Analysis Of Work-Related Accidents In Italian Landfills

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Abstract

Despite the international efforts to promote the circular economy and waste recycling, landfilling is still a common practice for waste disposal around the world, with considerable impacts on the environment and public health. However, while such a sector was addressed in many countries through a consistent environmental legislative framework, safety management for workers in landfills has not been sufficiently considered by policymakers. Moreover, in the scientific literature OHS issues related to landfill management were not deeply addressed through the elaboration of specific procedures.
Hence, with the goal to evaluate the existence of specific risk profiles in such working contexts, the paper provides a contribution through a data-driven approach. In fact, the study contains a detailed investigation of the biggest Italian occupational accident database (powered by INAIL) with reference to the landfill management sector, according to a methodology specifically designed to employ the European Statistics on Accidents at Work (ESAW) codes as data filters. After selecting a sample of n.78 accidents, likely to have occurred in Italian landfills in the period 2008/2019, accidents' dynamics were assessed for each event with reference to the use of work equipment. The results achieved allowed us to bring to light the potential risks related to this determinant. Thus, potential risk management measures were defined in order to improve the safety management of work equipment in this specific context.

Keywords
Accident analysis; work-related injuries; ESAW; Data mining; Landfill risks.

1. Introduction

In March 2020 European Commission adopted the new Circular Economy Action Plan (CEAP), with the aim to prevent waste production (European Commission, 2020). This plan has been promoted according to the sustainable development goal 12.5 stated by UN Agenda 2030, addressing waste prevention and recycling (United Nations 2015). But, in the meanwhile, in many European and high-income countries of the world waste landfilling still remains an important disposal practice, both for Municipal Solid Waste (MSW) and industrial waste, as shown in figure 1. The same could be argued with reference to low-income countries, where open dumpsites and uncontrolled landfills are a matter of serious concern, especially for industrial waste (Kaza *et al*. 2018; Ferronato and Torretta 2019).
As reported by (Limoli et al. 2019), landfills are responsible for the emission of hazardous gases, dust and leachate in the environment, due to waste bio-chemical degradation. Such emissions were accounted in literature to cause serious impacts on environment and public health (Mazza *et al.* 2015; Triassi *et al.* 2015; Njoku *et al*. 2019; Vaverková, 2019; Fazzo *et al.* 2020). Hence, during the years a consistent legislative framework has been developed to avoid/limit waste impacts on environment and public health due to landfilling operations (Lombardi et al. 2021). Just to make some examples, in 1976 in the U.S.A the Resource Conservation and Recovery Act provided criminal punishment for bad waste disposal. In Europe, Directive 1999/31/CE (updated in 2018) addressed disparities in technical standards for landfills construction and management, providing common project and monitoring features. Moreover, in the

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framework of UN-Habitat Programme, a requirement list for landfills has been recently released to make such facilities better accomplishing SDGs of Agenda 2030 (RCR Act, 1976; European Commission, 1999; UN-Habitat, 2018; Idowu *et al.*, 2019).

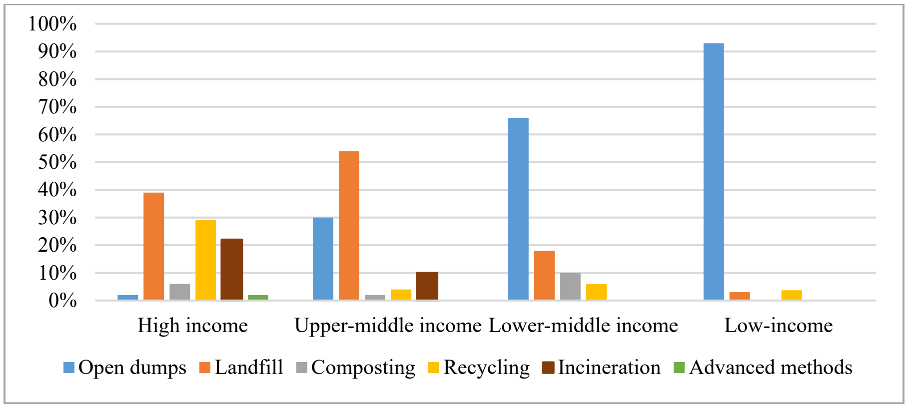

Figure 1. Waste disposal practices around the world (elaboration on World Bank data, 2018)

