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Identification of areas of intervention for public safety policies using multiple correspondence analysis

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Abstract
Analysis of accident reports has been a useful tool in occupational safety research. According to European Statistics on Accidents at Work framework (ESAW), important variables related to the main circumstances of accidents are being gathered in Europe. The purpose of this paper is to present a method for analysis of accident databases that are coded according to the ESAW and based on Multiple Correspondence Analysis. The method proposed considers the implicit conceptual relationship between the exposure and accident variables in order to identify main areas for public policy intervention. This method is presented by analyzing specific working processes using a dataset of the accidents that were reported in the Andalusian manufacturing over a ten-year period. The method presented allowed easy identification of the main associations candidates for public intervention programs. Each could be object to further detailed research before designing the intervention program. This method could help policy makers when identifying areas for public intervention.

Keywords: occupational safety, accident analysis, risk factors, multiple correspondence analysis, ESAW.

Identificación de aéreas de intervención de políticas públicas en seguridad laboral usando análisis de correspondencias múltiple

Resumen
El análisis de los partes de accidentes ha sido una herramienta útil en la investigación en materia de seguridad laboral. De acuerdo a marco para la elaboración de Estadísticas de Accidentes Laborales en Europa (ESAW), hay importantes variables relacionadas con las principales circunstancias de los accidentes que se están recopilando en Europa. El objetivo de este artículo es presentar in método de análisis de bases de datos de accidentes codificados de acuerdo a ESAW mediante el uso de Análisis de Correspondencias Múltiple. El método propuesto tiene en cuenta las relaciones conceptuales implícitas entre las variables relacionadas con la exposición y las variables relacionadas con el accidente para identificar las áreas de intervención pública de las políticas de seguridad laboral. Este método es presentado analizando procesos específicos de trabajo en la información reportada de los accidentes laborales en el sector industrial de Andalucía en un período de 10 años. El método presentado permite una identificación fácil de las principales asociaciones que puedan ser objeto de programas de intervención pública. Cada una de estas asociaciones puede ser analizada en mayor detalle antes del diseño del programa de intervención. Este método puede ayudar a los responsables de elaborar políticas para identificar áreas de intervención pública.

Palabras clave: seguridad laboral, análisis de accidentes, factores de riesgo, análisis de correspondencias múltiple, ESAW.

1. Introduction

1.1. Accident analysis

Analysis of accident reports have been a useful tool in occupational safety research [1].

Governments have also understood the importance of the quality of accident reports data. For instance, the European Union developed a project denominated European Statistics on Accidents at Work (ESAW hereinafter), launched in 1990 [2]. The main purpose of ESAW is to harmonize data on accidents at work and also to incorporate meaningful variables from accident scenarios.

Over the last decades, most researchers have used statistical analysis to discover the relationships between circumstances and accident occurrence.

Accident circumstances are usually structured as a flow of events [3] and then analyzed with contingency tables. Also, exploratory techniques [4] and clustering tools [5] have been used to identify sequences of events and their prevalence. Accident analysis has been used for risk assessment as well [6,7].

Also, correspondence methods have been applied to explore relationships among certain variables, such as between deviations and the type of accident injury[8].

All these methods are useful for identifying relation ships between accident circumstances variables; nevertheless, from a prevention and risk assessment perspective, the key factor is to analyze the relationships between the categories of these variables and not just the between-variable relations [9].

An important issue is that accidents need to be analyzed considering their different etiology. A group of accidents from the same scenario share a common internal structure in terms of the exposure and circumstances leading to the accident's occurrence [10].

1.2. Accident notification according to ESAW

In Europe, as harmonized variables and classifications of the circumstances of accidents at work that establish the prevalent situation and conditions at the time of the accident are coded using ESAW, identifying the accident scenarios in accident reports should be undertaken using the ESAW taxonomy.

European Parliament and of the Council regulation (EC) No 1338/2008 of 16th December 2008 on community statistics on public health and health and safety at work sets out obligations to supply statistics on accidents at work to the European Commission, according to the third phase of ESAW (ESAW-III). In the third phase of ESAW [2], the harmonized and common data set to be provided on accidents at work cover new characteristics of the accident, including the sequence of event characterizing the accident's causes and circumstances.

