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Occupational Road Safety Management: A Preliminary Insight for a Landfill Remediation Site

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Abstract: Road crashes have been internationally recognized as one of the main causes of death. On one hand, in Europe, many governments are struggling with the ambitious target of zero road deaths by 2050. On the other hand, they are facing remediation of illegal waste dumps, subject to European infringement procedures and involving a lot of workers and heavy materials transportation. With the aim to further explore occupational health and safety (OHS) issues related to the remediation of such contaminated sites close to urban areas, we decided to focus our attention on road crashes involving people while working in the transport of materials and goods (i.e., occupational road safety). In the scientific literature, it is considered an emerging matter of concern, but no significant contribution nor specific procedures have been provided in this research field for workers in charge of contaminated sites. With the aim to fill such a gap, we decided to, first, investigate the impacts of a landfill remediation site (Malagrotta landfill, near Rome—Italy) on road safety in the surrounding context. Then, road safety management measures for workers driving heavy vehicles from and toward the reference site were suggested through the means of cluster analysis. The main road accident determinants (road safety signs and traffic conditions) for heavy vehicles in the Rome municipality, derived from a sample of 166 events, occurred in the period 2017–2021 on target road infrastructures for the case study. The events were finally grouped with a k-means three-centroid solution. Overall, despite the intrinsic limits related to the data's details, this paper provides a specific and data-driven methodology to address occupational road safety near a landfill remediation site and encourages further research in this field.

Keywords: occupational road safety; road accidents; landfill; remediation site; cluster analysis

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1. Introduction

The World Health Organization's (WHO) statistics point out that road accidents cause about 1.3 million people to die each year, with inevitable impacts on public health services [1]. In Europe, statistics on road accidents show a slight reduction in serious road injuries in recent years, but the goal of "Vision Zero" in 2050 is still far away [2]. Consequently, target 3.6 of the UN Agenda 2030 on road safety can be considered a milestone to reach sustainable development [3,4].

Among road safety issues, accidents involving people while working represent a matter of serious concern for transport companies [5,6]. The probability of workers being injured while driving vehicles is a risk that is likely to be higher in developing countries, where adequate infrastructures and safety training are still scarce [7]. Road safety involving workers is a complex problem that needs safety models to take into account road crashes [8]. However, this issue also needs to be addressed also in developed countries, where the use of emerging technologies in vehicles, as well as the sprawling of micro-mobility operators, have caused new challenges for road safety regarding the risk management model in a new dynamic society [9].

Over the years, several studies warned about the need to improve safety for drivers of heavy vehicles [10–12]. Moreover, some researchers demonstrated that construction sites, especially the ones located on roads, can be responsible for changes in territorial safety [13,14]. In fact, work zones or the high concentration of heavy vehicles can expose both workers and road users to accidents, thus requiring specific procedures for traffic management.

Furthermore, due to European infringement procedures, several EU Member States have also been struggling with the remediation of illegal waste dumps. Just to illustrate this concept, in Portugal, a research project was financed to evaluate risks caused by the construction and demolition of illegal waste dumping [15]. In Italy, a specific department was started in 2017 to carry out the remediation of 200 illegal landfills of urban/industrial solid waste [16]. According to the Italian legislative framework on construction site management [17], risk assessment should also include risks for the external context caused by the working site. However, the legislator has not provided specific methodologies to cope with such an issue and, above all, with road safety near a remediation site.

Hence, with the goal to fill such a gap, we decided to focus our attention on occupational road safety near a remediation landfill site. More in detail, we tried to develop a specific procedure aimed at the following:

- Evaluating impacts on road safety caused by the working processes in landfills at first;
- Identifying road accident determinants to further assess preventive measures for workers when driving heavy vehicles from and toward a landfill remediation site.

The remainder of the article is organized as follows. In the next section, a brief literature background on road safety assessment is provided. Sections 3 and 4 explain the research approach and the datasets used to reach the study's goals. Section 5 illustrates the results achieved, while Section 6 discusses the potential limits of the study. Finally, Section 7 concludes the paper and addresses further research in this field.

2. Literature Review

According to the Decade of Action 2021–2030 promoted by the United Nations [18], road safety needs to be addressed through a holistic approach. In fact, this will result from the interaction of several factors related to infrastructural conditions, the environment, users' behavior and vehicle safety [19]. In this section, a narrative focus on the main methods and datasets related to road safety assessment is provided.

2.1. Road Safety Assessment Methods

After some dangerous events that occurred in the 2000s regarding high-stakes infrastructure (e.g., fires in the tunnels of Mont-Blanc (1999), Gotthard (2001) and Frejus (2004)), Directive 2004/54/EC promoted the application of risk analysis as a supporting decision tool in Europe. However, Directive 2008/96/EC gave a greater impulse to promote road safety by identifying the following main phases for the trans-European road network [20,21]:

1. Road safety impact assessment: a comparative analysis of impacts of new roads/modifications on the safety of the entire road network in the preliminary planning step;
2. Road safety audit: a systematic safety check of the design features of road infrastructure;
3. Road infrastructure safety inspection: a random check of defects requiring maintenance due to safety reasons;
4. Network safety management: this is aimed at ranking road safety and identifying road lines with a high rate of accidents.

