



A METHODOLOGICAL FRAMEWORK FOR RAILWAY TRESPASS RISK ASSESSMENT AND PRIORITIZATION

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Abstract

The paper presents the conceptual development and the implementation of an engineering methodology designed to define a priority ranking for the mitigating actions along sections of a railway network affected by the trespass phenomenon, the unauthorized access of individuals to railway premises. The proposed approach integrates territorial, infrastructural, and behavioral datasets to identify the main contributing factors and quantify the intensity of trespass occurrences according to spatial and land use characteristics of the concerned areas. The methodological framework is conceptually derived from Ohm's law, where the potential difference represents the need for movement across the railway infrastructure, while resistance refers to natural or artificial barriers that hinder such movements. Thereafter, the model was refined through the adoption of a gravitational interaction approach, inspired by Newton's law, linking population density, point-of-interest attractiveness, and territorial impedance to the likelihood of unauthorized crossings. By integrating data from the database of physical infrastructures and additional parameters provided by the Infrastructure manager, 42 territorial and infrastructural featuring elements were identified and classified as points of attraction (V) or resistances (R). Each parameter was associated with specific extraction ranges, normalized units, and GIS-based computational procedures. The resulting indicators allow the classification of railway sections and locations according to their trespass risk level, supporting evidence-based planning of preventive and safety-oriented actions across the railway system.

Keywords: railway, safety, trespass, methodology, GIS

1 Introduction and problem position

Rail transport is governed by strict safety regulations aimed at preventing accidents and ensuring public safety. However, trespassing, i.e. unauthorized access to tracks or adjacent areas, represents a persistent criticality that impacts both human safety and rail traffic operations. The primary purpose of this study is to develop a scientific methodology to prioritize interventions on railway lines and stations, guiding targeted prevention strategies.

2 Trespass, correlated aspects and state-of-the-art

The first step of the research involved an extensive review of the state-of-the-art, classifying the literature into four macro-areas: railways, social services, safety and risk analysis. The review of the bibliographic sources [1-7] revealed key elements regarding unauthorized access to the railway network, and in particular:

- **motivations:** trespass is often used as a shortcut respect to authorized routes, normally perceived as too long, when they are over 300 m away, for recreational purposes, for illegal activities (graffiti, equipment theft, etc.), or simply as a consolidated habit
- **geographical contexts:** the most affected zones include areas adjacent to the stations, densely populated urban areas, areas with low socioeconomic status and areas where attractive services, such as schools, shopping centers, bus stops, etc., are located on opposite sides of the railway
- **related factors:** the lack of physical deterrence, such as fences and low risk awareness favor intrusions.

3 Identification of relevant factors and territorial analysis

The study cross-referenced international research with internal data from a national infrastructure manager, specifically analyzing investigations into dangerous events classified as unauthorized crossing and unauthorized presence. The study started from the analysis of 47 significant investigations. The accidents were located via mileage or descriptive elements using tools, such as Google Earth and Street View as a support to study the morphology of the territory and the characteristics of the infrastructure. Specific critical case studies were selected according to the frequency of the events in Lombardy and Tuscany regions, and various validation tests have been carried out in these areas. The territory along the railway was mapped by the Single Physical Infrastructure Model (Modello Unico Infrastruttura Fisica = MUIF) [8], a comprehensive, visual and georeferenced digital mapping system, developed by the Italian Infrastructure Manager. The MUIF provides standardized geo-topographic data with information organized into layers covering hydrography, orography, vegetation, buildings and infrastructure. Starting from a set of 166 MUIF classes, the study selected 68 input parameters (41 general and 27 specifics to the Infrastructure Manager (IM) assets), which were considered crucial to the study of the trespassing phenomenon, such as port service areas, buildings, sports facilities and noise barriers. The excluded parameters (territorial administrative information, geographical details, railways components of signaling, electrification, etc.), included in the MUIF due to its general-purpose use by the IM, have been considered as not influencing the study.

4 Methodology: physical analogy and spatial models

The heart of the study lies in the interpretation of the trespass as an interaction between factors that generate a need for movement and factors that counteract it. An initial understanding of the phenomenon is based on the transposition of the physical principle of Ohm's law to the railway context:

$$I = \frac{V}{R} \quad (1)$$

where:

- the intensity (I) represents the trespass phenomenon
- the voltage (V) represents the need for the movement, powered by the points of Interest located on the opposite side of the infrastructure (with respect to the point of origin of the movement)
- the resistance (R) represents the physical obstacle provided by natural or artificial barriers.

In this scheme, a movement is favored by a greater attractiveness of the destination and is hindered by disincentivizing factors, such as distance and physical barriers. All territorial parameters were therefore coded as V, when they favor movement, or R, when they hinder movement.

