Work-related road accidents: a statistical multivariate analysis in Italy

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Abstract

Despite the relevance of road accidents and their impact on social and health care costs, their work-related component is seldom studied. The available data about road accidents lack of occupational parameters that allow studying the phenomenon. We produced an integrated archive linking, at individual level, road accidents data with compensation for occupational injuries data referring to accidents occurred in Italy from 2014 to 2018. Data were statically analysed by frequency, time series, cluster and multiple correspondence analysis to describe their characteristics, time evolution, and to highlight the most representative road accidents among fatal and non-fatal events at work and during commuting. Results indicate a higher occurrence of accidents during commuting and the importance of miscellaneous economic activities as well as the transport and warehouse economic sectors.

Keywords: Road accidents, occupational injuries, compensation data, data linkage, time series.

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1. Introduction

Road traffic injuries represent a relevant public health problem. According to the WHO, road traffic accidents account for almost 1.3 million deaths a year around the world, and between 20 and 50 million victims sustain non-fatal injuries (WHO, 2018). In Italy, the Italian National Institute of Statistics - Istat registered about 170,000 road accidents during the year 2019, for which 3,173 persons died and 241,384 were injured. A 30% reduction is estimated for the year 2020 due to lockdown for COVID-19 pandemic (Istat, 2020). A substantial fraction of these road accidents have an occupational origin. Workers use vehicles either for commuting (home-work travelling routes) or for activities at work (*e.g.* in the transport sector). According to data collected by the Italian National Institute for Insurance against Accidents at Work (Inail), the occupational accidents occurring using a transport vehicle represent about 14% of the total registered occupational injuries, of which 11% are related to commuting and 3% to activities at work (Inail, 2020).

Risk factors for work-related road accidents have been investigated by some authors. Weather is considered to be an important factor particularly for those activities involving heavy truck vehicles. Driving in windy, rainy and snowy conditions was found to be associated with a higher risk (Ahmed *et al.*, 2018; Moomen, Rezapour, and Ksaibati, 2019; Naik *et al.*, 2016; Uddin and Huynh, 2020). Extreme temperatures were also found to be associated with risk of road accidents (Gariazzo *et al.*, 2021; Wu, Zaitchik, and Gohlke, 2018). Additional risk factors are fatigue, stress and sleepiness (Öz, Özkan, and Lajunen, 2010; Robb *et al.*, 2008). Other studies addressed factors like driving behaviours (Mitchell, Bambach, and Friswell, 2014), age of drivers (Newnam *et al.*, 2018), exposure (Pei, Wong, and Sze, 2012), and scheduling issues as well as physical constrains at work (Fort *et al.*, 2010) as determinants for work-related road accidents.

The analyses of road accidents and their determinants are often limited by the amount and quality of data, particularly for work-related road accidents. Road accidents data are routinely collected by national or local Authorities at the time of the event, as in Italy, but the information about the occupational origin is rarely or partially collected and factors useful for an insight analysis are missing. To overcome these limitations, some authors used either case-control studies or cross-sectional studies based on trauma registry, self-

administered postal questionnaire or interviews, in a restricted sample of road accidents. In this way they could analyse the occupational characteristics of work-related road accidents and obtain better knowledge of the types of occupational groups and industry sectors involved (Fort *et al.*, 2010; Hours *et al.*, 2011). Other studies are focussed on particular categories of workers, like truck drivers, to collect information on risk factors (Uddin and Huynh, 2020). The use of workers compensation data, linked with the police road accidents' records, allows increasing the effectiveness of the epidemiological analysis, adding supplementary occupational information otherwise not available (Boufous and Williamson, 2006). The efficiency of data linkage between the two archives often limits its application, as recording errors in the two registration systems, the different sources of registration (police intervention *vs.* occupational accident compensation claims), and missing declarations of occupational accidents, might have produced missed matches. A recent study in Italy linked the two archives for the year 2015 finding that only 23% (20,941) of individuals who claimed for compensation were linked to the general road accidents archive provided by Istat (Brusco *et al.*, 2019). As most of these events caused injury to the involved subjects, the number of fatal events were not sufficient to be analysed. In addition, time series analysis was not possible using this time-restricted dataset.

Due to the above restrictions, the studies about the occupational component of road accidents are rather limited and focussed either on the determinants of road accidents or on their occupational characteristics, but not both at the same time. Consequently, there is a need for combining and analysing road accidents and occupational data as a whole to obtain detailed information about which type of road accidents is more involved by workers characteristics and economic sector.

The aim of the present study is to provide, by means of a multi-year data archive and statistical analysis procedures, a more complete picture of the circumstances of work-related road accidents occurring in Italy, including both fatal and non-fatal events, getting a new insight in the occupational risk factors of road accidents.

2. Materials and methods

2.1 Work-related road accidents data archive

In Italy data about road accidents, in which an injury or fatality occurred, are collected by Istat on the basis of data recorded from different national and local Authorities. Although such data should contain information about the occupational condition of the driver involved in an accident, this is rarely available. Consequently, the only established observatory of work-related road accidents is that provided by Inail in the frame of occupational injuries. The Inail archive (Inail, 2019) covers about 80% of the Italian workforce. It receives compensation claims for occupational injuries over the whole national territory, regarding all workers, except for some categories (armed forces, firefighters and police workers, air transport personnel, autonomous tradespeople and professionals with VAT registration). Inail collects all requests of compensation for accidents occurred during the course of work for violent and external causes with injuries that determined temporary inability (higher than 3 days), permanent inability or death. In case of road accidents, it classifies them either as during commuting (home-work journey) or on-duty (involved vehicle is used for work activity). The requests of compensation are processed to verify if they are work-related, and to determine the type of indemnity assigned (temporary; annuity to survivors; direct annuity; capital account) and, if the case, the duration of leave. Inail process all these events and produces statistical reports about this phenomenon.

We selected from the Inail archive the compensation claims for injuries occurring with the use of a vehicle during either commuting or activities at work. The collected data include date/time and location of accident; demographic variables (gender, age at injury); modality of occupational accident (commuting; on-duty); economic sector of activity derived from the Inail classification of tariff group[3]; information on the gravity of the injury, measured as the duration of leave (including those events below the allowed threshold of 3 days, which were not compensated); and degree of impairment. All the above information are available at individual level. No information

3 The tariff group refers to an aggregation of industrial processes that associate the production sector with the premium rate.

is provided about the characteristics of the road accident. Such information could be gathered from the Istat archive, through a proper individual record linkage between the two archives.

