✓ Open tracks (everyday shortcuts)</td>
</tr>
<tr>
<td>(Silla and Luoma, 2012) [43], (Silla and Luoma, 2009) [11], (Skladana et al., 2019) [44], (Beiler et al., 2019) [54], (Pelletier, 1997) [13], (Rådbo and Andersson, 2012) [55],</td>
<td>The temporal frequency of railway trespassing</td>
<td>inconclusive evidence:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>✓ During the day (morning or afternoon)</td>
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<td></td>
<td></td>
<td>✓ Weekly trespassing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>✓ On weekends and during the night</td>
</tr>
<tr>
<td></td>
<td></td>
<td>✓ Month of highest trespassing frequency (evenly spread across the seasons, March, August)</td>
</tr>
<tr>
<td>(Silla and Luoma, 2012) [43], (Silla and Luoma, 2009) [11], (Skladana et al., 2019) [40], (Pelletier, 1997) [13], (Patterson, 2004) [24], (Federal Railroad Administration, 2008) [30], (Davis et al., 1997) [56], (Matzopoulos et al., 2006) [57], (Rådbo, 2012) [49], (Rådbo and Andersson, 2012) [55], (Ozdo˘gan et al., 2006) [58], (Beiler et al., 2019) [54], (Zhang, et al., 2018) [10], (Kuˇcerová et al., 2019) [59], (Hua et al., 2019) [60]</td>
<td>Trespasser profile and behaviour</td>
<td>✓ Males tend to trespass more than females</td>
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<td></td>
<td></td>
<td>✓ Males between 20–60 years old (average age of trespassing victims up to 40 years old)</td>
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<tr>
<td></td>
<td></td>
<td>✓ Students, pupils, dog owners</td>
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<tr>
<td></td>
<td></td>
<td>✓ Local population</td>
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<tr>
<td></td>
<td></td>
<td>✓ Alcohol presence confirmed by several studies</td>
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<tr>
<td></td>
<td></td>
<td>✓ Pre-crash behaviour included victims standing, walking, or lying on the tracks</td>
</tr>
<tr>
<td></td>
<td></td>
<td>✓ Younger population (peer-influence and no consequence for bad behaviour)</td>
</tr>
<tr>
<td>(Silla and Luoma, 2009) [11], (Rådbo and Andersson, 2012) [55], (Silla and Luoma, 2012) [43], (Skladaná et al., 2016) [7], (Skladaná et al., 2019) [44], (Kučerová et al., 2019) [59], (Freeman and Rakotonirainy, 2017) [61], (Freeman and Rakotonirainy, 2015) [62], (Lobb et al., 2001) [6], (Harris and Napper, 2005) [63]</td>
<td>Motivation for and general knowledge of railway trespassing</td>
<td>✓ Lack of knowledge on the illegality of railway trespassing</td>
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<tr>
<td></td>
<td></td>
<td>✓ Distance to legal crossings, railway stations, and stops</td>
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<td></td>
<td></td>
<td>✓ Fear of using legal crossings (underpasses considered dangerous and long)</td>
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<td></td>
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<td>✓ Trespassers are often in a hurry</td>
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<td></td>
<td></td>
<td>✓ Common reasons to trespass are going to work or school</td>
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<td></td>
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<td>✓ Younger populations are aware of dangers but show limited knowledge of assessing the risks</td>
</tr>
<tr>
<td></td>
<td></td>
<td>✓ Most trespassers knowingly trespass</td>
</tr>
</tbody>
</table>
Table 2. Cont.

<table>
<thead>
<tr>
<th>Authors</th>
<th>Trespassing Sub-Categories</th>
<th>Main Findings</th>
</tr>
</thead>
</table>
| (Kang et al., 2019) [64], (Zhao et al., 2019) [65], (Austin and Carson, 2002) [66], (Ghomi et al., 2016) [67], (Rajabalinejad et al., 2016) [68] | Other factors and models for railway trespassing accidents | ✓ Extension of the railway line, weekly trespassing  
✓ Increase in population density (increase in the number of trespassing incidents)  
✓ Higher train speed and daily number of trains  
✓ Higher number of railway tracks  
✓ Freight trains  
✓ Lack of flashing lights, warning systems  
✓ Increase in the ratio of elderly in population (injury severity) |

Table 3. Summary of key findings—Measures for trespassing prevention.