Recently, road safety management approaches have changed, which started when countries decided to guide themselves by setting quantitative targets for evaluating fatalities due to road crashes [22].

In such a legislative framework, specific procedures to carry out the abovementioned activities were not identified. Hence, the scientific literature that has been collected over the years contributes to such aspects.

As regards road safety assessment, many research contributions considered the implementation of risk analysis models to comply with the regulations imposed [23]. For example, Lombardi et al. [24] discussed the use of fault tree analysis (FTA) and event tree analysis to identify the hazard/damage chain of the starting event (of an accident). Other researchers focused their attention on the use of models aimed at addressing specific hazards in selected types of road infrastructures. Haddad et al. investigated the state of the art related to the critical ventilation velocity and back-layering conditions in tunnels in the case of fire [25]. Others [26] investigated the issues of risk analysis in railway transport.

It is worth mentioning the attention placed on emergency planning and resilience capacity of infrastructures in the scientific literature [27–29]. For example, Rasulo et al. provided a model to assess the seismic resilience of a road network and, above all, of road bridges, which are considered the most vulnerable element to earthquakes [30]. Rohr et al. addressed the development of a model that evaluates the systemic interrelations of emergency services (e.g., firefighting, rescue teams and ambulances) and their dependencies on road networks [31]. Kong et al. [32] analyzed the multihazard and the consequent effect on infrastructure resilience: the resilience of the infrastructural system relative to two events, in fact, is lower than its resilience relating to a single one and also change regarding the speed for the repair of the infrastructure.

Data mining techniques recently addressed road safety with cutting-edge approaches. According to Raval et al., data mining is aimed at extracting new patterns and correlations from huge amounts of data [33]. Moreover, it shows great flexibility: in fact, it includes machine learning, artificial neural networks, etc., thus addressing several kinds of data. This is the reason why such techniques were recently used in many research topics (e.g., accidents at work [34] and environmental issues [35]).

Regarding road safety, some applications are related to the classification of national big data, open access local data and data collected by GPS sensors installed on vehicles. Such applications are aimed at identifying hazardous situations related to the use of selected infrastructures/vehicles in order to promote preventive measures for territorial road safety. Our work can be included in this research field. Consequently, the next paragraph is aimed at providing a focus on road accident databases.

2.2. Databases for Road Accident Analysis

At an international level, researchers agree on considering road accident databases powered by national road authorities as the most reliable sources of data on road accidents [36]. In fact, such data are collected from different raw sources (e.g., police, local administration and surveys of law enforcement) and show details that are useful for research purposes at a national level [37,38].

However, as reported by Chand et al. [39], interesting results were also yielded from other data sources. They include open access datasets [40], technology installed on road infrastructures and GPS sensors installed on vehicles for safety purposes [41,42].

Furthermore, some researchers could argue that another valuable source of data is social media (e.g., Facebook and Twitter). In recent years, opinion-mining techniques, i.e., the ability to extract significant correlations from textual information, allowed for risk perception assessment in several fields (e.g., cultural heritage [43], customer satisfaction [44] and industrial safety [45]). Dai et al. developed a research work concerning road safety in the state of Washington, starting from the analysis of tweets posted between March 2015 and February 2019 [46].

In Table 1, a summary of the main features of road accident databases is reported.

Table 1. Main road accident datasets.

Data Sources	Main Features
Databases with restricted access [37,38,47]	Organized according to several formats (e.g., CSV and geographic readable formats) and they take into account different sources of data on road accidents (e.g., police reports, municipal data and road operators data). Events are described through synthetic variables in order to be comparable at a national level and due to privacy reasons.
Open access data [40,48]	They are released according to the provisions of Directive 2019/1024/EU (Open data directive). They can be organized according to comma-separated values (CSV) and/or vector geographic formats. They include variables identified by short text or numbers. The number of variables can change according to local administrative needs. Details depend on the amount of information included in the initial source (e.g., police reports) and administrative borders.
On-board technology [41,42]	Technology installed on new vehicles to provide their localization. Data are sent to a control room to give assistance in case of an emergency.
Infrastructure technology [49]	Radar, cameras, unmanned aerial vehicles, etc., that provide real-time information on traffic and potential causes of road crashes. Resolution can be decided by the infrastructure's operator according to several factors (e.g., common users, average speed and infrastructures conditions)
Social media and newspapers [46]	Information is reported in short texts on social media and may include the author's personal point of view. Through opinion mining techniques (e.g., natural language process), data from both social media and newspapers are further elaborated to perform risk perception assessments. Analyses are consistently dependent on language knowledge.