The accident data collected by Istat contain information about some characteristics of the road accident, such as: information about date and localisation (built-up area or outside built-up areas and subcategories); type of road and weather conditions; type of junction; number and types of vehicles involved; road accident type (among moving vehicles, between a moving vehicle and pedestrian, between a moving vehicle and a stationary one or other obstacle, moving vehicle without collision and subcategories), the role of person involved in the accident (driver, passenger, pedestrian), names of individuals involved in the road accident. Istat and Inail archives were linked at individual level using a combined deterministic and probabilistic procedure (Taiano *et al.*, 2021). Briefly, as the data collected by Istat refer to accidents, possibly involving one or more individuals, this archive were first transformed into n records, each one representing a person involved in the accident. Then we linked this archive to the compensation claims one provided by Inail using common variables such as name, surname and age of involved individual, date and location of event. Afterwards, to increase the number of linked data, a probabilistic procedure were applied to residual data, in which matching variables ranged in a predefined window size and a linkage probability is assigned using a sorted neighbourhood algorithm. The data linkage project is included in the Italian National Statistical Programme (PSN) and allowed by the Data Protection Authority. Sensitive data were anonymised after the data linkage for further use.

The data linkage of the two archives produced a unique dataset including subjects injured or death in work-related road accidents occurred in Italy from 2014 to 2018. For the statistical analysis, a few categorical variables were re-aggregated to obtain both a synthesis of the information and an increase in the number of occurrence. As for the economic sectors, the Inail codes of tariff group was used and recoded in macro-economic categories. Table 2.1 lists some variables selected for this study with a short description.

Table 2.1 - List of variables of work-related road accidents

Variable	Value	Description
Age class	<23; 23-40; 41-60; 61+	
Gender	Men; Women	
Modality of occupational accident	Commuting	Road accident occurring during home-work journey
	On-duty	Road accident using a vehicle for working reasons
Road accident type	Collision with obstacle or parked vehicle;	Impact with stationary vehicle; Impact with parking vehicle; Impact with an obstacle
	Nose-to-tail accident;	Nose-to-tail collision
	Collision among moving vehicles; Running down pedestrian;	Frontal collision; Frontal/lateral collision; Lateral collision; Impact with pedestrian
	Moving vehicle without collision	Off-road vehicles; Sudden braking; Dropped from vehicle
Type of vehicle	Private car;	Private passenger car; Trailer passenger car; Four-cycle
	Agriculture machine;	Road tractor; Agricultural tractor; Animal traction vehicle; other agricultural vehicle
	Heavy vehicle;	Private coach; Truck; Articulated lorry; Special vehicle
	Motorcycle;	Moped; Motorcycle one person; Motorcycle with passenger; Three-wheeler
	Public vehicle;	Urban public service bus; Rescue or police car; Tram; Public car; Public coach
	Bike	Bike
Junction	Straight; Crossroad; Bend; Other	
Localisation of the accident	Motorway; Suburban road; Urban road	
Severity	0; 1-14; 15-30; 31-90; >90	Number of days of leave
Macro-economic sector	Agriculture	Agricultural or forestall workers employed in cultivation, forestry and animal husbandry
	Public employees/Students	Employees of central state administration; public educational employees; students
	Servants	
	GG0 - Various activities	Sale; Reception and catering; Health and social services; Cleaning, sanitation and disinfestation; Cinematography, entertainment, cultural and sports activities; Education, scientific research, survey and prospecting; Various activities
	GG1 - Agricultural and food processing	Agricultural mechanical processing; foods processing; animals slaughter
	GG2 - Chemical, paper, leathers	Plastics and rubber; paper and polygraph; leather
	GG3 - Buildings and installation	Construction; Road and rail constructions and maintenance; Construction of urban lines and pipelines; civil and industrial plant engineering
	GG4 - Energy and communication	Production, transmission, conversion and distribution of energy, gas; water, vapour and conditioning installations
	GG5 - Wood and related	Wood manufacturing; Carpentry and restoration works
	GG6 - Metals and machinery	Metallurgy and works connected; Metals transformation; construction, transformation and repairing of machineries
	GG7- Mining, rocks and glass	Research, extraction and processing of minerals and rocks; production and processing of glass
	GG8 - Textiles and packaging	Processing of textile yarns; packaging of clothing, furniture and shoes; laundries, ironing, dry cleaners
	GG9 - Transport and warehouses	Transports; upload, download, porterage of goods and materials; warehousing and goods handling

Source: Authors' processing on Inail and Istat datasets

2.2 Statistical analysis

Data of subjects involved in work-related road accidents occurred in Italy from 2014 to 2018 were first analysed in a descriptive and univariate analysis for their occurrences according to accident and occupational variables. Then a time series analysis was carried out to study possible trends and seasonality. Afterwards, two statistical multivariate analyses were applied to classify groups of data and to reduce dimensionality of the studied topic: cluster analysis and multiple correspondence analysis. The above statistical techniques are described in details in the following paragraphs. All analyses have been performed separately for fatal and non-fatal accidents.

2.2.1 Time series analysis

In order to investigate about possible trend and seasonal components in the observed number of subjects involved in work-related road accidents, a decomposition of the time components was carried out. A Seasonal and Trend decomposition using Loess (STL) was applied (Cleveland *et al.*, 1990). STL is a filtering procedure for decomposing a time series into trend, seasonal, and remainder components. STL has a simple design that consists of a sequence of applications of the loess smoother. It allows the seasonal component to change over time with a user-controlled rate of change, as well as to control for the smoothness of the trend-cycle. The two main parameters to be chosen when using STL are the trend-cycle window and the seasonal window. These parameters control how rapidly the trend-cycle and seasonal components can change. The former is the number of consecutive observations to be used when estimating the trend-cycle, the latter is the number of consecutive years to be used in estimating each value in the seasonal component. In this analysis, the option "periodic" was used for the seasonal window parameter (*i.e.* identical across years), which means that smoothing is effectively replaced by taking the mean, while the trend-cycle window parameter was left to be calculated by the internal STL code. The robust fitting was used in the loess procedure. The analysis was implemented by using the STL code implemented in R package.