However, safety management for workers involved in waste disposal through landfills has not been sufficiently addressed by decision policy makers. Actually, European safety legislative framework includes general provisions on risk assessment and management, without providing detailed procedures for each productive sector. Moreover, in developing countries the lack of specific safety requirements in this sector is a matter of urgency workers, as demonstrated by scientific literature on waste pickers (Patwary *et al*. 2011; Al-Khatib *et al*. 2020).

So, the goal of this article is to evaluate the existence of specific risk profiles for safety management in landfills through a data-driven approach. Following the idea that work accidents are not only "holes" in the safety management system (Reason 2000), but also an opportunity to improve safety climate of workplaces (ISO 2018), a study on work accidents occurred in the period 2008-2019 in such sector was developed from INAIL database.
The remainder of the article is organized in the following way: in Section 2 there is a brief literature review on work-related injuries data analysis; in Section 3, data collection and structure are illustrated; Section 4 provides details on the research methodology, specifically designed for this study, while Section 5 discusses the achieved results and the study's limitations. Finally, Section 6 concludes the paper, highlighting the way for further research works.

2. Literature background

The scientific interest in accident at work data analysis is far to be recent. Some psychologists have tried to investigate dynamics of single events since 1900, to understand how human behavior influenced accident effects (injury or death). However, a modern concept of work-related injury analysis, based on the evaluation of accident causes, began in 2000s. In fact, through the elaboration of decisional models and, lately, systemic models, work accidents have been studied considering the interaction of several factors in the final event (Reason 2000), as well as the energy exchange from machinery/environment to human body (Campo et al. 2006). However, the approach to accidents analysis has changed recently, thanks to data mining techniques. Moreover, it has to be noted that most working accidents in different fields are related to the use of work equipment and machinery (Fargnoli 2021; Fargnoli *et al*. 2018).
According to (Larose 2005),*"data mining is the process of discovering meaningful new correlations, patterns and trends by sifting through large amounts of data stored in repositories, using pattern recognition technologies as well as statistical and mathematical techniques"*. Thanks to data mining and the revision of accident classification systems, in many countries accident analysis has turned from single event analysis to the contemporary assessment of several data, in order to identify general risk profiles for each productive sector and suitable mitigation measures. In figure 2, an overview of accident data models is provided.
In the scientific literature, the implementation of data mining techniques for occupational accident prevention is mainly related to performing the following tasks:

- clustering of similar events;
- identification of typical risky dynamics in specific workplaces, derived from the identified clusters.

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In fact, starting from risky dynamics you are able to identify risk causes, which can be assessed and further prevented or mitigated, to avoid new accidents at work (Lindberg *et al.* 2010; ISO 2018). The opportunity of studying accident consequences is generally excluded in safety management, as the same consequence may be the result of several occupational risks (for example, an injured leg could be related to risk of falling from the height as well as risk of falling materials).