<table>
<thead>
<tr>
<th>Authors</th>
<th>Trespassing Sub-Categories</th>
<th>Main Findings</th>
</tr>
</thead>
</table>
| (Waterson et al., 2017) [69], (Havârmeanu et al., 2015) [70], (McLaughlin et al., 2014) [71], (Havârmeanu et al., 2016) [72], (Havârmeanu et al., 2015) [16], (Hookestra and Wegman, 2011) [73], (Waterson et al., 2015) [74], (DaSilva and Carroll, 2011) [75], (Department of transportation (FRA), 2011) [76], (Edwards, 1953) [77], (Cohen et al., 2003) [78], (Ricketts et al., 2010) [79], (Ricketts, 2015) [80], (Lobb et al., 2003) [81], (Hallewell et al., 2022) [82] | Educational measures | ✓ Video-based education (aged 16–25),  
✓ Railway safety curriculum (aged 9–11)  
✓ Communication measures (safety communication, e.g., towards the elderly population)  
✓ Safety campaigns (e.g., billboards, Operation Lifesaver, etc.) and institutional cooperation  
✓ Education through storytelling  
✓ Combination with enforcement measures  
✓ Education on the risk of getting struck by electricity |
| (Silla and Luoma, 2011) [83], (Federal Railroad Administration 2011) [84], (Waterson and Monk, 2014) [85], (Horton and Da Silva) [86], (Oh et al., 2022) [87], (Gao et al., 2021) [88], (Tang et al., 2023) [89], (Bashir et al., 2019) [90], (Zhao, 2021) [91], (Müller and Boos, 2002) [95], (Fayyaz and Johnson, 2020) [93], (John and Federal Railroad Administration, 2022) [94], (Zhang et al., 2018) [8], (Havârmeanu et al., 2017) [95], (Hallewell et al., 2022) [82], (Lin et al., 2022) [96] | Signalization, technological and technical measures for trespassing prevention | ✓ Landscaping  
✓ Prohibitive signs  
✓ Increase in visibility of train  
✓ Sound warning systems  
✓ Trespassing detection measures  
✓ Lightning measures (illumination measures) and other deterrent measures |
| (Barić et al., 2018) [97], (Haryono and Hidayat, 2022) [98], (Joshi and Shanker, 2016) [99], (Wullems et al., 2014) [100], (Li et al., 2021) [101], (John and Federal Railroad Administration, 2022) [94], (Zaman et al., 2019) [102], (Xue et al., 2022) [103], (Havârmeanu et al., 2016) [72], (Lobb et al., 2001) [8], (Lobb et al., 2003) [81], (Silla and Kallberg, 2017) [104], (Silla and Kallberg, 2016) [105], (Catalano et al., 2014) [106] | Pilot studies of railway trespassing preventive measures | ✓ Testing measures using surveys, cameras (e.g., specific locations, trains, etc.) and method of observation  
✓ Algorithms, AI, deep learning  
✓ Automated sound and warning systems  
✓ Comparison of the effectiveness of separate measures and combination of several measures  
✓ Installation of sensors |

5.2. Limitations and Critical Analysis of Findings

The searched and collected literature regarding trespass problems on railway tracks were separated to identify factors and preventive measures. In this way, the trespassing accident can be analysed for the factors that contributed to its occurrence. Based on one factor or several factors, preventive measures can be implemented. This is also the key process in building sustainable and safe rail transportation, because while rail accidents often result in tragic events, they also cause train schedule delays and depletions of resources that could be allocated in different sectors. Ideally, it would be optimal to identify universally recognised factors for each location and measures for trespassing on railway tracks, but this is a challenging task to solve. The problem of trespassing on railway tracks is very complex and requires a review of the whole trespassing area to fully understand it, starting
from the statistics and historical data, followed by the accident causes, consequences, and prevention measures. The problem with railway reports of trespassing accidents is that there is often a lack of detail regarding the accidents or the records are textually presented, from which it is difficult to extract data. This is particularly a problem for researchers trying to identify the factors that influence the occurrence of railway trespassing accidents and aiming to develop preventive measures. For example, reports [20] or [18] demonstrated a lack of detail regarding railway accidents. The better way to analyse the data is to link the factors and accidents in a coherent and logical way, as shown in [64], where the negative mixed effects binomial model was applied. For accident analysis, it is recommended to use accident analysis models and methods [107] rather than the simple collection of text and numerical records as many railway operators and agencies use for data collection; e.g., in Croatia.