2.2.2 Cluster analysis

In order to group and order homogenous data of subjects involved in work-related road accidents, data were analysed by cluster analysis using the Partitioning Around Medoids (PAM) and Clara methods depending on the amount of data to be clustered (Kaufman and Rousseeuw, 2005).

The main objective of clustering is to find groups of cases (*e.g.* road accidents) which show a high degree of similarity (a cluster), being as dissimilar as possible to those belonging to other clusters. The PAM method is an iterative procedure to search for k representative objects (Medoids) which represent various aspects of the structure of the data. The quality of resulting medoids is measured by the average dissimilarity between every object in the entire dataset and the medoid of its cluster. The metric used for calculating dissimilarities between observations is the Euclidean distance. The Clara method is an extension of PAM methods and it is suitable to deal with large amount of cases in order to reduce computation time and memory usage. Instead of using the full dataset to cluster data, it samples a chosen amount of cases to be clustered, and applies the PAM algorithm to generate an optimal set of medoids for the sample.

Data about subject involved in work-related road accidents were stratified for type of outcome (fatal or injured) and modality of occupational accident (commuting and on-duty) and cluster analysed separately. This choice is motivated by the different data structures involved when the types of outcome and occupational accidents are both taken into account. As an example, we expect a large spread in the economic sectors involved in accidents during commuting, while a more focussed number of sectors for those during on-duty activities. The following categorical variables were selected for clustering: road accident type, type of vehicle involved, localisation of the accident, junction, age class of involved person, macro-economic sector, all as defined above. In a few analyses some modalities of the macro-economic sector were further aggregated to increase the number of occurrences (*e.g.* public employees, servant and agriculture; wood and related, mining, rocks and glass, textiles and packaging).

In this study, the fatal datasets (commuting and on duty) were clustered by means of PAM method, while non-fatal road accidents datasets (commuting and on-duty) were clustered using the Clara method using 50,000 and 10,000

sample sizes, respectively. The optimal number of clusters were chosen by iteratively applying the PAM and Clara method from 2 to 20 number of clusters and by calculating the silhouette width at each step, which is an aggregated measure of how similar is an observation to its own cluster compared its closest neighbouring cluster. Their highest values determine the optimal number of clusters.

As a result, the clustering analysis assigns each case to a specific cluster. The frequency of the each modality of the selected variables has then been calculated by cluster, to describe the cluster's accident and occupational characteristics (fingerprint). Given variable categories, the lesser the spread of the frequencies among its modalities, the more the cluster is defined for that variable. The modalities with the largest frequency are usually close to medoids descriptors.

2.2.3 Multiple Correspondence Analysis

A Multiple Correspondence Analysis (MCA) has been performed to detect and represent the underlying structures of data, searching for the basilar dimensions. MCA can be seen as a generalisation of principal component analysis when the variables to be analysed are categorical instead of quantitative (Abdi and Williams, 2010). It provides the associations between variable categories, whose distance between any points gives a measure of their similarity or dissimilarity.

The MCA was applied to analyse the association among the following variable: type of accident; modality of occupational accident (commuting or on duty); accident severity according to classes of days of leave (0; 1-14, 15-30; 31-90; >90) and macro-economic sectors. As for the latter, a different classification was adopted to get better information on some subsectors of the GG0-various activities sector. This sector contains a significant portion of the collected work-related road accidents. In particular, the following sectors were used in the MCA analysis, as the most contributing ones: GG01-Sales; GG02 - Reception and Catering; GG03 - Health and social services; GG07 - Various activities; GG3 - Buildings and installation; GG6 - Metals and machinery; GG9 - Transport and warehouses; Other.

The above variables allow for a combined analysis that would have been impossible to carry out using only the respective data archives they were taken from.

3. Results

3.1 Statistical description and time series analysis of work-related road accidents

Table 3.1 shows a statistical description of the subjects involved in work-related road accidents registered by Inail and successful linked to Istat archive. In total 128,795 subjects involved in work-related road accidents were identified during the years 2014-2018. About 25,000 accidents were registered each year with a little yearly variation. Northern regions of Italy show the largest contribution with about 82,000 accidents (64%), followed by the Central regions with 25,900 (20.2%). Less than 12,000 are observed in Southern Italy and Islands. Injuries make the most relevant outcome (98.5%) in occupational road accidents, and men are more involved than women (62 *vs.* 38% respectively). Workers with age between 23 and 60 are the most contributing (89%), while younger ones (<23 years old) are found in 7% of the total cases. The greater number of accidents occurs during commuting (77.7%), while road accidents during the use of a vehicle for on-duty account for 22.3% of cases. The collision among moving vehicles represents the largest type (54.8%), followed by the nose-to-tail ones (26%). Private cars and motorcycles are the two most involved types of vehicle (53.5 and 25.9% respectively). Road accidents mostly occur in urban and suburban roads (62.4 and 29.4% respectively), mainly in straight sections (46.1%) and in crossroads (36.1%).

As far as the macro-economic section is concerned, the various activities group (GG0) largely contributes to the total number of work-related road accidents (53.6%). This is a miscellanea group of different activities like sales, reception and catering, health and social services, cleaning services, entertainment, technical services and other activities. Originally, these activities were grouped to avoid an excessive granularity of cases. Much lower contributions are found for the remaining macro-economic sectors. The second largest contribution is ascribed to the metals and machinery sector (8.8%), closely followed by the transport and warehouses (8.3%). Buildings and installation sector accounts for about 6% of cases, while public employees sector contributes for about 5%.