Regarding the quality of the data from accident notification, according to [10] Spain has properly implemented ESAW, which is comparable to most western countries [11]. It is important to highlight that every accident notification is accepted by the mutual insurance system in Spain, which covers the cost of rehabilitation after an accident, and it must be also reviewed by the Labor Authority, which on occasion performs its own accident investigations. In an unpublished report by the Instituto Nacional de Seguridad e Higiene en el Trabajo (the National Institute for Occupational Health and Safety in Spain), the quality of accidents notified from 2003 to 2008 was analyzed. It was concluded that the circumstances of the accidents showed adequate information in more than 90% of those cases [12].

In a deeper analysis, using cross-sectional double-blind design, Molinero-Ruiz et al. (2015) found a moderate agreement reliability coefficient (Kappa index) for most categories with the *Deviation* and *Contact* variables [13].

Analysis of the ESAW data needs to be undertaken with a clear differentiation between the circumstances related to risk exposure and the circumstances related to the accident occurrence [14].

The variables relating to exposure are *Working Process* and *Specific Physical Activity*, and the variables relating to the accident itself are *Deviation* and *Contact*. For each variable there are two levels of coding.

1.3. Paper objective

The purpose of this paper is to present a method to analyze accident databases that are coded according to ESAW and based on Multiple Correspondence Analysis (hereinafter MCA).

The method proposed considers the implicit conceptual relationship between exposure variables and accident variables in order to identify main areas for public policy intervention.

This method is presented analyzing specific working processes using a dataset of the accidents reported in the Andalusian manufacturing sector over a ten-year period.

2. Materials and Methods

2.1. Data

In order to present the method, we have gathered all accidents that have led to at least one day of absence in the Andalusian manufacturing sector, from 2003 to 2012, with a total of 201,311 valid accident notifications.

According to Eurostat, the manufacturing sector uses NACE economic classification. Manufacturing is the sector in Europe with the highest number of annual days of absence due to accidents [15]. In order to limit the analysis to accidents occurring in industrial sites, we used the ESAW variable working environment.

The latest incidence rate for the manufacturing sector published by Eurostat is 3,097 accidents per 100,000 workers, which shows the importance of manufacturing sector accidents for accidents with more than three days' absence in the European Union and Norway in 2007

It is important to add that Andalusia is one of the biggest regions in Europe, represents approximately 12% of the Spanish manufacturing sector, and employs on average more than 200,000 workers.

In Spain, accident reports are electronically collected in "Official Workplace Incident Notification Forms" [16]. All accidents that result in an absence from work for one or more days must be notified.

For each accident, variables related to main circumstances are gathered according to ESAW: *Working Process*, *Specific Physical Activity*, *Deviation* and *Contact*.

2.2. Implicit structure of the accident circumstances

Another important issue is that in-depth analyses of accident circumstances of should only be carried out for accidents classified as fitting the same scenario [6, 10]. The accident scenario is identified by the combination of accident circumstances (see Fig. 1).

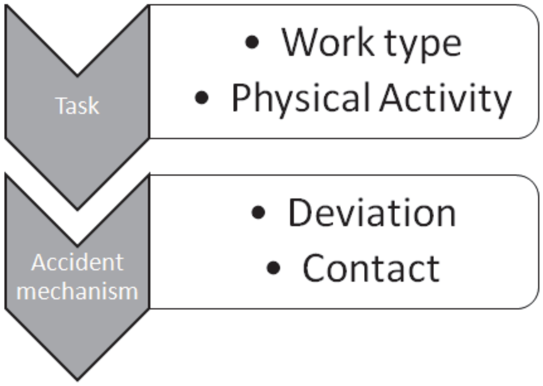

Figure 1. Concepts of task and accident mechanisms in the flow of events.
Source [6].

According to previous researchers' findings, and regarding ESAW variables, meaningful concepts underlie the structure of accident reports [6]. In particular, two main concepts are directly linked with flow of events that lead to the accident: *Task* and *Accident Mechanism*.