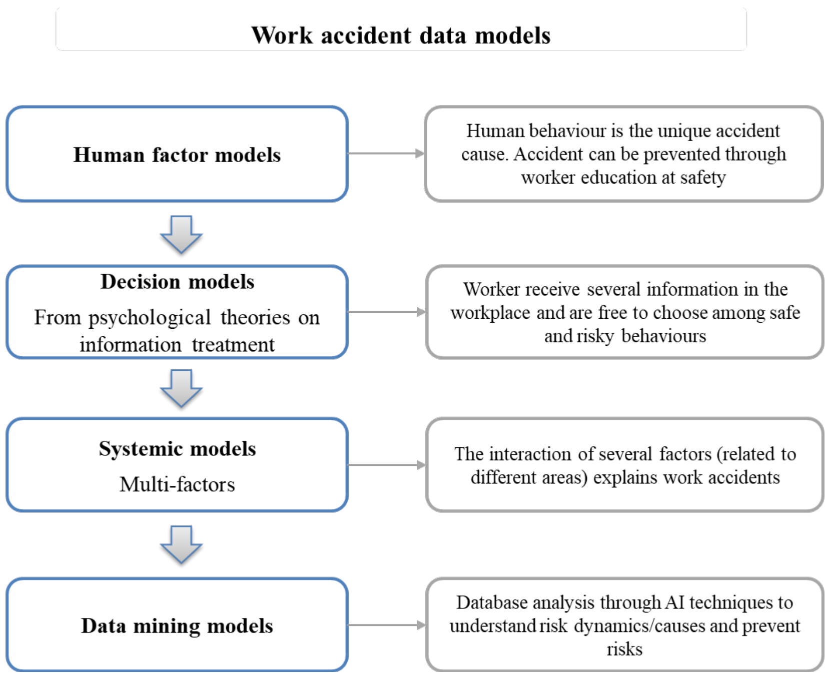

Figure 2 Models for accident prevention through data-driven approach

However, applications of data mining approaches to risk prevention require the definition of appropriate data classification models through synthetic variables (expressed through numerical or brief text features). For instance, in Europe such approaches have been promoted by Regulation n.1338/2008, which stated European Statistics for Accidents at Work (ESAW) model for data classification in 2008 (Eurostat 2013; Jacinto and Soares 2008).
With reference to Italian wood industry of Piedmont Region, (Comberti et al. 2018) reported the application of self-organizing maps and K-means clustering to a sample of n.1200 events, selected from the restricted access INAIL database. (Lombardi *et al.* 2019) showed the application of K-means clustering to a sample of n. 116 accidents occurred in Italy in the period 2002–2015, selected from Infor.MO database to investigate electric shock in the construction sector. In Arizona (USA), (Chokor et al. 2016) designed a Natural Language Processing (NLP) methodology to evaluate risk profiles in construction industry from OSHA safety inspection reports.
Hence, with the goal to propose a data driven contribute for safety in landfills, in the next sections further details on data structure and research methodology are provided.

3. Data collection and structure

In Italy work-related accidents are managed by several public authorities, whose activities are related to public health or safety at work protection (e.g. Local Health Agencies, Regions, National Health Institute, INAIL etc.). In fact, according to national laws concerning safety at work (Republic of Italy 2008), accident management (Republic of Italy, 1965) and the National Health System's (NHS) duties (Poscia *et al.* 2018), such events are communicated:

- to public entities of the NHS involved in the organization of public health assistance;
- to the National Compensation Authority (INAIL), responsible for workers' compensation, according to the provisions of DPR 1124/1965.

In spite of the large efforts made to state a national accident registration methodology in the framework of Infor. MO project and ESAW model (Campo et al. 2020), data currently detected at a local level are still a little different in

details. For this reason, it is advisable to use databases powered by national research institutes to carry out national studies.
For the study's purposes, the database called "Information Fluxes INAIL-Regions" was selected. In this database, whose access is restricted to research works, accidents events are organized in a matrix model, providing details on accident dynamics, injured worker, employer, accident consequences and complementary accident features (i.e. the so-called "accident categories"). An overview of INAIL database structure is provided in table 1: for each category, related factors were identified, starting from the analysis of the first sample.
In such database, alpha-numeric coefficients or short text features are assigned to accident factors to avoid recognizing people involved in the event (workers and employer), due to European privacy requirements. With reference to the first category (accident dynamics), in table 2 examples of accident coding are reported, where:

- AC stands for accident code;
- Activity is the specific task performed by the worker when the accident occurred;
- Material agent of activity is the object, material etc. used to carry out the activity;
- Deviation is the determinant, i.e. the initial event that lead to the injury;
- Material agent of the deviation is the object, material etc. that generated the source of injury;
- Contact stands for the way leading to injury;
- Material agent of contact is the object, material etc. that inflicted the injury;
- Workplace is the working area where the accident occurred;
- Working process is the company process which the performed activity is part of.