At a European level, the Council Decision of 30th November 1993, n.704 (further modified by Regulation 2003/1882/EU) introduced a Community Database on Road Accidents (so-called CARE) resulting in death or injury (i.e., crashes *"between road users involving at least one vehicle in motion on a public highway normally open to traffic and causing the death of and/or injury to one or more of the road users"*). However, this decision let Member States decide their own collection standard. The European Commission has further recommended the Common Accident Dataset Standard (CADaS) since 2011, which includes 73 variables and 471 values. However, the implementation of a unique standard is currently not mandatory in European countries [50].

In most cases, Italian datasets on road accidents are organized to collect the information reported in Table 2. More factors can be evaluated by local authorities according to specific territorial conditions.

Table 2. Main information on road accidents in Italian datasets.

Accident Categories	Accident Factors
General information	Accident code (AC), number of people and vehicles that crashed
People injured	Name and surname, sex, age, driving license, working condition (at work/while commuting)
Time and place	Province, location, geographical coordinates, hour, year
Consequences	Death, fractures, hospital conclusions
Road infrastructure	Road code (RC), pavement, weather, road safety signs, point km
Vehicles	Type(s) of vehicles, power

3. Research Approach

The research approach included two main phases:

1. The impact assessment of a landfill remediation site on territorial road safety by considering the general principles stated for the Environmental Health Impact Assessment for civil and industrial engineering works;
2. The identification of road safety management measures for workers driving heavy vehicles from and toward the landfill site after establishing the main road accident determinants in the study area.

The first phase required the following:

(a) The selection of a relevant case study by taking into account some criteria: (a) the availability of reliable information on the case study, (b) the short distance of the landfill site from a metropolitan area and (c) the presence of large waste volumes;
(b) The Job Hazard Assessment [51] for territorial road safety, starting from the analysis of the information available for the case study;
(c) The identification of target road infrastructures through the definition of a buffer zone (according to the distance from the nearest highway) and the road classification, in compliance with the Italian Road Act [52];
(d) The identification of the site's impacts on road safety according to the distance from the remediation site.

During the second phase, the main accident determinants were identified through the means of cluster analysis. The clustering criteria are described in the next subsection.

Safety measures were further suggested, according to the hierarchy of controls stated in ISO 45001 [53]. Figure 1 summarizes the entire research approach.

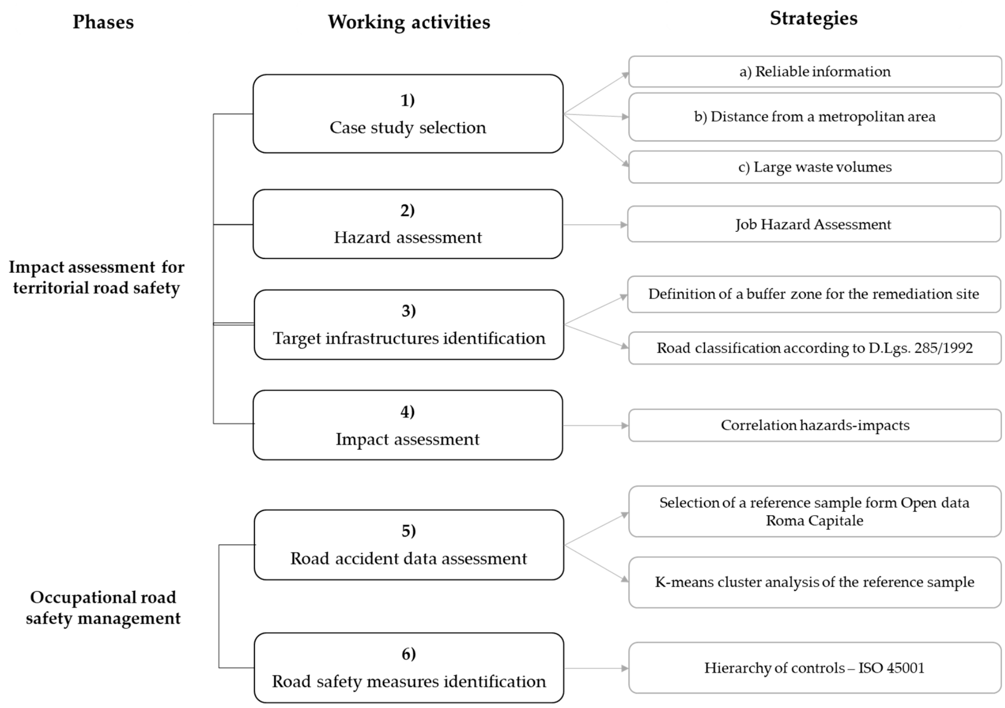

Figure 1. Research approach.

Cluster Analysis

Cluster analysis is aimed at grouping data with similar features according to certain variables. It first requires the selection of a reference sample of data (according to the study's purposes). Then, data need to be organized in order to apply statistical techniques. Finally, the algorithm is applied to the grouped data to extract new patterns [54].