Table 3.1 - Frequencies of work-related road accidents by variables

Work-related road accidents	Number of subjects involved	%
Overall	128,795	100.0
Year		
2014	25,372	19.7
2015	24,813	19.3
2016	26,041	20.2
2017	25,863	20.1
2018	26,706	20.7
Macro-region		
North-East (Emilia-Romagna, Friuli-Venezia Giulia, Trentino-Alto Adige, Veneto)	40,905	31.8
North-West (Liguria, Lombardia, Piemonte, Valle d'Aosta)	42,007	32.6
Centre (Toscana, Umbria, Marche, Lazio)	25,985	20.2
South (Abruzzo, Molise, Campania, Puglia, Basilicata, Calabria)	12,890	10.0
Islands (Sicilia, Sardegna)	7,008	5.4
Outcome		
Dead	1,891	1.5
Injured	126,904	98.5
Gender		
Men	79,875	62.0
Women	48,920	38.0
Age class		
<23	9,456	7.3
23-40	54,247	42.1
41-60	60,475	47.0
61+	4,617	3.6
Modality of occupational accident		
Commuting	100,033	77.7
On-duty	28,762	22.3
Road accident type		
Moving vehicle without collision	13,060	10.1
Running down pedestrian	3,700	2.9
Collision among moving vehicles	70,627	54.8
Nose-to-tail accident	33,298	25.9
Collision with obstacle or parked vehicle	8,110	6.3
Type of vehicle		
Private car	69,217	53.7
Agriculture machine	164	0.1
Heavy vehicle	12,263	9.5
Motorcycle	33,419	25.9
Public vehicle	2,075	1.6
Bike	7,113	5.5

Source: Authors' processing on Inail and Istat datasets

Table 3.1 continued **- Frequencies of work-related road accidents by variables**

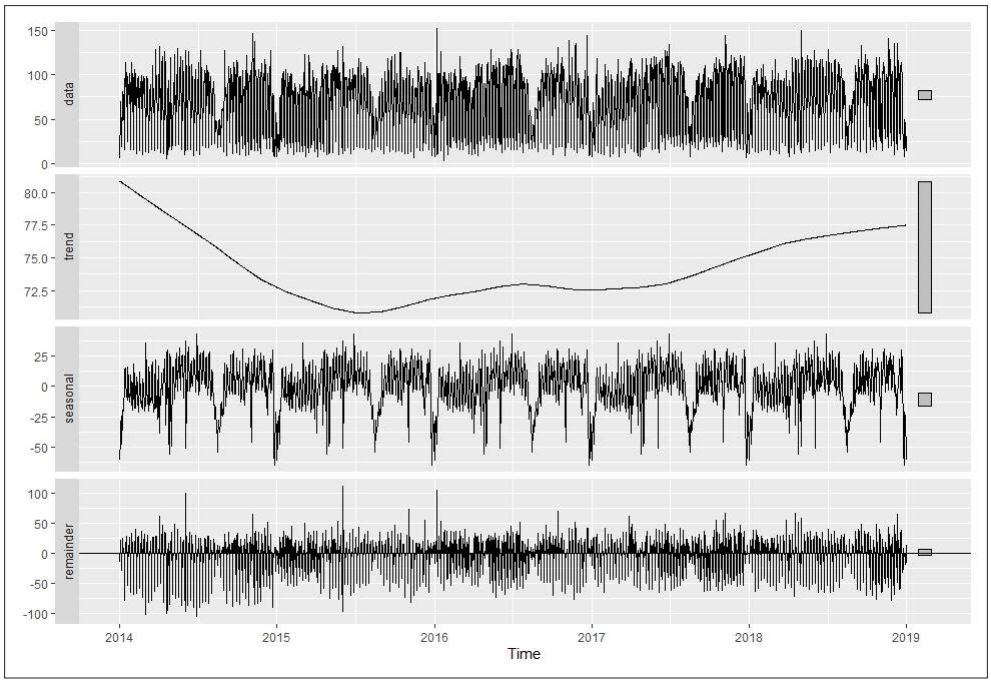
Work-related road accidents		Number of subjects involved	%
Localisation of the accident			
Motorway		10,635	8.3
Suburban road		37,836	29.4
Urban road		80,324	62.4
Junction			
Straight		59,359	46.1
Crossroad		46,467	36.1
Bend		14,277	11.1
Other		8,692	6.7
Macro-economic sector			
Agriculture		2,823	2.2
Public employees/Students		7,084	5.5
Servants		1,497	1.2
GG0 - Various activities		69,022	53.6
	GG01 - Sales	11,421	
	GG02 - Reception & Catering	9,165	
	GG03 - Health & social services	9,958	
	GG04 - Cleaning, sanitation and disinfestation	4,946	
	GG05 - Cinematography, entertainment, cultural and sport activities	813	
	GG06 - Educational, scientific research, survey and prospecting	1,574	
	GG07 - Various activities	28,928	
	GG08 - undefined	1,919	
GG1 - Agricultural and food processing		2,821	2.2
GG2 - Chemical, paper, leathers		2,866	2.2
GG3 - Buildings and installation		8,210	6.4
GG4 - Energy and communication		631	0.5
GG5 - Wood and related		1,037	0.8
GG6 - Metals and machinery		11,305	8.8
GG7- Mining, rocks and glass		759	0.6
GG8 - Textiles and packaging		2,379	1.8
GG9 - Transport and warehouses		10,715	8.3
n.a.		7,646	5.9
Severity [days of leave]			
0		38,799	30.1
1-14		32,833	25.5
15-30		18,691	14.5
31-90		24,097	18.7
>90		14,375	11.2

Source: Authors' processing on Inail and Istat datasets

Figure 3.1 shows the time series of daily number of subjects involved in work-related road accidents occurred in Italy from 2014 to 2018. Up to 150 involved subjects are observed on a daily bases, with a minimum of about 25. A strong weekly and seasonal variability is also detected, with a significant decrease in the number of events during weekends and holidays, as well as in the month of August, usually used for summer holidays in Italy. A plot of the total monthly road accidents is shown in Figure A1 in the Appendix. The positive association between extreme temperature and road accidents occurrence has been previously estimated (Gariazzo *et al.*, 2021), with an increase of risk of work-related ones for both hot and cold.

The trend and seasonal components are also shown in Figure 3.1. The trend exhibits a decrease up to the middle of 2015, to increase gently from that year on. The seasonal component ranges from -50 to 25 on a daily bases. The lowest values are observed during summer and Christmas holidays when workers have days off. The remainders, the number of events after removing trend and seasonal components, ranges between -75 and 50 events per day, with a significant weekly pattern. Based on a measure of strength of trend and seasonality defined by Wang *et al.* (Wang, Smith, and Hyndman, 2006), a value of 0.99, in a range 0-1, was obtained for both trend and seasonality.