Table 1. INAIL accident database structure

Accident categories	Accident factors
Accident dynamics	Activity; contact; deviation; material agent of activity; material agent of contact; material agent of deviation; working process; workplace
Injured worker	Working task; age range; sex; nationality; level of working experience; student; athlete
Employer	INAIL compensation rate; ATECO code (i.e. the Italian classification of Economic Activities); type of company; number of employees
Accident consequences	Type of accident; Type of injury; part of the body injured; lost days at work
Complementary accident features	"In itinere" accident (yes/not); road accident; geographic accident location (region); year of the event; accident compensation

Table 2. Description of accident dynamics in INAIL database (examples)

AC	Material agent of activity	Material agent of contact	Material agent of deviation	Activity	Contact	Deviation	Working process	Workplace
AC_01	14000000	14000000	14000000	40	53	44	12	13
AC_02	01000000	01000000	12000000	60	31	60	61	10

Just to illustrate accidents dynamics coding, in table 2 AC_01 relates to an injury occurred in a storage area (workplace 13), during the manipulation of objects/materials (activity 40), required in the storage process (working process 12). The accident started with the lack of control (deviation 44) of something (working material, i.e. the material agent of deviation) and the injury occurred because the worker got in contact with an abrasive and cutting object (contact 53).
Accident samples can be also selected using accident factors related to the "Employer" category, such as:

- the statistical classification of economic activities (i.e. ATECO classification), established in Italy by the National Statistics Institute according to NACE (Nomenclature of Economic Activities, which is the European statistical classification of economic activities) codes (Rev_2), which were introduced in the European Community through Regulation EC 1893/2006 (European Commission 2006);

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- INAIL compensation rates, which are regularly updated according to national accident statistics.

Finally, in the INAIL database the factor "working task" (concerning the injured worker) could be useful to reach desirable information on accident events, when the above-mentioned classifications are not sufficiently detailed with reference to the working context.

4. Research methodology

Considered INAIL database structure and recent scientific literature, research methodology was designed to employ ESAW classification variables as data filters. So, it consisted in the following phases:

1. Identification of the first accident data sample from INAIL database (period 2008-2019), using the following filters:
   a. INAIL compensation code related to "Cleaning up and urban waste cleaning" (code 0420);
   b. ESAW variables "workplace" and "working process" related, respectively, to:
      i. industrial sites (group code 010) and other working places (group code 999);
      ii. "Other activities, complementary to groups 10, 20, 30, 40" (group code 050);
   c. Economic sector of the company (i.e. ATECO codes) related to solid waste management or remediation activities;
2. Screening of data through the selection of the following filters:
   d. Accident occurred in the working place (not "in itinere");
   e. INAIL compensation rate related to "Urban cleaning up, landfill and incinerators management" (code 0421);
   f. ATECO code related to solid waste treatment and disposal;
   g. working tasks, likely to be performed in landfills;
3. Exclusion of those events not provided with sufficient information related to accident dynamics;
4. Accident dynamics analysis, through the factors stated in table 2;
5. Potential risk profiling, concerning working equipment use;
6. Evaluation of mitigation measures in landfills to address risks related to working equipment.

In figure 3 the research methodology is summarized and strategies were identified for each phase.
INAIL data were assigned a unique AC by the authors and organized in a table model. Elaborations were carried out in Microsoft Excel®.
In table 3 codes related to Step 1) are reported, while table 4 shows INAIL working task codes selected to identify accidents likely to have occurred in landfills.