For the study's purposes, cluster analysis was applied to a reference sample of 166 events. The selection of events was performed in October 2022 using Roma Capitale Open Data. More in detail, such a process consisted of the selection of road accidents that met the following conditions:

1. Occurred in the last 5 years to obtain a recent "picture" of road safety. For this reason, we decided to consider the period 2017–2021.
2. Occurred on the target infrastructures identified in step 3 and registered in Roma Capitale Open Data.
3. Involved heavy vehicles that were likely moving from or toward a remediation site (see Table A1).
4. Involved marching/under arrest heavy vehicles (see Table A1).

5. Involved people driving a heavy vehicle.

Records without information on the conditions of the road pavement, safety signs, traffic and visibility were eliminated. Furthermore, duplicates of the same event (i.e., the descriptions of the same event from different points of view) were elaborated to consider each event once in the reference sample (with a unique ID).

Cluster analysis was performed through the preliminary organization of the reference sample according to the model of the "matrix of descriptors". As explained by Lombardi et al. [55], it allows for transforming categorical variables into algebraic vectors, which can be easily elaborated using statistical techniques. More in detail, the matrix of descriptors reported the influence (presence/absence) of selected determinants in the events through Boolean coefficients according to the following general rule: 0 stood for the absence of the determinant, while 1 indicated the presence of the determinant. During this phase, 96 events were excluded from further analysis due to the high uncertainty in establishing the influence of accident determinants. Determinants were assumed as clustering variables and defined according to the initial structure of the road accident dataset and the study's goal (i.e., to evaluate site-specific measures for occupational road safety).

Data clustering was performed on the matrix of descriptors, through the means of a k-means analysis [56]. The initial number of clusters k was assumed to be equal to the number of variables. After a random selection of initial centroids, data clustering was carried out according to the minimum Euclidean distance from centroids.

The final results were further assessed through the analysis of variance (ANOVA) tests [57] to decide whether the initial number k should be reduced. Figure 2 summarizes the iterative approach of k-means clustering.

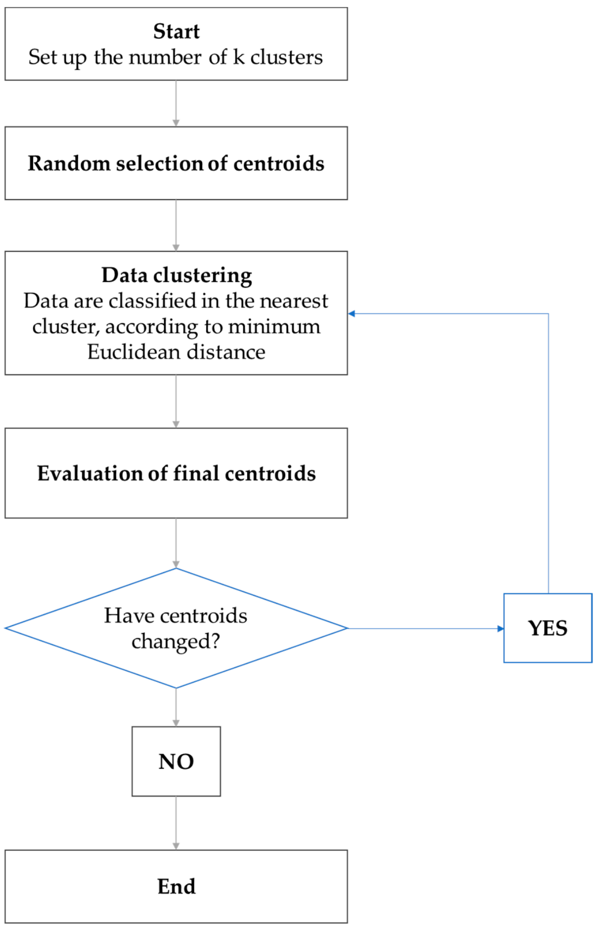

Figure 2. The k-means clustering flow chart.

Elaborations were carried out through the software IBM SPSS Statistics vers. 28, which is recognized as a valuable tool among academics [58,59]. In Table 3, the criteria for the cluster analysis are reported.

Table 3. Criteria for the cluster analysis of road accidents.

Algorithm	k-Means (Centroid Method)
Distance criterion	Minimum Euclidean distance from centroids
Significance of results	Performed through ANOVA test
Cluster variables (descriptors)	Categorical variables D1: road pavement, D2: visibility, D3: traffic conditions, D4: safety signs

4. Data Collection

The study was developed starting from the analysis of Italian open access datasets. First, the case study (Malagrotta landfill) was selected from the database powered by the Italian Extraordinary Commissioner for the Remediation of Landfills. Second, road accidents that occurred in the Rome municipality were extracted from the database powered by Roma Capitale. Figure 3 summarizes the data collection process.