Figure 3.1 - Decomposition of time components of subjects involved in work-related road accidents



Source: Authors' processing on Inail and Istat datasets. Number of subjects involved in daily accidents (upper figure), trend component (higher middle figure), seasonal component (middle figure), reminder component (bottom figure). Boxes in the right side represent the relative scale of components

3.2 Cluster analysis results

The cluster analysis identifies 13 clusters for both on-duty and commuting non-fatal work-related road accidents. Nine and ten clusters were obtained for on-duty and commuting fatal road accidents respectively. As described above, the cases belonging to each cluster were grouped to calculate the frequencies of modalities of each selected variable. Based on these frequencies, heat maps were then plotted to show the accident and occupational characteristics of each identified cluster. Figure 3.2 shows the heat maps of the frequencies of the modalities of each selected variable by cluster, obtained for on-duty and commuting in non-fatal road accidents. Figure A2 in the Appendix shows the correspondent plot for fatal accidents.

As for non-fatal on-duty results, we found five clusters (CL1-4 and CL11) which identify the private car as vehicle involved, with events mostly occurring in urban and suburban roads and an accident type involving moving vehicles or nose-to-tail accident in straight or crossroads, out of those represented by cluster 11, which occur in motorways. These events involve workers at age 23-60 employed in various activities (GG0) (CL1-3, CL11) and transport, warehouses (GG9), as well as the metals and machinery sector (GG6) (CL4). All these car-related events contribute for about 41% of the total on-duty non-fatal road accidents. Another significant portion of road accidents is ascribed to those occurring using a heavy vehicle (27%) (CL6, CL7, CL10, CL12, CL13). They mainly occur in suburban roads and motorways, with the exception of cluster 12, which takes place in urban roads, and are characterised by an accident type involving prevailing moving vehicles or nose-to-tail accident with some cases (5%, CL10 and CL13) by moving vehicle without collision. The macro-economic sectors mostly involved in these heavy vehicle related accidents are the transport and warehouses sector (GG9), the buildings and installation sector (GG3) and the various activities sector (GG0). The remaining clusters (CL5, CL8, and CL9) are represented by different type of vehicles with a small prevalence of motorcycles, occurring in urban roads. The involved workers have age class either 23-40 or 41-60, and are employed in the various activities sector (GG0) or in the transport and warehouses macro-economic sector (GG9).

As for non-fatal commuting results, the use of a private car is found in 8 of 13 clusters. These clusters contribute for about 62% of the total non-fatal commuting road accidents. They mainly occur in urban and suburban roads in proximity of straights or crossroads and involving an accident type among moving vehicles or nose-to-tail accident. The most representative age classes are the middle age classes (23-40, 41-60) which cover almost the entirety of the working period. The most frequent macro-economic sector involved in this kind of accidents is the various activities sector (GG0) with an additional contribution from other sectors like the transport and warehouses (GG9), the metal and machinery (GG6) and the building and installation (GG6), all ascribed to cluster 3 and 9. Four clusters are related with the use of a motorcycle, accounting for about 33% of the total non-fatal commuting work-related road accidents. The urban roads are the most frequent type of road where they take place, mainly involving collision among moving vehicles,

as accident type, in proximity of straights or crossroads. For these accidents the various activities economic sector (GG0) contributes for 20% of the total non-fatal commuting accidents, followed by the metal and machinery sector (GG6), the transport and warehouses sector (GG9), and the building and installation sector (GG6), which contribute with one cluster (CL13) for about 9% of the total. The remaining cluster (CL3 in Figure 3.2, bottom) is associated with other macro-economic sectors with about 3% of the cases. Finally, we found a cluster which is characterised by the use of a bike (CL10 in Figure 3.2, bottom), and contributes for about 5% of the non-fatal commuting road accidents. Its profile is described by occurring in urban road, with a collision among moving vehicles, as accident type, in proximity of straights or crossroads and involves workers of middle age classes employed in the various activities sector (GG0).

The cluster analysis results of fatal on-duty work-related road accidents (Figure A2 of Appendix, upper) show similar characteristics as those of non-fatal ones. The only remarkable differences are the larger contribution of heavy vehicles compared to private cars (45 *vs.* 26%), followed by accidents involving motorcycles (22%) with two clusters, and the additional contribution of accidents involving pedestrians, not accounted in the non-fatal analysis, with 6.7% of the cases. In addition, motorways appear with higher frequencies in two clusters. The various activities sector (GG0) and the transport and warehouses sector (GG9) are confirmed to be the most frequent macro-economic sectors involved. As for fatal commuting road accidents, the main characteristics of clusters obtained for non-fatal accidents are also confirmed (Figure A2 of Appendix, bottom). Workers employed in the various activities sector (GG0) involve nine of ten identified clusters. Private cars and motorcycles are confirmed as the two most involved vehicles in fatal commuting road accidents. A remarkable difference with respect to non-fatal commuting road accidents is the higher frequency of suburban roads compared to urban ones.

Figure 3.2 - Heat map of distribution of characteristics of on-duty (upper) and commuting (bottom) work-related non-fatal road accidents by cluster