The *Task* is what the worker was doing. This concept can be used to identify the risk that the worker was exposed to when the accident occurred. Tasks are identified through the ESAW variables *Working Process* and *Specific Physical Activity*.

According to ESAW, *Working Process* is the "main type of work or task (general activity) being performed by the victim at the time of the accident" and *Specific Physical Activity* is "the victim's exact specific physical activity at the instant of the accident."

The *Accident Mechanism* is what happened in the lead-up from normal work to when the accident occurred. The accident mechanism is used to identify each central bow-tie events and it is defined by the combination of the ESAW variables *Deviation* and *Contact* [6,17].

According to ESAW, *Deviation* is "the event that triggers the accident" and *Contact* is "the contact that injured the victim."

2.3. Method

The relationships between the variables and their categories in ESAW can be identified using Multiple Correspondence Analysis (MCA hereinafter).

MCA analysis, as an exploratory technique and provides an intuitive representation of how certain categories are close enough to intuit an association [8]. MCA is also a useful method for presentation purposes as the plots are very intuitive [18].

MCA is a multivariate statistical technique. It is conceptually similar to principal component analysis, but applies to categorical rather than continuous data. In a similar manner to principal component analysis, it provides a means of displaying or summarizing a set of data in two-dimensional graphical form.

The nearest two modalities are in the plot, the stronger one is the evidence of the relationship between them. It must be considered that in the center of the correspondence plot, very little can be said as it represents the average profile.

A group of categories that are close to each other and separated from the rest is called a cluster, and in terms of accident analysis a cluster identifies a scenario of accidents that could be prevented.

The identification of category clusters is subjective. To provide a more objective identification, the Phi coefficient test has been used to identify all significant associations [19]

Table 1.
Most frequent tasks for accidents in Production.

(ESAW code) *Working Process*	(ESAW code) *Specific Physical Activity*	*Task*	Number
(1x) Production, manufacturing, processing, and storing	(4x) Handling of objects (manually)	T1	53,241
	(2x) Working with hand-held tools	T2	26,205
	(6x) Movement (walking, getting in/out, jumping, etc.)	T3	25,088
	(5x) Carrying by hand, transporting	T4	18,189
	(1x) Operating machine	T5	17,582

Source: Elaborated by the authors based on Accidents notified in the Andalusian manufacturing sector 2003-2012

Table 2.
Most frequent accident mechanisms for accidents within the tasks identified in Table 1.

(ESAW code) *Deviation*	(ESAW code) *Contact-Mode of Injury*	*Accident mechanism*	Number
(7x) Body movement under/with physical stress	(7x) Physical or mental stress (includes stress on the musculoskeletal system)	M1	33,968
(4x) Loss of control (total or partial)	(5x) Contact with a sharp, pointed, rough, coarse material agent	M2	9,839
(4x) Loss of control (total or partial)	(4x) Struck by, collision with object in motion	M3	7,989
(5x) Slipping - Stumbling and falling - fall	(3x) Impact with or against a stationary object …	M4	8,369
(6x) Body movement without any physical stress	(7x) Physical or mental stress (includes musculoskeletal system)	M5	7,858
(3x) Breakage, bursting, splitting, (…) of Material	(4x) Struck by, collision with object in motion	M6	5,593
(6x) Body movement without any physical stress	(5x) Contact with sharp, pointed, rough, coarse material agent	M7	5,190
(6x) Body movement without any physical stress	(3x) Impact with or against a stationary object	M8	4,375
(3x) Breakage, bursting, splitting, (…) of Material Agent	(5x) Contact with a sharp, pointed, rough, coarse material agent	M9	3,567

Source: Elaborated by the authors based on Accidents notified in the Andalusian manufacturing sector 2003-2012