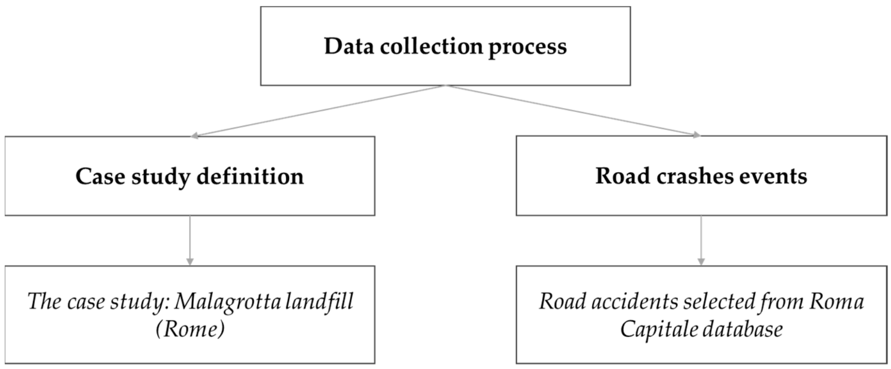

Figure 3. Data collection flow chart.

4.1. The Case Study: Malagrotta Landfill (Rome)

Malagrotta is a small industrial area located in the west of the Rome municipality (Italy). Oil refineries, medical waste incinerators, concrete production plants and tar factories are common in the area, as well as intensive agriculture. Malagrotta is very close to the urban area of Rome: in fact, it is about 3 km away from the big circular highway surrounding the capital of Italy (the so-called Grande Raccordo Anulare or G.R.A.).

The area has recently overgrown in popularity due to the presence of the largest European landfill, with serious impacts on both the environment and public health [60,61]. For this reason, the landfill was included in an EU pilot procedure and, consequently, in the province of the Italian Extraordinary Commissioner. Like other illegal waste dumps, information on the Malagrotta landfill is available in Italian on the website powered by the Office of the Extraordinary Commissioner. More in detail, data are organized into three modules related to (1) the environmental features of the site, (2) the territorial framework and (3) the administrative procedures carried out to remediate the site.

The landfill was created in an ancient cave in the 1970s. It is located in a hilly area, with a maximum height of 65–70 m a.s.l. (meters above sea level). The landfill has an area of about 160 ha.

An annual average of 1.3 million tons of municipal solid waste coming from the metropolitan area of Rome have been driven to such a landfill. However, the lack of adequate management has caused a significant need to remediate the site quickly in order to reduce penalties paid by the Italian government to the European Commission. According to information provided by [16], the landfill is going to be the subject of permanent safety works.

Figure 4 reports an aerial view of the site, which was obtained from Google Earth [62].

Figure 4. Map showing the location of the Malagrotta landfill (red box). Source: Google Earth (reference date: 14 May 2013–15 June 2013). Main road infrastructure: Aurelia Road (E80) and G.R.A. (A90).

4.2. Road Accidents Selected from the Roma Capitale Database

Roma Capitale has curated a large collection of open access data since 2016. Data have been released under the CC-BY 4.0 user license and concern 11 main topics, such as mobility and transport, urban safety, sport, land and culture [63].

Road accident data are included in the "Mobility and transport" category and result from the elaboration of raw information that comes from several departments of the Rome municipality (e.g., local police and communications office). All events included in such a dataset occurred on road infrastructure in the municipality of Rome and required the presence of a municipal police team.

Data are available in the comma-separated values (CSV) format, showing information for 37 variables. Applications of data mining techniques to such a database were found in the scientific literature [64]. Each tabular record reports a synthetic description of the event from a specific point of view (e.g., pedestrian, driver of a heavy vehicle and motorcyclist). Therefore, the same event can appear in the database several times, according to the number of people involved and, above all, they are available to declare something concerning the event in the police report.

Data are reported as brief texts/numbers: for example, the road names and conditions are textual features, as well as data about the people injured and vehicles. Personal data (e.g., name, surname, job, home address) are not included to respect European privacy provisions. By contrast, the date and hour or geographic coordinates are number features. All textual features are in Italian.

5. Results

5.1. Impacts of the Landfill Site on Road Safety

Starting from the information about the Malagrotta landfill and the analysis of the scientific literature concerning contaminated sites, we identified the main hazards for territorial road safety for each working process (Table 4). Then, we established a buffer zone of approximately 3 km, equal to the distance of the landfill to the nearest highway (G.R.A.). In this area, we identified the main target roads (Table 5) and classified the potential impacts on road safety (Table 6) according to the distance.

Table 4. Hazards assessment for road safety.

Working Process	Main Hazards for Road Safety
Cleaning up	Heavy vehicles, dust, noise
Installation of a plastic barrier around the landfill body	Dust, noise, vibrations
Development of protection systems to collect and treat leachate and landfill gas	Dust, noise, vibrations
Capping installation	Heavy vehicles

Table 5. Target road identification.

Target Roads	Main Features (D. Lgs. 285/92)
Grande Raccordo Anulare (G.R.A.)	Highway with two carriageways and 3 lines for each direction. The speed limit is established at 110 km/h. Transit is not allowed for motorcycles with a power < 250 kWh.
Via Aurelia	Extra-urban road with two lines for each direction. The speed limit is about 90 km/h until G.R.A. Then, the speed limit is reduced to 50 km/h due to the urban context.
Via del Casale Lumbroso Via di Malagrotta Via di Ponte Galeria Via Portuense	Urban road with one carriageway and one line for each direction. The speed limit is established at 50 km/h.