Source: Authors' processing on Inail and Istat datasets

3.3 Multiple correspondence analysis results

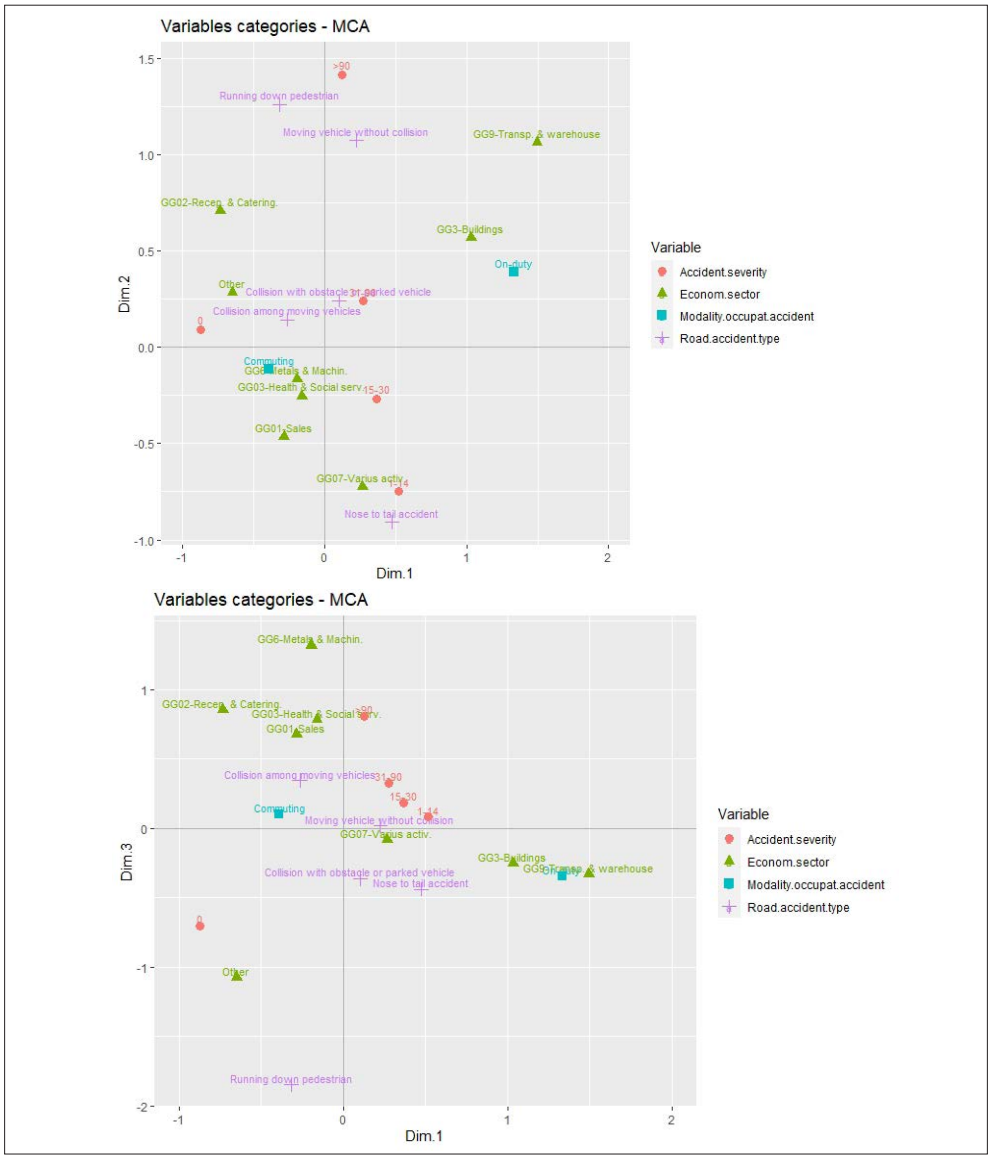
MCA results indicate that more than ten dimensions are needed to explain about 67% of the observed variance. Figure A3 in the Appendix shows a scree plot of explained variance by each MCA dimension. It can be seen that the three principal components explain about 23% of the observed variance. Figure A4 in the Appendix shows the correlation between variables and the MCA principal dimensions. It can be seen that the modality of the occupational accident is correlated with dimension 1 and the type of accident with dimension 2. Figure 3.3 shows two plots of coordinates of each variable categories with dimensions 1 and 2 (upper figure) and dimensions 1 and 3. In these plots, variable categories with a similar profile are grouped together and negatively correlated variable categories are positioned on opposite sides of the plot origin. Furthermore, the distance between category points and the origin measures the quality of the variable category on the factor map. Category points that are away from the origin are well represented on the factor map.

Figure 3.3 shows that the two modalities of occupational accidents (on-duty and commuting) are inversely correlated, as well as the nose-to-tail accident with the others types of accidents. The three variable categories On-duty, GG3-Buildings and GG9-transports and warehouse seem to group, suggesting that these economic sectors are related with on-duty accidents. Another group is formed by accidents during commuting, occurring in GG6-Metals and machinery sector, GG03-Health and social services sector and GG01-Sales economic sector with a severity of 15-30 days of leave. The "Running down pedestrian" and "Moving vehicle without collision" types of accidents are close to the 'more than 90 days of leave' category, meaning that a greater severity is associated to these kind of accident. Finally, the "Nose-to-tail accident" likely groups with accidents occurring in the GG07-Various activities economic sector, and with a severity of 1-14 days of leave. It confirms that this kind of accident is not related with a particular economic sector but spreads over miscellanea of them.

The contributions of variables categories to MCA principal dimensions is shown in Figure A5 of Appendix. The categories On-duty, GG9-Transports & warehouse, Nose-to-tail accident, the severities with days of leave >90, 0 and 1-14 days, GG07-Various activities sector and commuting for the modality of occupational accidents, are the most important in the definition of MCA

dimensions 1 and 2. However, since a low percentage of variance is explained by the first two principal dimensions (16%), more dimensions would be needed to fully describe the contribution by variables categories.

Figure 3.3 - Coordinates of each variables categories in each dimension. Dim. 1 *vs.* Dim. 2 (upper figure), Dim. 1 *vs.* Dim. 3 (bottom figure)



Source: Authors' processing on Inail and Istat datasets

4. Discussion

Work-related road accidents are known to be a significant portion of the registered occupational accidents (WHO, 2018). Their contribution to the total road accidents is unknown as the registration systems often fail in collecting information about the possible occupational origin of these events. The requests for compensation for occupational injuries are consequently the most reliable available data sources to study the phenomenon. Such archives contain information about the individuals claiming for compensation, the municipality where the accident occurred, the health consequences, the economic sector in which the workers was employed, the duration of leave and the degree of impairment, but nothing about the characteristics of the road accident which determined the request for compensation. To overcome this limitation, this work developed a data linkage procedure which combined at individual level the data provided by the Italian road accidents archive, with the data of requests for compensation for occupational injuries. This is the first multi-year combined work-related road accidents data archive ever provided in Italy. It allows, for the first time, to study not only the occupational characteristics of this phenomenon, but also the descriptors of road accidents.

The main findings of this study are the statistical description of the dataset, the results of the time series analysis, the classification of the accidents in terms of road, nature, localisation and involved macro-economic sectors parameters, as well as the reduction of dimensionality to represent the underlying structures of data.