The next step involved the introduction of the human factor, evolving the methodology towards a Gravitational Model inspired by Newton’s law, where the flow of people between an origin (i) and a destination (j) is directly proportional to the mass (representing population and attractiveness) and inversely proportional to the distance (representing barriers). Indeed, attractiveness is not a unique characteristic of rail services, but extends to other factors such as buildings, which can serve as the destination for journeys across the railway or, more generally, generate the conditions for mobility. The attractiveness of an object or place could be determined by associating the function/intended use of the place itself with socio-demographic data wherever both these sets of information are available in the database. Differently, considering that the primary driver of the trespass is the individual, the attractiveness of the area or object was considered as a function of its size. The extension of the investigated network did not allow yet systematic on field investigations for checking and updating the information available in MUIF. Nevertheless, the information has been updated with the fresh information available on Google Maps e Street View, meanwhile on-site information will be collected for the test areas in the research steps.

5 Parameters, categories and pertinence bands

The analyses and assessments described in the previous paragraphs led to a reduction in the number of useful parameters from 68 to 42 (table 1), excluding those that could not be correctly identified in the area or have not been considered able to encourage or discourage the occurrence of a trespass.

Table 1 Methodological input parameters

N.	Parameter	N.	Parameter	N.	Parameter
1	Railway service area	15	Cultivated land	29	Level crossing
2	Port service area	16	Building	30	Railway platform canopy
3	Watercourse bed	17	Minor structure	31	Staging areas
4	Cycle path area	18	Partition element	32	Railway bridge
5	Pedestrian area	19	Railway buildings	33	Bridge, viaduct, overpass
6	Motor vehicle traffic area	20	Railway tunnel	34	Railway culvert
7	Excavation site or landfill	21	Watch boxes	35	Railway boundary fencing
8	Area under development	22	Artificial reservoir	36	Railway hydraulic drainage systems
9	Green area	23	Industrial structure	37	Railway underpass
10	Levee	24	Railway platform	38	Railway flyover
11	Sports facilities	25	Retaining wall	39	Open water surface
12	Railway noise barriers	26	Railway embankment wall	40	Secondary mixed-use road network
13	Forested area	27	Rockfall and avalanche protection barriers	41	Railway viaduct
14	Railway overpass	28	Pasture or uncultivated land	42	Railway track

In assigning parameters to categories V and R, we proceeded by considering those with typical features to be considered resistances, while others could assume a different role depending primarily on their location, therefore:

- typical resistances (R) are noise barriers, retaining walls, fences, natural barriers, such as waterways or impracticable terrain
- variable roles have parameters, such as the presence of commercial buildings, which can act as voltage (V) if located on the opposite side to the origin of the movement, or as resistances (R) if located on the same side, as they reduce the need to cross the tracks to satisfy a need.

Based on the urban planning concept of pedestrian travel radius (approximately 15 minutes' walk) [9], the following data extraction bands, parallel to the railway line, were defined for quantifying the parameters:

- 500 m band: for general Points of Interest (V)
- 60-75 m band: for parameters related to sparsely populated or abandoned areas (e.g., potential shelters or meeting places)
- 5-15 m band: for physical, natural or artificial, Resistances (R), which must be adjacent to the tracks to be effective in acting as an obstacle to crossing the railway.

All parameters were homogenized into a percentage unit of measurement (%), through the ratio between the length (or area) of the parameter and the length (or total area) of the reference section or location (in case of using the area to calculate its value, the width of the band was used as defined above). For surface parameters, the corresponding linear extension was often calculated by assimilating the object to a rectangle to allow for consistent use in formulas requiring the extension along to the railway line. Some parameters (tunnels, viaducts) were considered as unique whole objects within the section.

6 Definition of the calculation indicators

The process that led to the final ranking included three incremental stages, identified by 3 indicators:

- potential trespass intensity
- trespass index
- trespass reporting index.

6.1 Potential intensity of the trespass

The Potential Intensity of the Trespass represents the area's predisposition to generating the trespass phenomenon. It is calculated by adding the bidirectional movements contributions using the following formulas:

$$Int_{Potential\ Trespass} = \frac{\sum_j V_{(l-r)P_j}}{\sum_j R_{(l-r)P_j}} + \frac{\sum_j V_{(r-l)P_j}}{\sum_j R_{(r-l)P_j}} \quad (2)$$

Where:

- $\sum_j V_{(l-r)P_j}$ - is the summation of the attractive capacity of the parameters representative of the points of interest (V) favoring the movements across the railway
- $\sum_j R_{(l-r)P_j}$ - is the summation of the attitude of the parameters representative of the Resistance (R) to ban or reduce the movements across the railway
- $l - r$ - is the movement from left to right of the railway
- $r - l$ - is the movement from right to left of the railway.