Table 6. Impacts on road safety.

Hazards For Road Safety	Impacts on Road Safety *
Heavy vehicles	LD, MD; SD
Dust	MD; SD
Noise	SD
Vibrations	SD

* Legend: LD—long distance (>1000 m), MD—medium distance (300–1000 m), SD—short distance (100–200 m).

Then, we decided to focus our attention on the hazard "heavy vehicles" that caused impacts for long distances. The next subsection explains the results that were achieved through a cluster analysis of road accidents that involved heavy vehicles on the target roads (except for G.R.A.) to evaluate potential safety measures for workers driving such vehicles.

5.2. Road Accident Determinants for Heavy Vehicles

Screening of road accidents through the criteria reported in Table A1 allowed for identifying 289 tabular records. The exclusion of records without information on the conditions of road pavement, safety signs, traffic and visibility led to identifying 282 records. Then, duplicate removal allowed us to consider 262 events that occurred on the target infrastructures included in Table A1 in the period 2017–2021. Finally, the evaluation of the road accident determinants (through the matrix of descriptors) led to considering a reference sample of 166 events (in 96 event determinants were not associated with sufficient precision). In Figure 5, the data filtering scheme is reported.

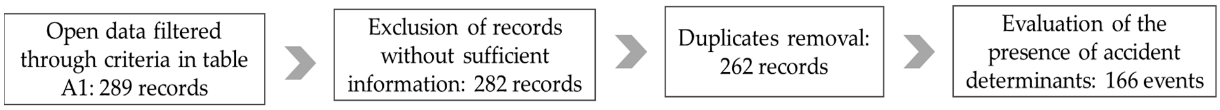

Figure 5. Data-filtering scheme.

The 166 events were organized through the "matrix of descriptors" (see Supplementary Materials, Table S1). Such a matrix represented the input of the k-means cluster analysis. Table 7 reports the descriptive statistics that were found for the matrix of descriptors.

Table 7. Descriptive statistics for the reference sample.

	Descriptive Statistics					
Descriptors	**Minimum**	**Maximum**	**Average Value**	**Error on A.V.**	**St. Dev.**	**Error on St. Dev**
D1	0	1	0.230	0.033	0.421	0.178
D2	0	1	0.170	0.030	0.381	0.145
D3	0	1	0.490	0.039	0.501	0.251
D4	0	1	0.310	0.036	0.465	0.216

Valid events = 166, missing values = 0.

The initial number of groups was set equal to four (i.e., the number of descriptors). The software provided the distribution of events in four clusters after two iterations. Then, we evaluated the determinants' frequencies in each cluster. The solution with four centroids is reported in Table 8 (red coefficients highlight the most relevant variables in each cluster). Further details (e.g., initial and final centroids are included in Supplementary File S2.

Table 8. The k-means clustering solution with 4 centroids.

Descriptors	**Frequencies in Clusters** 1 $N_1 = 40$	2 $N_2 = 74$	3 $N_3 = 4$	4 $N_4 = 48$
D1	0.800	0.000	1.000	0.042
D2	0.600	0.014	0.000	0.083
D3	0.000	1.000	1.000	0.083
D4	0.075	0.000	0.250	1.000

Red coefficients highlight the most relevant variables in each cluster.

By contrast, Table 9 shows the solution with three centroids (further details are available in Supplementary File S3). In Figures 6 and 7, we assessed the results through the means of a radar diagram.

Table 9. The k-means clustering solution with 3 centroids.

Descriptors	**Frequencies in Clusters** 1 $N_1 = 40$	2 $N_2 = 49$	3 $N_3 = 77$
D1	0.800	0.061	0.039
D2	0.600	0.082	0.013
D3	0.000	0.102	1.000
D4	0.075	1.000	0.000

Red coefficients highlight the most relevant variables in each cluster.