The statistical description of this dataset highlights the greater occurrence of commuting road accidents with respect to those occurring during on-duty activities (77 *vs.* 23%). These results are well known from a number of statistical reports published by Inail about work-related road accidents (Inail, 2020; Brusco *et al.*, 2019). Men are more represented than women (62 *vs.* 38%) and this result reflects what was reported in the last annual report of Inail (Inail, 2020). A similar result is obtained about the disproportion between fatal and non-fatal events (1.5 *vs.* 98.5%). Consequently, as far as the occupational parameter are concerned, the dataset used in this study is consistent with those reported by Inail in its annual reports about occupational accidents. The economic macro-sector ascribed to various activities (GG0) is found to be the most involved one (54%). It covers a number of miscellaneous activities

composed by different type of services and reflects the tertiary component of the Italian economic structure. Minor contributions are detected for the transport and warehouses sector, the metals and machinery sector and the building and installation sector. A novel additional information provided by this study is about the road accidents characteristics. Collisions due to moving vehicles or nose-to-tail ones are the two most frequent types of work-related accidents (55 and 26% respectively). The accidents involve mainly private cars and motorcycles (54 and 26% respectively), with an additional contribution of heavy vehicles (9%). As for motorcycles during the last decade, the traffic congestion occurring in metropolitan areas has increased the use of such travelling mode (Automobile Club d'Italia 2021). This has dramatically increased the number of accidents involving motorcycles with a correspondent increase in number of motorcyclists dead or injured. The result is corroborated by the findings of this study, which addressed the urban roads as the most frequent location where accidents occur (62%), followed by the suburban roads (29%) with straights and crossroads as the two most frequent types of localisation where accidents occur.

These results confirm those obtained by both national reports (Istat, 2020) and published research papers (Eboli, Forciniti, and Mazzulla, 2020) obtained for indistinct road accidents.

The work-related road accidents were found to have strong weekly and seasonal components. The former mainly depends on the organisation and scheduling of work activities, which is distributed in working days and reduced in weekends. The latter component has a periodical behaviour with a minimum in August and during holidays periods as well as an increasing monthly trend from winter to middle of summer. The number of yearly road accidents was found almost constant (about 25,000 per year) in compliance with findings in France (Charbotel, Martin, and Chiron, 2010), but a slightly variation in the long-term trend was detected.

A novel result of this study was the classification of work-related road accidents in terms of accident and occupational parameters. To account for health outcome, representative road accidents were identified by clustering data for fatal and non-fatal outcome and each of them by accidents occurring during commuting or on-duty activities. As for non-fatal on-duty events we found five clusters, accounting for 41% of all events, which describe road

accidents occurring using a private car in a urban road, driven by workers at age 23-60 and involving the various activities macro-economic sector, the transport and warehouses sector, and the metals and machinery sector. Others types of non-fatal accidents on-duty were those involving heavy vehicles, involving five clusters and contributing for 27% of these kind of events. The descriptors of these accidents are suburban roads or motorways, moving vehicles or nose-to-tail accident, as accident type, and involve mainly the transport and warehouses sector, the building and installations sector, and the various activities economic sector. The results about heavy vehicles are consistent with those obtained in Australia (Boufous and Williamson 2006) and France (Charbotel, Martin, and Chiron, 2010; Hours *et al.*, 2011). As for non-fatal road accidents during commuting, we found two large groups of clusters. The first one is characterised by accidents occurring in urban or suburban roads in proximity of straights or crossroads, and involving private cars. This group of clusters contributes for about 62% of this kind of events and involve primarily the various activities sector and secondarily the transport and warehouses sector, the metal and machinery sector and the building and installation sector. The second group is composed by clusters involving a motorcycle in an accident occurring in an urban road due to a collision among moving vehicles. They account for about 33% of the non-fatal commuting events and involve mainly the various activities economic sector with smaller contributions from the metal and machinery sector, the transport and warehouses sector and the building and installation one. With respect to on-duty accidents, commuting ones show a larger spread in the involved economic sectors, mainly for both the larger number of workers involved and the number of economic sectors.

The results of the cluster analysis for fatal work-related road accidents show similar characteristics as those about non-fatal ones, with a few remarkable differences like the involvement of pedestrians and a larger contribution of heavy vehicles compared to private cars in on-duty accidents.

The multiple correspondence analysis provided results indicating how the different types of accidents group when the modality of occupational accidents, economic sector and severity of events (measured as number of days of leave) are taken into account. The large heterogeneity of data did not allow for describing their variance with a few principal components. Using

three dimensions, the MCA analysis was able to explain about 23% of the total variance. Results showed that on-duty accidents grouped with the "Transports and warehouse" sector, as well as with the "Building "economic sector. It confirms the results of cluster analysis for the on-duty accidents datasets. These economic sectors are known to be exposed as transports of goods. The accidents occurring during commuting were found by MCA analysis to group in the first two dimensions with the "Metal & machinery" sector, the "Health & social services" sector, and the "Sales" economic sector, as well as with the 15-30 days of leave group. On a lesser extent, the GG07-Various activities sector was found also linked with accidents during commuting. Such results partially confirm those obtained by the cluster analysis, but also allow us to distinguish the contribution of the "Health and social services" sector and the Sales sector, which were aggregated in the larger GG0-various activities economic sector when cluster analysed. Conversely, to on-duty accidents, such commuting events seem to be related with multiple economic sectors, confirming their heterogeneous origin.

Based on the above findings, we can consider that work-related road accidents are mainly involved in non-fatal events occurring during commuting and in a limited extent by events during on-duty activities. The cluster results provided the occupational and accident characteristics of these events, identifying key descriptors and consequently possible directions of prevention measures aimed to reduce the occurrence of such events. The home-work journey by car or motorcycle is found at risk particularly in urban and sub-urban areas where both traffic and intersections are quite high. These commuting events involve mainly the service industry sector in which miscellanea of different activities can be found. Among the possible measures to reduce the incidence of such commuting events, we should consider to limit the use of private vehicles by increasing the public transports particularly during rush hours in urban areas. An additional measure could be to increase the number of workers who could work at home at least for those kind of jobs in which this work activity can be applied. Such measure can be applied particularly in the service industry sector, which has been identified in this study as that mainly involved in such events. A recent national report (Inail, 2021) address the smart working during the COVID-19 as one of the key factor of the observed reduction in the work-related road accidents. The road-accidents occurring during on-duty activities were found to involve specific

economic sectors such as transport and warehouses, service sector, as well as building and installation. To reduce such events, the limitation in the use of vehicle is not a reliable solution. General prevention measures, such as the limitation of exposure by reducing the number of working hours and the introduction of rest time, as well as training and information sessions about road safety, could help in reducing such on-duty events. Fatigue, stress and sleepiness are other factors to be considered in work-related accidents and prevention measures could be identified to limit them.