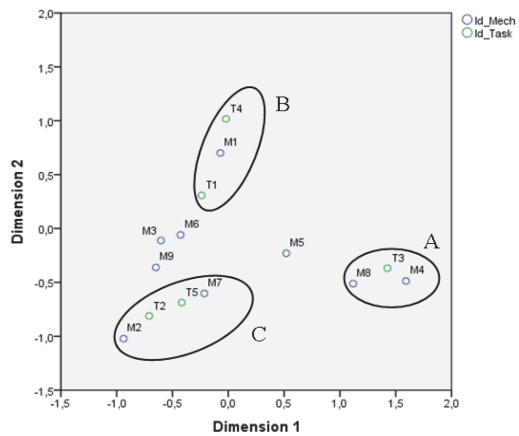

Figure 2. Plot of Task and Accident Mechanism in "Production". The label in each Task and Accident Mechanism from tables 1 and 2 is indicated.
Source: Elaborated by the authors

3. Results

3.1. Correspondence analysis of accidents in "production"

In this section we use the ESAW first level of coding. The symbol x is used to identify all possible codes with the same first digit in the code.

The method proposed is used to analyze a specific type of accidents: accidents with code 1x for *Working process* in ESAW. For ESAW, code 1x is used for "Production, manufacturing, processing, and storing", including storing.

The most frequent tasks are presented in Table 1, and the most frequent accident mechanisms are presented in Table 2. Note that in ESAW the codes used for each variable are the same, so depending on the variable in the column title, the meaning of a code can be different.

For those tasks and accident mechanisms, two dimensions captured 98% of the total inertia.

In Fig. 2, there is a representation of the categories after correspondence analysis.

In terms of accident prevention, this association identifies an accident scenario. Main associations, according to Fig. 2, are the following generic accident scenarios:

1. Scenario A: "Movements" tasks (T3) are associated with the accident mechanisms "slipping - stumbling and falling - fall", or with "body movement without any physical stress", which leads to "impact with or against a stationary object" (M4) and (M8).
2. Scenario B: "Handling of objects (manually)" (T1) and "carrying by hand, transporting" (T4) are associated with "body movement under/with physical stress" which leads to "physical or mental stress (including stress on the musculoskeletal system)" (M1).
3. Scenario C: Tasks such as "operating machines" (T2) and "working with hand-held tools" (T5) are associated with "loss of control" accident mechanisms, which leads to "contact with a sharp, pointed, rough, coarse material agent" (M2), and "body movement without any physical stress" accident mechanisms, which leads to "contact with a sharp, pointed, rough, coarse material agent" (M7).

Table 3.
Most frequent tasks for accidents in setting up, preparation, installation, mounting, disassembling, and dismantling.

(ESAW code) *Working Process*	(ESAW code) *Specific Physical Activity*	*Task*	Number
(51) Setting up, preparation, installation, mounting, disassembling, dismantling	(41) Manually taking control of, grasping, seizing, holding, placing - on a horizontal level	T1	4,394
	(61) Walking, running, going up, going down, etc.	T2	2,172
	(21) Working with hand-held tools - manual	T3	1,540
	(51) Carrying vertically - lifting, raising, lowering an object	T4	1,119
	(22) Working with hand-held tools - motorized	T5	963
	(43) Fastening, hanging up, raising, putting up - on a vertical level	T6	933
	(40) Handling of objects - not specified	T7	630
	(67) Movements on the spot	T8	531
	(53) Transporting a load - carried by a person	T9	505
	(42) Tying, binding, tearing off, undoing, squeezing, unscrewing, screwing, turning	T10	488

Source: Elaborated by the authors based on Accidents notified in the Andalusian manufacturing sector 2003-2012

Table 4.
Most frequent accident mechanisms for accidents in setting up, preparation, installation, mounting, disassembling, and dismantling (within the ten tasks identified in Table 3).