Table 3. ESAW, ATECO and INAIL compensation codes used as data filters for Step 1)

ESAW Codes	ATECO codes	INAIL compensation code
Workplace 010: industrial sites 999: other workplaces not mentioned in ESAW classification **Working process** 050: Other activities, complementary to groups 10, 20, 30, 40	E 38.21.09 urban solid waste treatment and disposal E 38.22.00 hazardous solid waste treatment and disposal E 39.00.09 remediation and other solid waste management activities	0420: Cleaning up and urban waste cleaning

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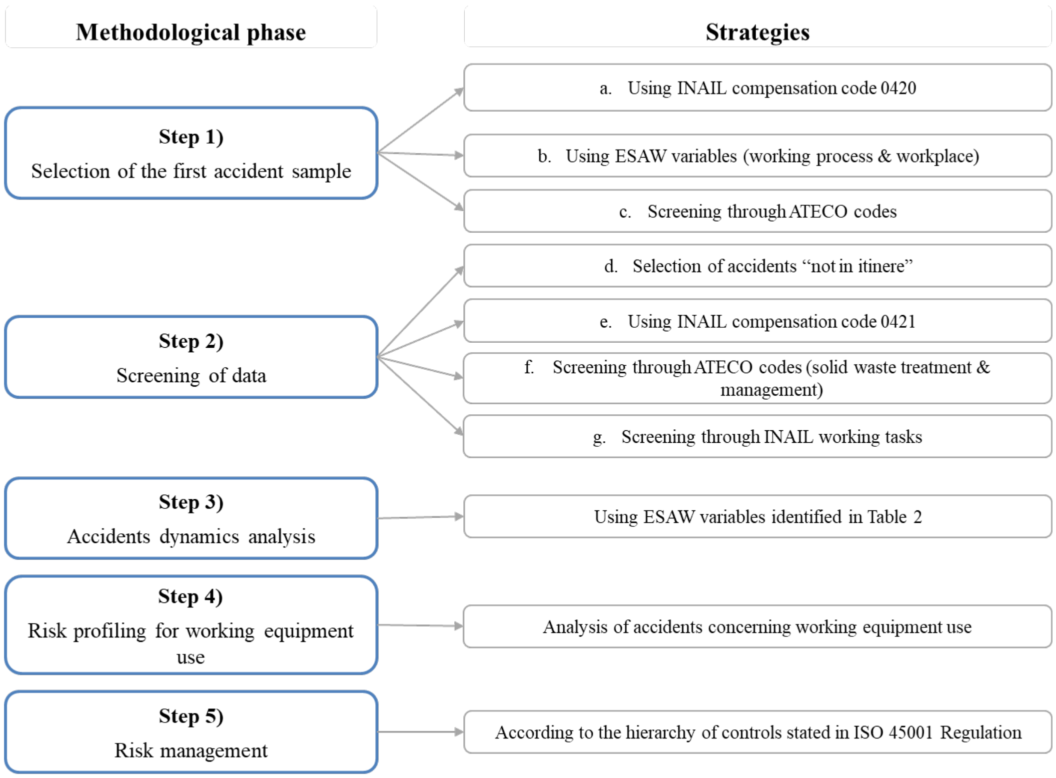

Figure 3. Research methodology

Table 4. INAIL working task codes used as data filters for Step 2)

INAIL working task codes	Description
1132	Operator at urban solid waste landfills
133	Driver
381	Electrician for vehicles
384	Excavator operator
595	Warehouseman
602	Maintenance operator
702	Guardian
741	Light-wheel mechanic
797	Operator at press brakes
1094	Driver of waste compactors
1230	Operator at pump area
1321	Operations management worker

5. Results and Discussion

Due to privacy reasons, the first step of the research methodology was carried out by an INAIL officer, who organized the first accident data sample in n.10 files editable in Microsoft Excel®, according to:

- The geographic location of accidents, through n. 5 classes stated by INAIL (North-East, North-West, Middle, South Italy and Islands);
- ESAW variables "working place" (n.5 files) and "working process" (n.5 files). In such files, accidents data were also organized according to the geographic classification as stated above.

5.1 Results

For the purposes of this study, the attention was focused on files where "working place" factor was selected as the leading one to profile specific risks. Screening of data (Step 2) was carried out on a preliminary sample of n.636 events, organized as follows:

- n. 56 cases in Central Italy;
- n. 108 events in Italian islands;
- n. 89 cases in the North-East of Italy;
- n. 333 events in the North-West of Italy;
- n. 50 events in the South Italy.