6.2 Trespass indicator

The trespass indicator introduces the human factor by multiplying the potential intensity by the population of the area originating the movement, integrated with the passenger flows at stations and stops:

$$Ind_{Trespass} = \frac{\sum_i V_{(l-r)} P_i}{\sum_j R_{(l-r)} P_j} \times Pop_{lTr-Lo} + \frac{\sum_i V_{(r-l)} P_i}{\sum_j R_{(r-l)} P_j} \times Pop_{rTr-Lo} \quad (3)$$

Where Pop_{lTr-Lo} and Pop_{rTr-Lo} represent the population of the areas respectively located of left and right side of the railway infrastructure.

6.3 Trespass detection indicator

The trespass detection indicator is used for the ranking. It multiplies the Trespass Indicator by the trains' flow (F_{Train}) because the presence of the trains increases the probability that the Trespass is detected or cause an accident:

$$Ind_{Detection\ Trespass} = Ind_{Trespass} \times F_{Train} \quad (4)$$

For the calculation are used the matrices associating to each section the values of V and R, weighted from 0 to 1 according to their relevance. The flowchart in figure 1 synthetizes this logic flow, from the state-of-the-art analysis to the definition of the ranking.

7 Introduction of the half-section concept

Due to the heterogeneity of the sections' lengths (up to 52 km), the study introduces a half-section, approximately 1 km in length. This subdivision resulted in 19,878 half-sections from the initial 3,521 sections, significantly increasing the level of detail of the analysis.

8 Distribution of passengers and aggregated section indicator

To distribute passengers from/to stations and stops (Pax_{st}), the introduced logic is based on the distribution of specific parameters of the area, correlated with the presence of person attracted by the features of the area (railway assets, buildings, industrial facilities, etc.). Specifically, from left to right and vice versa, the share of passengers in the railway area, to be added to the population, was obtained by:

$$Pax_{st} = \frac{\sum_i A_{(l-st)}^i}{\sum_j A_{(tot-st)}^j} \times Pax_{tot-st} + \frac{\sum_i A_{(r-st)}^i}{\sum_j A_{(tot-st)}^j} \times Pax_{tot-st} \quad (5)$$

An aggregated section indicator is introduced to provide an overall measure of the entire section, calculated as a weighted average of the indicators of the individual half-section over the total length. The calibration of the model was carried out by selecting the weights associated with the different parameters, using artificial intelligence (ChatGPT integrated by Excel) and specifically with:

- rank-aware top-focus algorithm: implemented to optimize weights by comparing model results with actual delays caused by Trespass events (driving variable)

- sigmoid function: data normalized using a sigmoid function to increase sensitivity in critical areas
- hard exclusion: exclusion of 30% of the most discordant rows with respect to the ordering of delays caused by the occurrence of Trespass to improve the robustness
- discretization: final weights step wise into five levels (0.2, 0.4, 0.6, 0.8, 1.0) to facilitate the interpretation of the results.

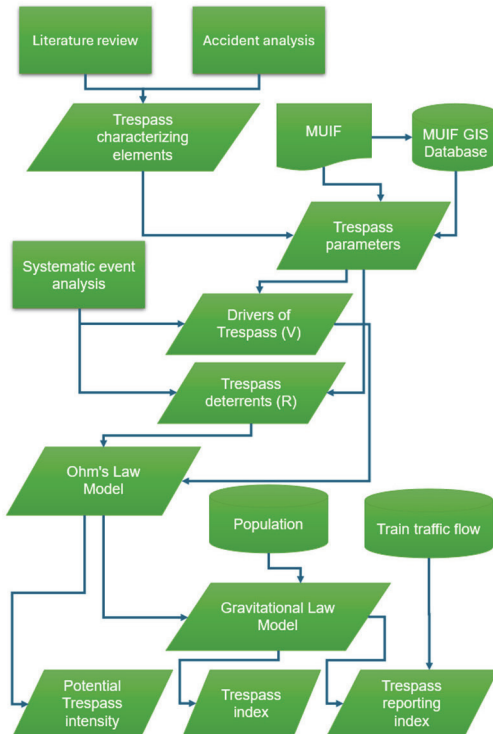


Figure 1 Flowchart of the stages for defining the indicators

9 Conclusion

The developed methodology transforms spatial data into a potential strategic decision-making tool. The integration of Ohm's law, gravity model and AI optimization allows at:

- identifying hotspots with 1-km level of detail
- evaluating the potential effectiveness of new physical barriers able to increase R
- adapting the model over time by refining geo-topographic data and capturing caused delays from real-world data.

The main result is the priority ranking, which allows the infrastructure manager to plan mitigation interventions, such as fencing, underpasses, overpasses, awareness campaigns, etc., efficiently and based on evidence. The next research developments will include also the collection of on-site information for the test areas. In this respect, the model is structured to be easily integrated by further relevant parameters, as well as updated by the additional information acquired remotely or on-site.

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