(ESAW code) *Deviation*	(ESAW code) *Contact-Mode of Injury*	*Accident mechanism*	Nº cases
(71) Lifting, carrying, standing up	(71) Physical stress - musculoskeletal system	M1	1,546
(64) Uncoordinated movements, spurious or untimely actions	(71) Physical stress - musculoskeletal system	M2	486
(51) Fall of person - to a lower level	(31) Vertical motion, crash on or against	M3	422
(70) Body movement under or with physical stress - not specified	(71) Physical stress - musculoskeletal system	M4	429
(52) Slipping - Stumbling and falling - Fall of person - on the same level	(31) Vertical motion, crash on or against	M5	315
(44) Loss of control (total or partial) - of object	(42) Struck - by falling object	M6	306
(72) Pushing, pulling	(71) Physical stress - musculoskeletal system	M7	279
(33) Slip, fall, collapse of material agent - from above	(42) Struck - by falling object	M8	268
(43) Loss of control (total or partial) - hand-held tool (motorized or not) or of the material being worked by the tool	(51) Contact with sharp material Agent (knife, blade etc.)	M9	230
(74) Twisting, turning	(71) Physical stress - musculoskeletal system	M10	229

Source: Elaborated by the authors based on Accidents notified in the Andalusian manufacturing sector 2003-2012

Table 5.
Most frequent contacts for accidents in setting up, preparation, installation, mounting, disassembling, and dismantling (within the ten tasks identified in Table 3).

(ESAW code) *Contact-Mode of Injury*	*Contact*	Nº cases
(71) Physical stress - musculoskeletal system	C1	4,000
(31) Vertical motion, crash on or against	C2	1,224
(42) Struck - by falling object	C3	1,222
(50) Contact with a sharp, pointed, rough, coarse material agent - not specified	C4	1,039
(51) Contact with a sharp material agent (knife, blade etc.)	C5	902
(32) Horizontal motion, crash on or against	C6	808
(41) Struck - by flying object	C7	517
(40) Struck by object in motion, collision with - not specified	C8	504
(30) Horizontal or vertical impact with or against a stationary object (the victim is in motion) - not specified	C9	392
(52) Contact with a pointed material agent (nail, sharp tool etc.)	C10	293
(43) Struck - by swinging object	C11	288

Source: Elaborated by the authors based on Accidents notified in the Andalusian manufacturing sector 2003-2012

3.2. *Correspondence analysis of accidents in "Setting up, preparation, installation, mounting, disassembling, and dismantling"*

In this section, the method is used to analyze in-depth a specific type of accident: accidents with code 51 in ESAW for the *Working process* variable, which is used for "Setting up, preparation, installation, mounting, disassembling, and dismantling".

This type of work is part of the manufacturing activities process, but is most of the time related to construction and on-site delivery of pieces of equipment or industrial products. The most frequent tasks are presented in Table 3.

For those tasks, the most frequent accident mechanisms are presented in Table 4, and the most frequent modes of contact are presented in Table 5.

Note that in ESAW the codes used for each variable are the same, so depending on the variable in the column title, the meaning of a code can be different.

3.2.1. Analysis of associations between task and accident mechanisms in "*setting up, preparation, installation, mounting, disassembling, and dismantling*" accidents.

MCA of the Task and Accident Mechanism variables with two dimensions captured 82% of the total inertia and identified at least two scenarios for intervention (see Fig. 3):

1. Scenario D: "Working with hand-held tools – motorized" (T5) tasks are associated with "loss of control (total or partial) - of hand-held tool (motorized or not) or with the material being worked by the tool" accident mechanism, which lead to "contact with a sharp material agent (knife, blade etc.)" (M9).
2. Scenario E: "Walking, running, going up, going down" (T2) tasks are associated with "fall of person - to a lower level" or "Slipping - Stumbling and falling - Fall of person - on the same level" accident mechanisms, which lead to "vertical motion, crash on or against (resulting from a fall)" (M3, M5).

The phi coefficient test identifies the following significant associations (see Table 6):

3.2.2. *Analysis of associations between Task and Contact in "setting up, preparation, installation, mounting, disassembling, and dismantling" accidents*

MCA for the variables *Task* and *Contact* with two dimensions captured 90% of the total inertia and identified at least four scenarios for intervention (see Fig. 4):

1. Scenario F: "Walking, running, going up, going down, etc." (T2) tasks are associated with "vertical motion, crash on or against" (C2) or "horizontal motion, crash on or against" contacts (C6).