Step 2) lead to select a sample of 78 events: among them, only n.8 events involved someone whose working task related to landfill operations management (code 1132). Then, accident dynamics analysis (Step 3) ended with the identification of 40 accident variables influencing the accident factors previously reported in table 2.

In the following tables accident variables are reported, while the relationship among variables, factors and accident dynamics in landfill management sector is illustrated in figure 4.

Table 5. Variables related to "Material agent" factors (j=1,2,3) and physical activity

Material agent		**Physical activity**	
$V_{1,j}$	Construction element (i.e. stairs, floor etc.)	V_{10}	Operations on machinery
$V_{2,j}$	Materials	V_{11}	Objects manipulation
$V_{3,j}$	Utensils	V_{12}	Working with utensils
$V_{4,j}$	Machinery	V_{13}	Manual transport of items
$V_{5,j}$	Means of transport	V_{14}	Body movements
$V_{6,j}$	Waste	V_{15}	Other activities
$V_{7,j}$	No agent		
$V_{8,j}$	Superficies		
$V_{9,j}$	Other material agent		

Table 6. Variables related to Contact and Deviation factors

Contact		**Deviation**	
V_{16}	Contact with flame/thermic source	V_{22}	Material loss
V_{17}	Crushing	V_{23}	Breaking of material
V_{18}	Hit with an external item	V_{24}	Control loss
V_{19}	Contact with sharp or abrasive materials	V_{25}	Falling
V_{20}	Physical effort	V_{26}	Body movements
V_{21}	Other	V_{27}	Other

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Table 7. Variables related to Working Process and Workplace factors

Working process		**Workplace**	
V_{28}	Treatment/transformation	V_{37}	Industrial site
V_{29}	Storage	V_{38}	Maintenance/production area
V_{30}	Building works	V_{39}	Storage area
V_{31}	Services	V_{40}	Other site
V_{32}	Maintenance		
V_{33}	Cleaning up		
V_{34}	Waste management		
V_{35}	Circulation (with/without means of transport)		
V_{36}	Other process		