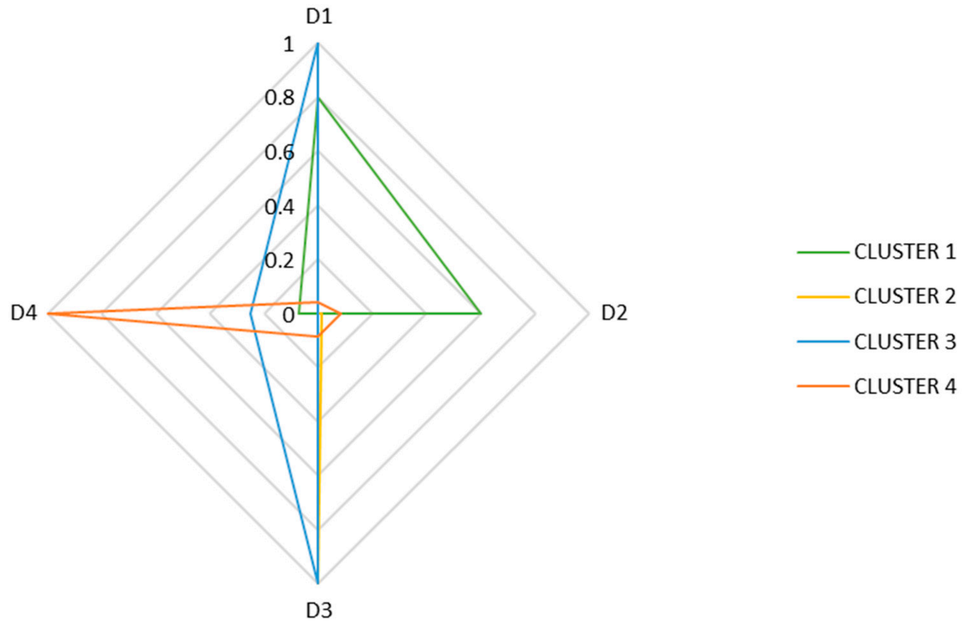

Figure 6. The k-means clustering solution with 4 centroids.

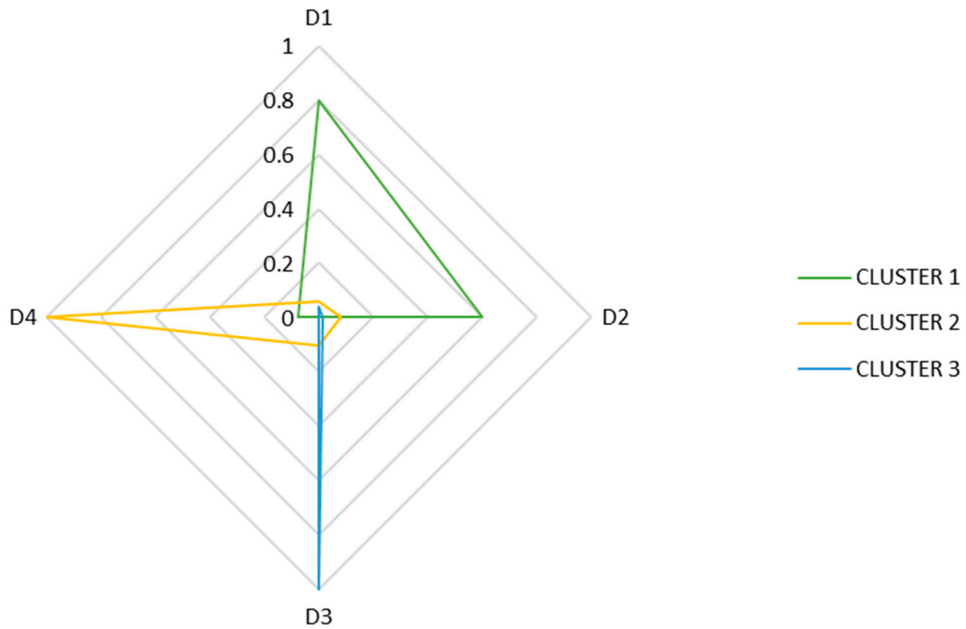

Figure 7. The k-means clustering solution with 3 centroids.

Finally, Tables 10 and 11 report the results of the ANOVA analysis used to evaluate the determinants' effects on the clusters.

Table 10. ANOVA table for the k-means clustering solution with 4 centroids.

	Cluster Mean Square	df	Error Mean Square	df	F	Sign.
D1	6.995	3	0.051	162	136.252	<0.001
D2	3.227	3	0.088	162	36.676	<0.001
D3	12.609	3	0.023	162	557.093	<0.001
D4	10.729	3	0.022	162	493.060	<0.001

Table 11. ANOVA table for the k-means clustering solution with 3 centroids.

	Cluster Mean Square	df	Error Mean Square	df	F	Sign.
D1	8.601	2	0.074	163	115.868	<0.001
D2	4.837	2	0.087	163	55.284	<0.001
D3	18.502	2	0.028	163	671.710	<0.001
D4	16.468	2	0.017	163	967.305	<0.001

5.3. Occupational Road Safety Management

Overall, the cluster analysis of road crashes allowed us to suggest some measures for occupational road safety of workers driving heavy vehicles from and toward the Malagrotta landfill. According to the hierarchy of controls stated in ISO 45001 [53], we highlight the need to implement both organizational and engineering controls. More in detail, we recognized the importance of the following:

- To avoid falling materials from heavy vehicles by using textiles to cover materials;
- To provide heavy vehicles with AI-based devices to help workers to recognize safety signs and road pavement conditions while driving;
- To organize a suitable timetable to avoid high rates of stress to drivers;
- To train workers in order to avoid dangerous driving behaviors (e.g., drink-driving and use of drugs) and negative consequences in the case of an accident;
- To establish a management control room at the remediation site to provide workers with immediate help in the case of an accident.

6. Discussion

As reported in IBM SPSS documentation [58], data clustering was evaluated using an ANOVA table, including univariate F tests for each clustering variable. In such a tool, the F tests are descriptive and can only allow for establishing whether the final clusters are well separated. Hence, the resulting probabilities should not be interpreted [65]. Using the ANOVA table, we observed that the F-statistic increased with the three-centroid solution. Thus, it allowed us to provide evidence that the three-centroid solution produced clusters that were more disjointed than the four-centroid one.