The factors that contribute to railway trespassing accidents are difficult to define in general terms. Looking at the locations where trespassing accidents frequently occur, one can only assume that there are more such incidents in urban areas. Therefore, urbanisation is almost certainly the factor behind the increasing frequency of trespassing accidents. Researchers should use new tools to analyse the location near the railway line. This in turn can help define current critical sites or the possible formation of new sites in the future. One of these tools is certainly GIS, as shown in one study [48]. The key factor of time in the highest railway trespassing occurrence is highly problematic. Based on the information obtained from different studies, there is no clear timeframe. It may be at night, during the day, during rush hour, or during a special event that contributes to the high number of trespassing cases recorded. Therefore, the assumption is that the timeframe for each location of trespassing on railway tracks is different and, therefore, each location should be separately analysed. Different percentages of the time of day, month, and year were found in a number of studies [11,13,44]. Regarding those who trespass more often, the data and research confirmed that men generally trespass more often, although this is not certain, as shown by the study from the Czech Republic, where the ratio between men and women was almost equal [44]. This could be due to a specific time, day, or place. The problem with most studies is that the researcher did not include all age groups in the survey. To explain, it is possible that, on a specific day of observation, males trespass more than females and, on other days, this is not the case. That is why a long period of observation is needed, which in turn requires larger funds for study. Another factor that is a common feature of trespassing accidents is alcohol. This is a significant problem because people with alcohol in their blood often have impaired thinking skills, cannot react in time, and are more prone to injuring themselves and others [108]. However, the problem is that many studies presented in the review did not separate alcohol-intoxicated suicides and trespassing victims. Adults are often the ones who influence children’s behaviour. There is a need to change the general public opinion about trespassing on railway tracks, as adults often set a bad example. The best way would be to promote correct behaviour, but also to make it socially unacceptable for people to trespass. Changing public opinion is a difficult task in many cases. The best way to prevent these kinds of accidents is to prevent access to railway tracks (wherever it is not a legal level crossing). Good examples can be found in the literature review on effective measures to change public opinion [109]. People’s behaviour is often influenced by a lack of knowledge about the dangers and the legislation, but also by the lack of appropriate infrastructure. The problem with studies is that they are conducted on a small scale. There are many misconceptions in people’s minds and this is also directly related to education in schools. There is not enough research on trespassing on railway tracks in which researchers used the survey, and the different results indicate that the responses in the survey questionnaire varied from country to country and at each location. The train driver needs time to stop the train, and by the time the object or person is visible, it is often too late. Many people know that trespassing on tracks is illegal but persist in their belief: “It will not happen to me”. Again, it is very important to understand the factors for trespassing on railway tracks because every prevention measure is based
on these factors. If the factors are not properly identified, the impact of the measures can be reduced. Other factors that are often not taken into account are population density, the frequency of trains during the day, or the speed of trains, and these directly correlate with the severity of injuries and the risk of trespassing.

Any prevention measure must be based on the severity of accidents and how their effects can be minimised. Educational measures are often tested alone, but show promising results when targeted at younger populations (6 to 7, 8 to 11, or 11 to 15 years old) because children are more receptive to safety messages when they are younger, and they are more willing to learn. Messages should be realistic to elicit an emotional response from students, but also factually accurate so that they learn about rail safety. Younger children should be involved in focus groups, workshops, or role plays to make learning fun and not make them feel uncomfortable. Education is often a preventive measure better targeted at children, but adults can also benefit. The problem is that education measures are often tested in a short period, which in turn negates their effects over time. Pilot studies where education has been carried out have shown good results. The reduction in railway trespassing was higher than 10% in some cases, but the general problem with all studies is that the effect wears off over time [110]. The best way to increase effectiveness is to include safety messages in the school curriculum. Storytelling is also a good way to convey safety messages, although these should be age-appropriate. For example, the same stories cannot be used for children aged 6 to 7 years old and young people aged 16 to 25 years old.