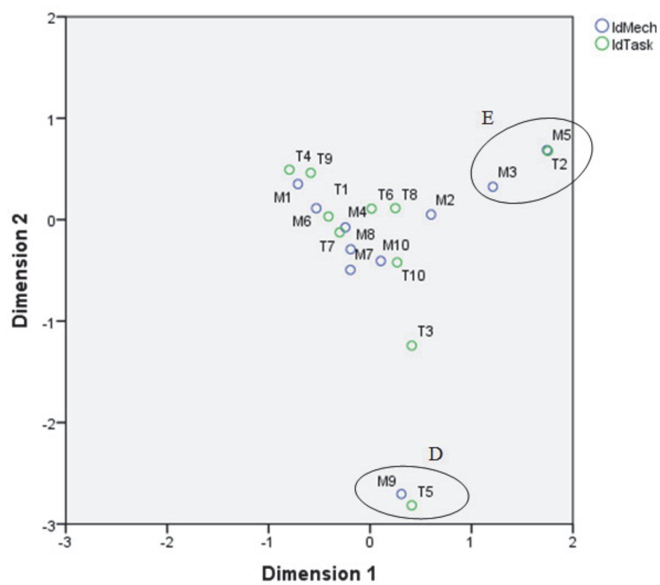

Figure 3. Plot of Task and Accident Mechanisms in "setting up, preparation, installation, mounting, disassembling, and dismantling". The label in each Task and Accident Mechanism from Tables 1 and 2 is indicated. Source: Source: Elaborated by the authors.

Table 6.
Phi coefficient analysis of Task and Accident Mechanisms in "setting up, preparation, installation, mounting, disassembling, and dismantling".

Tas K	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
T1						#				
T2		#	#		#					
T3									#	
T4	#					#				
T5									#	
T6			#			#		#		
T7				#						
T8		#								#
T9	#					#				
T10		#					#			#

Source: Elaborated by the authors based on Accidents notified in the Andalusian manufacturing sector 2003-2012

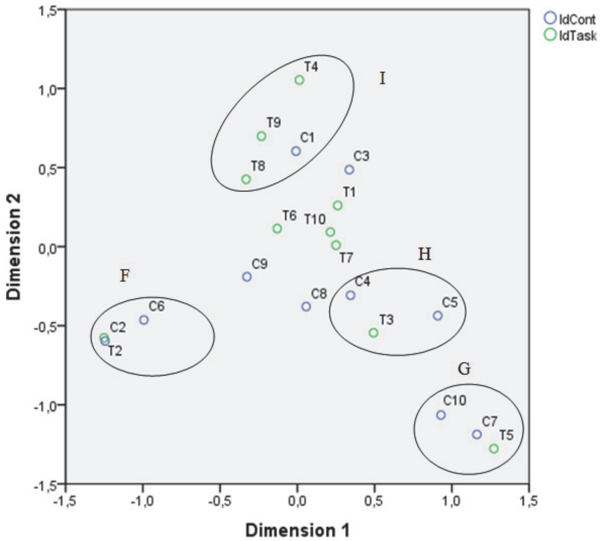

Figure 4. Plot of Task and Contact in “setting up, preparation, installation, mounting, disassembling, and dismantling”. The label in each Task and Contact from Tables 1 and 2 is indicated.
Source: Elaborated by the authors.

Table 7.
The phi coefficient analysis of Task and Accident Mechanisms in “setting up, preparation, installation, mounting, disassembling, and dismantling”.

Task	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
T1	#		#		#						#
T2		#				#			#		
T3					#		#	#		#	#
T4	#		#								
T5				#	#		#				
T6		#									#
T7				#				#			
T8	#										
T9	#										
T10			#	#							

Source: Elaborated by the authors based on Accidents notified in the Andalusian manufacturing sector 2003-2012

2. Scenario G: “Working with hand-held tools - motorized” (T5) tasks are associated with “struck - by flying object” (C7) or “contact with a pointed material agent (nail, sharp tool etc.)” contacts (C10).
3. Scenario H: “Working with hand-held tools – manual” (T3) tasks area associated with “contact with sharp Material Agent (knife, blade etc.)” contacts (C5).
4. Scenario I: “Carrying vertically - lifting, raising, lowering an object” (T4), “movements on the spot” (T8) and “transporting a load - carried by a person” (T9) tasks are associated with “physical stress - musculoskeletal system” (C1) contacts.