Moreover, looking at the radar diagrams, we could argue that in the solution with four centroids, the clusters were partially disjointed and only clusters 2 and 4 were relevant for discussing risk management. In fact, cluster 3 cannot be considered due to the limited number of events ($N_3 = 4$), while cluster 1 was not polarized on a specific determinant.

By contrast, k-means clustering with three centroids provided significant results for risk management. As is also shown in Figure 7, the clusters are well-balanced and disjointed. More in detail, clusters 2 and 3 were influenced by determinants D4 (safety signs) and D3 (traffic conditions), respectively, while cluster 1 showed the same results obtained in the previous configuration. The solution with three centroids was likely to have grouped better events that were previously divided among clusters 2, 3 and 4.

The influence of determinants D3 and D4 on road crashes (highlighted by the radar diagram) was confirmed by the values of the mean squares reported in Table 11.

The achieved results can be considered consistent with other research outputs related to road safety. In fact, traffic and safety sign conditions were already identified as potential determinants of accidents, especially in road construction site management [13,14,47]. At a more general level, this study confirmed the crucial role of the crash factors' identification to establish specific road safety measures [66].

Finally, this study relied on the matrix of descriptors [55,67], which allowed for transforming descriptive information on road accidents (derived from open data powered by public administration) into frequency data. Hence, a data-driven approach based on statistical techniques was shown to be able to manage risks in this specific field.

Limitations of the Study

However, this study had some limits, which were related to the organization of the open data considered here. First of all, the study considered CSV data that featured short descriptions, which were not always detailed and systematically organized (for example, according to a Likert scale). Just to illustrate this concept, the conditions of road safety signs could be described as “lack of horizontal signs”, “presence of both vertical and horizontal signs”, “horizontal signs”, etc., according to the professional background of the policemen involved in collecting the on-site data. Consequently, a systematic revision of data collection models could be undertaken to help researchers reach more precise results in such a field. More in detail, data on road accidents should satisfy more and more FAIR (findable, accessible, interoperable and reusable) principles [68]. This would be in compliance with some other research works that considered the FAIRness of synthetic healthcare data [69] and the strategic European view on research data [70].

Moreover, we could not include road accidents that occurred in the nearest part of G.R.A. Actually, road accidents on urban highways are not managed by Roma Capitale offices, but rather by different Italian authorities. Therefore, the integration of some databases could improve our results, especially in urban/suburban contexts.

Finally, our elaborations did not take into account road accidents influenced by the use of drugs, alcohol and mobile phones while driving. According to WHO, drink-driving causes 27% of global road accidents, while at least 15.6% of fatal accidents in Europe were related to the use of drugs [71,72]. Hence, including information on drink-driving or drug-using in accident reports could allow for performing more precise risk assessments.

7. Conclusions

According to the Agenda ONU 2030, safe cities are included in target 11.2 to achieve sustainable development of our planet. Among the conditions of a “safe city” [73], road safety and the quality of transport infrastructures play a crucial role.

In our study, we aimed to address occupational road safety for a landfill site. In the scientific literature, while several studies were developed to improve the safety conditions of road infrastructures through the use of different datasets, few researchers investigated the risks for workers involved in the transport sector. Moreover, even though several countries have been struggling with the remediation of illegal landfills, the lack of an integrated view of occupational road safety was identified, especially in the case of contaminated areas close to cities. Hence, a site-specific and data-driven methodology was developed, starting from the analysis of open data related to a case study (Malagrotta landfill) and road accidents that occurred in the surrounding context and collected in the open access database powered by Roma Capitale.

Overall, this contribution can be considered an operational tool for safety managers involved in the remediation of landfills to better address/limit occupational road accidents.

However, as pinpointed in the Discussion section, such results represent the output of a qualitative risk approach, which is essentially based on the availability of national datasets. Accordingly, the results were influenced by the current organizational data models.

Hence, further research is needed in this field through the analysis of different databases to reach more precise risk profiling and broaden the know-how from a quantitative perspective of risk analysis.

Supplementary Materials: The following supporting information can be downloaded from https://www.mdpi.com/article/10.3390/buildings13051238/s1: Table S1: Matrix of descriptors for road accidents (derived from Roma Capitale Open Data); Supplementary File S2: The k-means clustering solution with 4 centroids; Supplementary File S3: The k-means clustering solution with 3 centroids.

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Appendix A

Table A1 includes the codes used to screen the Roma Capitale Open Data.

Table A1. Variables and texts used as data filters (Roma Capitale Open Data).

(1) Vehicle	(2) Road 1	(3) Conditions of the Vehicle	(4) Person
Truck (<35q) Truck (>35q) Trailer truck motorway Operating machine Track	Via Aurelia Via del Casale Lumbroso Via di Malagrotta Via di Ponte Galeria Via Portuense	Marching, under arrest	Driver

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