Preventive measures such as signalization and technological and technical measures to prevent trespassing focus on preventing access and warning of the dangers. Fencing along railway tracks tends to significantly reduce trespassing, but is financially costly and requires maintenance. Landscaping had similar results, but cannot be implemented in every situation. Prohibited signs have been less effective and their effectiveness decreases over time. Technical measures on trains have the possibility to detect unauthorised persons or objects on the tracks. This raises the question of how the driver should react, especially if trespassing frequently occurs in some locations. For example, will the driver reduce the speed of the train and how will this affect rail traffic in general? However, it is good for the safety of rail traffic to introduce some kind of camera surveillance system (CCTV system) at level crossings or stations. Some of the measures for railway trespassing prevention require further research in the form of pilot studies to measure their effectiveness. The detection systems based on different algorithms can have a positive impact on the detection and better understanding of railway trespassing. The only problem is the implementation of using the new system, which may necessitate training staff. One study [6] found that the public should be informed about the implementation of new measures if the goal is the highest reduction of railway trespassing (only 40% of people noticed prohibitive signs). This can be achieved through the media, leaflets, billboards, etc. The previously mentioned educational measures work best when combined with other measures. If implemented alone, the educational measures lose effectiveness over time. Detection systems are best installed in trains, stations, and at level crossings.

6. Conclusions

The summary of the knowledge on railway trespassing consists of publications ranging from 1953 to 2023. The publications included in the review are 73.6% journal papers, 18.1% conference papers, and 8.3% expert reports. A high number of journal papers were chosen in the literature review because they possess consistency in terms of their scientific contributions when compared to other publications. In recent years, more studies have been conducted on this topic, however, there is still a need for further research. More focus is placed on railway suicides and it is often hard to distinguish between the two. The problem is that identifying trespassing factors is difficult because, in many cases, they are tied to a specific location. Therefore, the key is a detailed analysis of each location. The major problem in the process of extracting trespassing factors is the time of frequent occurrence of trespassing. More research is needed to provide an answer to this problem.
One possibility is that not all factors are included in one review and more can be identified through other methods of research (e.g., using software for data extraction, alternative methods for literature reviews, etc.). Trespassing preventive measures are often only tested in controlled environments and not in real-life situations as pilot studies, which in turn questions their effectiveness. The reasons for the former could be found in the possible insufficient funding or legislation that prevents the test of measures that are not defined by the law. There is a lack of research in the past five years on education measures in contrast signalization and technological and technical measures for trespassing prevention have received more attention (especially trespassing detection systems). The best evidence of the effectiveness of different trespassing measures comes from long-term pilot studies.

The limitations of the review should also be taken into account. First, the literature was exclusively searched for in the English language without considering the publications written in other languages. Second, in the process of literature collection, the keyword “trespassing” was always paired with other words, which in turn means the possibility that some publications were not included in the review. The categories of factors and trespassing preventive measures were formed by authors, possibly meaning bias in the decision process. Some studies that were included in the review did not focus on trespassing (e.g., in the category of educational measures) but were references for their possibility of implementation as such. The review also did not exclusively include safety campaigns, especially those that focused on the education of the general public or specific groups of people, but rather some were mentioned.

Research into the factors behind the occurrence of railway trespassing accidents is required and perhaps some factors should be universally recognised for specific locations. There is also a need for extensive work to research preventive measures. A combination of different measures could be beneficial and could also result in the development of previously unknown measures.

Future work should be focused on trespassing factors, especially human behaviour, and how to develop preventive measures to reduce high-risk behaviour. It would be useful to use different software tools to extract factors from collected data at different locations and from different statistical databases. Key attention should be given to behavioral measures with an emphasis on the promotion of sustainable transportation in the future, which is closely tied to safety. Testing of the current measures described in this paper and the development of new measures is preferred.

**Supplementary Materials:** The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su151813878/s1, Reference [111] is cited in the Supplementary Materials. Prisma 2020 Checklist as Supplementary.

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