The phi coefficient test identifies the following significant associations (Table 7):

4. Discussion

In this paper Multiple Correspondence Analysis is used to identify intervention areas for preventive programs. For such identification, the accident scenario concept is used.

The first of the areas is identified as an example (Scenario A), in which tasks related to “movements” (T3) are associated with accident mechanisms in terms of “slipping - stumbling and falling -fall” or with “body movement without any physical stress”, which leads to “impact with or against a stationary object” (M4) and (M8). The methodology presented identifies an intervention area focused on the prevention of falls and other movements, which leads to impact with stationary objects.

Although difficult to interpret the meaning of the dimensions in MCA, each scenario consists of accidents that are similar in the transformed space, and thus the preventive activities should be effective considering the flow of events.

The method presented allowed the main association candidates for public intervention programs to be easily identified. Each can be an object of further detailed research before designing the relevant intervention program [20].

Multiple Correspondence Analysis offers an improvement on the analysis of the relative frequency of each combination of variables [7,9] because the association in the transformed space of dimensions identifies an internal relationship that is related to the structure of the accident in terms of the codification of the variables used to describe the circumstances.

Although it is difficult to name the dimensions, the explanation of the inertia in the model is a measure of how the model explains those relationships between the categories of the variables.

It should be noted that this identification of accident scenarios is only based on some variables included in the technological subsystem. Other subsystems, such as human factors and organization, are unfortunately not yet incorporated with the same level of detail in ESAW. As Jacinto et al. (2009) [21] have proposed, it is necessary to incorporate new variables, such as individual contributing factors, work place factors and organizational and management factors to future research.

New variables available, such as the worker’s level of training, should be included in Multiple Correspondence Analysis for a more detailed identification of the accident scenarios.

In the phi test that was performed, not all the associations found were significant. We should highlight the differences in the methods, MLA and phi test..

4.1. Application in the design of preventive programs

The identification of scenarios should be complemented by accident analysis, with the specific accident scenario in order to identify the most frequent causes.

For example, in [19] there is an analysis of the most frequent causes of the accident mechanisms in the Andalusian manufacturing sector.

Therefore, the combination of Multiple Correspondence Analysis as presented in this paper, and the results of the analysis for the most prevalent causes of each of the accident mechanisms can be used to more effectively design public safety programs.

Note than in ESAW, some contacts relate to musculoskeletal injuries that come from physical stress, so some of the accidents reported are not the usual accidents generally considered in other scientific research on this topic.

4.1. Application of the initial analysis of types of accidents with little research available

In this paper, there is an exploratory analysis of accidents the following activities: "setting up, preparation, installation, mounting, disassembling, and dismantling." These accidents are part of the manufacturing activities, but in most cases involve construction techniques.

This paper presents an initial identification of the most important accident scenarios, and shows the usefulness of this method to analyze accidents with almost no literature available. It also makes suggestions as to which direction the following research should be focused.

Most of the scenarios identified in "setting up, preparation, installation, mounting, disassembling, and dismantling" have been studied in the literature for other activities, such as falls, handling, loss of control and being struck by accidents.

Therefore the exploratory methodology presented could be very effective for types of accidents for which there is only a small amount of literature available.

4.2. Limitations of the method

There is a concern related to quality of the data and underreporting issues, as there is with any method using accident reports data,. As was mentioned in Molinero-Ruiz et al. (2015) [13], public authorities need to look for a better and more reliable database for ESAW in order to enable better research on this topic.

Another limitation is the lack of information about how many workers are exposed to the risk that the individual worker was exposed to when the accident occurred.

Regarding the specific accident mechanism, it must be noted that the data is based on manufacturing in Andalusia and used all accidents. Other studies [22,23] show different results depending on the countries or industries analyzed or the injuries included, for instance when limiting results to fatal and non-slight accidents.

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