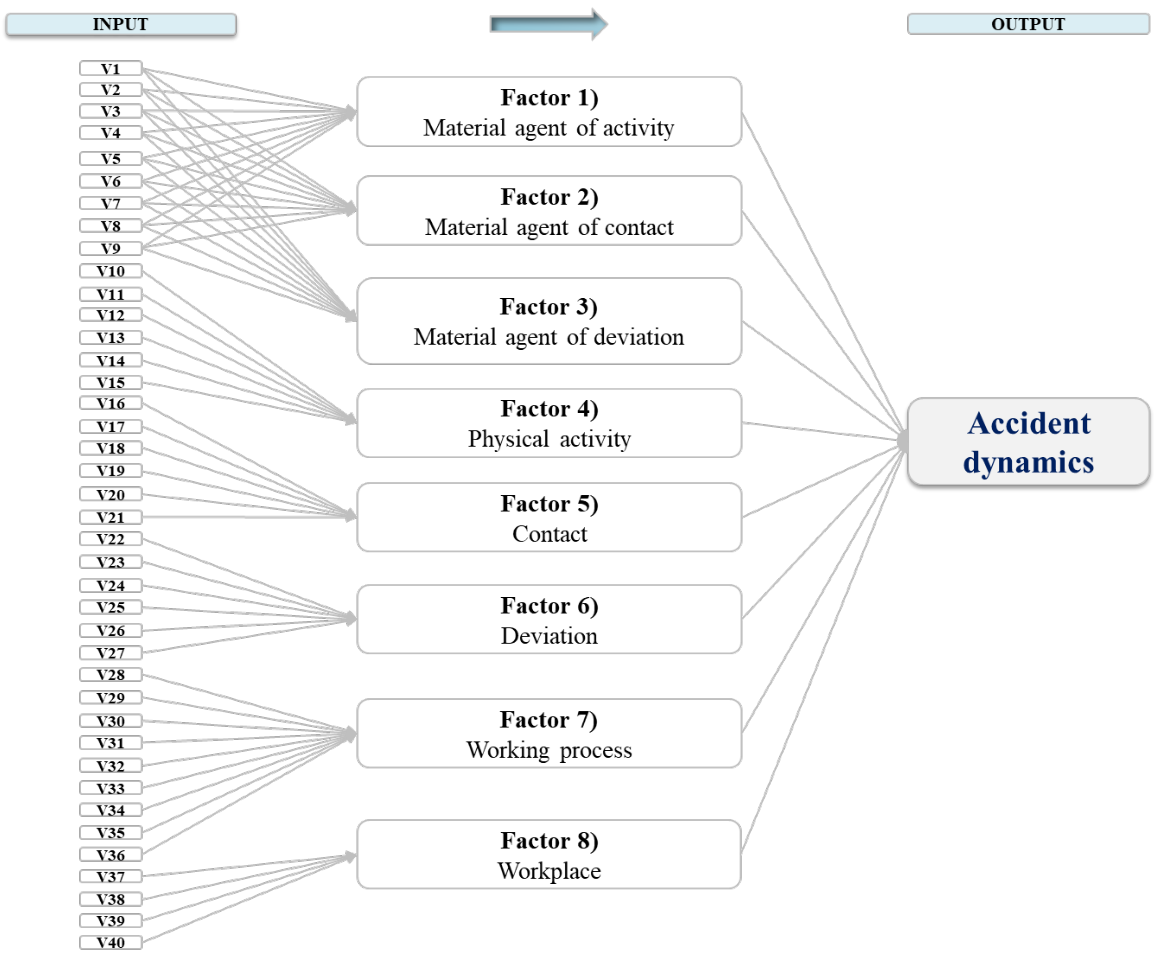

Figure 4. Relationship among variables, factors and accident dynamics for landfill management sector

K-means cluster analysis of events with reference to accident variables was excluded due to the similar dimension of events and variables vectors. Hence, risk profiling (Step 4) was carried out by evaluating the influence of risk determinant "working equipment use" in the selected events.

According to (Campo et al. 2020) "working equipment" stands for "*equipment of any type (or part of it) which in the incident dynamics presented critical issues such as set-up (lack of equipment security, insufficient safety of equipment, presence of dangerous elements, removal of protections, tampering with protections, etc.) or operating issues*." Any risk factor acts as a determinant if it increases the risk of accidents.
At the end of step 4, a further screening of the reference sample was made through V3 (utensils), V4 (machinery) and V9 (other material agent) variables influencing the "Material agent of deviation" factor. Such operation lead to identify a sample of n.36 events. Among them, only n.4 events involved operators at urban solid waste landfills (code 1132) and their accident dynamics is reported in table 8.

Table 8. Accidents involving a landfill operator and related to "working equipment" determinant (n.4 events)

AC	Material agent of activity	Material agent of contact	Material agent of deviation	Activity	Contact	Deviation	Working process	Workplace
AC_23	11090400	11090400	11090400 [Variable V9]	51	71	71	54	010
AC_24	1109020Y	01020101	1109020Y [Variable V9]	51	71	71	10	011
AC_35	11000000	11000000	11000000 [Variable V4]	61	71	50	54	019
AC_66	14030100	14030100	14030100 [Variable V3]	41	53	44	54	012

According to the accident sample reported in table 8, the following hazardous events were related to working equipment bad use in landfill management:

- AC_23 and AC_24: damages to the musculoskeletal system due to picking a heavy piece of equipment up (like a garbage can, a large container etc.);
- AC_35: slipping due to the physical effort related to picking a heavy piece of equipment up;
- AC_66: contact with an abrasive/sharp working item due to the loss of control of it.

Hence, the following risks were identified for operators at urban solid waste landfills (code 1132, table 4): slipping, manual handling of loads and contact with sharp or abrasive items. By contrast, the main risks for other workers related to working equipment use (i.e. n. 32 events) were reported in table 9.

Table 9. Accidents related to "working equipment" determinant (n.32 events)

Working task	Reference AC	Main risks
Driver [code 133]	n.22 events [AC:02;03;06;07;09;11;12;13;18;20;31;33;34;44;62;63;65;68;71;72;73;74]	Slipping, handling of loads, falling from the height, falling materials, road crushes, to be run over, contact with abrasive/sharp objects
Maintenance operator [code 602]	n.6 events [AC: 19;21;43;51;55;59]	Falling, crushing, contact with abrasive/sharp objects
Electrician for vehicles [code 381]	n. 2 events [AC: 53;60]	contact with abrasive/sharp objects

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Operations management worker [code 1321]	AC_25	Contact with abrasive/sharp objects
Driver of waste compactors [code 1094]	AC_16	Physical effort

Considering the results of risk profiling, some risk management measures were suggested according to the hierarchy of controls stated by ISO 45001 Regulation. This underlines the need of a safety management approach to augment the safety level of operators, in line with the research findings of other studies in the construction sector (e.g. Fargnoli et al. 2011; Gunduz and Laitinen 2017). More in details, whenever hazards cannot be eliminated or substituted, safety managers of landfilling plants should implement the following strategies to address the above-mentioned risks:

- Detailing the sequence of operations and working tasks in order to identify the most efficient and specific prevention and protective measures (OSHA, 2002);
- Checking regularly safety conditions of working equipment and places, in order to provide adequate maintenance to machinery;
- Planning in detail circulation in landfilling plants in order to prevent road accidents and people run over by working means of transport;
- Using safety signs to delimit dangerous areas due to falling materials and to prevent crushing risk;
- Providing workers with electric devices helping in handling loads (e.g. garbage cans, containers etc.), such as forklift trucks and wearable robotics (Park et al. 2021) to avoid musculoskeletal damages;
- According to the internal company factors, planning working task rotation, in order to prevent lack of attention during working processes;
- Providing all workers with adequate training on working equipment use, according to the internal factors of company, like working tasks, nationalities, levels of experience etc.;
- Providing all workers with appropriate Personal Protective Equipment (PPE), whenever residual risks are not acceptable.

5.2 Study limitations

The discussion of results took into account intrinsic limits related to current accident data models and to the number of the selected events.

First of all, results are strongly dependent on the use of ESAW and NACE (i.e. ATECO) models as data filters. Even though such classifications allowed European countries developing comparable accident databases and solving privacy issues in data analysis, they do not currently allow identifying accident samples related to specific workplaces. For this reason, as reported in section 2, accident data elaborations at national level are mainly focused on the economic sector (e.g. wood industry, constructions etc.) and not on the workplace.

Moreover, risk profiling was carried out from a limited accident sample related to the period 2008/2019, without distinguishing minor injuries from serious or fatal events. Unfortunately, with reference to landfill management, events occurred before 2008 could not been included, because INAIL working task classification, which was essential to identify events likely to occur in landfills, was introduced in 2008.

Finally, another limit is related to INAIL compensation classification. In fact, such model was designed to address national insurance issues related to health and safety at work and, in some cases, could be not sufficient detailed for research activities concerning risk profiling in specific workplaces.

6. Concluding remarks

The proposed study aimed at showing a research methodology to design goal-oriented safety prevention strategies in the landfill management sector, starting from well-structured accident data.

Hence, n.78 accidents, likely to have occurred in Italian landfills in the period 2008/2019, were selected from INAIL restricted access database and allowed recognizing n.40 variables influencing accident dynamics in this sector. Then, the main risks related to working equipment use in landfills were identified from a sample of n. 36 events, derived from the previous sample. The selection of 36 events was made through the variables V3, V4 and V9 influencing the "Material Agent of Deviation" factor. Finally, the following results were achieved:

- slipping, manual handling of loads and contact with sharp or abrasive items risks were identified as potential risks for operators at urban solid waste landfills;

- falling materials, road accidents, falling from the height and contact with sharps were identified as potential risks for other workers in landfills.

Starting from risk profiling, some mitigation measures were suggested according to the hierarchy of controls stated in ISO 45001. However, the critical discussion of results brought in light that further research is needed to promote data driven approaches of risk assessment and management in such field. In fact, current organizational models for accidents at work partially limit risk assessment from data analysis.

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