This work has provided useful information in characterising and classifying the work-related road accidents phenomenon occurring in Italy. However, it contains a number of limitations. We could not relate the accidents with both the individual aspects of involved drivers and the information about internal and external concurring factors linked with the accident. As for the individual aspects important features like fatigue, scheduling issues (organisational, procedural and timely measures), physiological conditions of drivers and its driving performance or drug assumptions were not available. Other concurring circumstances like traffic, speed of involved vehicles were not available. All this information is impossible to be retrieved at an individual level. The lack of this information does not allow us to investigate about the reasons of these accidents, and whether they are related to job tasks. However, such studies can be carried out at individual levels for specific type of workers, and it was out of the scope of this work, which was focussed on a more general picture of work-related accidents. In addition, there is an unknown number of work-related road accidents which were missing in this archive. First, some categories of workers were missing in the compensation data (about 20% of workforce), although a few of them are not expected to largely contribute to occupational road accidents (eg. armed forces, firefighters, police workers and air transport personnel) and consequently affect the findings of this study. However, autonomous tradespeople and professionals with VAT registration are missing in the Inail compensation archive, but could be included in the ISTAT one. They represent about 21% of the total workforce. In case of road accidents, these types of job can be hardly classified as commuting or on-duty events, as far as the heterogeneities of these kind of jobs are concerned. The lack of their inclusion in this study can be considered a possible limitation, but they should not modify the findings presumably. Second, some missing events come from the efficiency of the linkage procedure, which depends

on the correctness of the information contained in both the accidents and the compensation claims archives. Uncertainty in the linkage process could come from the probabilistic component of the linkage procedure, as for the deterministic pass, accuracy is enforced by the nature of the variables selected. The inclusion of additional filters allows accounting for most of the linked pairs (more than 90%). More than 95% of those pairs are localised in the same province or municipalities geographically close. This gives us enough confidence on the accuracy of the algorithm. In addition, the equality of the identifying fields make extremely narrow the chances that they can refer to distinct accidents (Taiano et. al., 2021). Consequently, uncertainties regarding the linkage process could not potentially influence the results. Other missing data could come from the lack of registration in one or both archives. As an example, a road accident cannot be registered in case of a missed intervention of local authorities or a registered accident could lack of a request for compensation and not be registered as an occupational injuries. For these reasons, the actual dimension of the phenomenon cannot be figured. We think that the combined archive is sufficiently representative of the work-related accidents phenomenon, as demonstrated by the consistency of other results with those obtained from this archive.

At the same time, this study addressed some of the limitations of work-related data systems in providing a more complete picture of the circumstances of occupational road accidents.

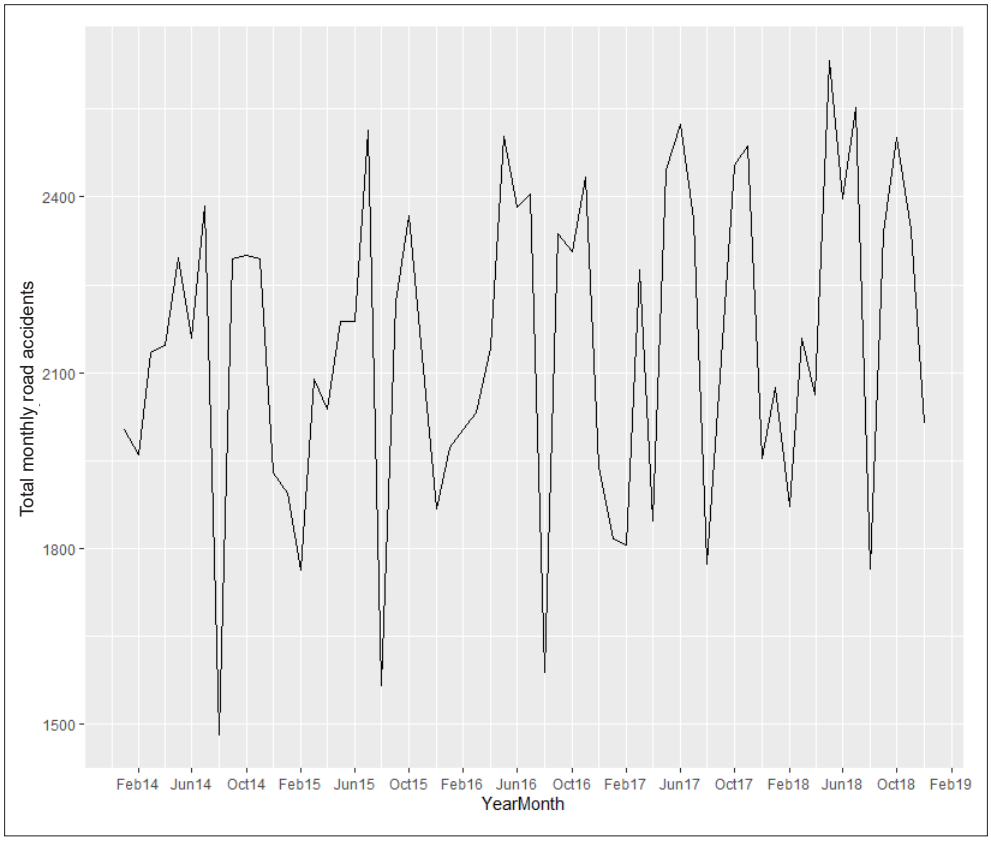
5. Conclusions

The work-related road accidents represent a significant portion of occupational accidents. The intrinsic limitations in assessing and monitoring such phenomenon and in identifying accident and occupational determinants where faced by combining linking the road accidents archive and the compensation claims for occupational injuries archive at individual level. Data were statistically analysed to extract combined information otherwise not available by evaluating them separately. Results address the urban and suburban areas as the most dangerous places where these events occur. Different types of collision are found as the origin of accidents, using private cars and motorcycles as preferred vehicle. Time series analysis highlights a strong weekly and seasonal variation. The cluster analysis allows to identify typical road accidents profiles, including both accident parameters and involved economic sectors, by health outcomes and modality of occupational accident. Both cluster and MCA analysis found that road accidents during on-duty service are dominated by the "Transports and warehouse" sector and by the "Buildings" economic sector, while commuting accidents can be ascribed to more heterogeneous sectors.

Based on these findings, prevention and reduction policies are needed to limit the impact on health and social costs of road accidents in general and of work-related ones in particular.

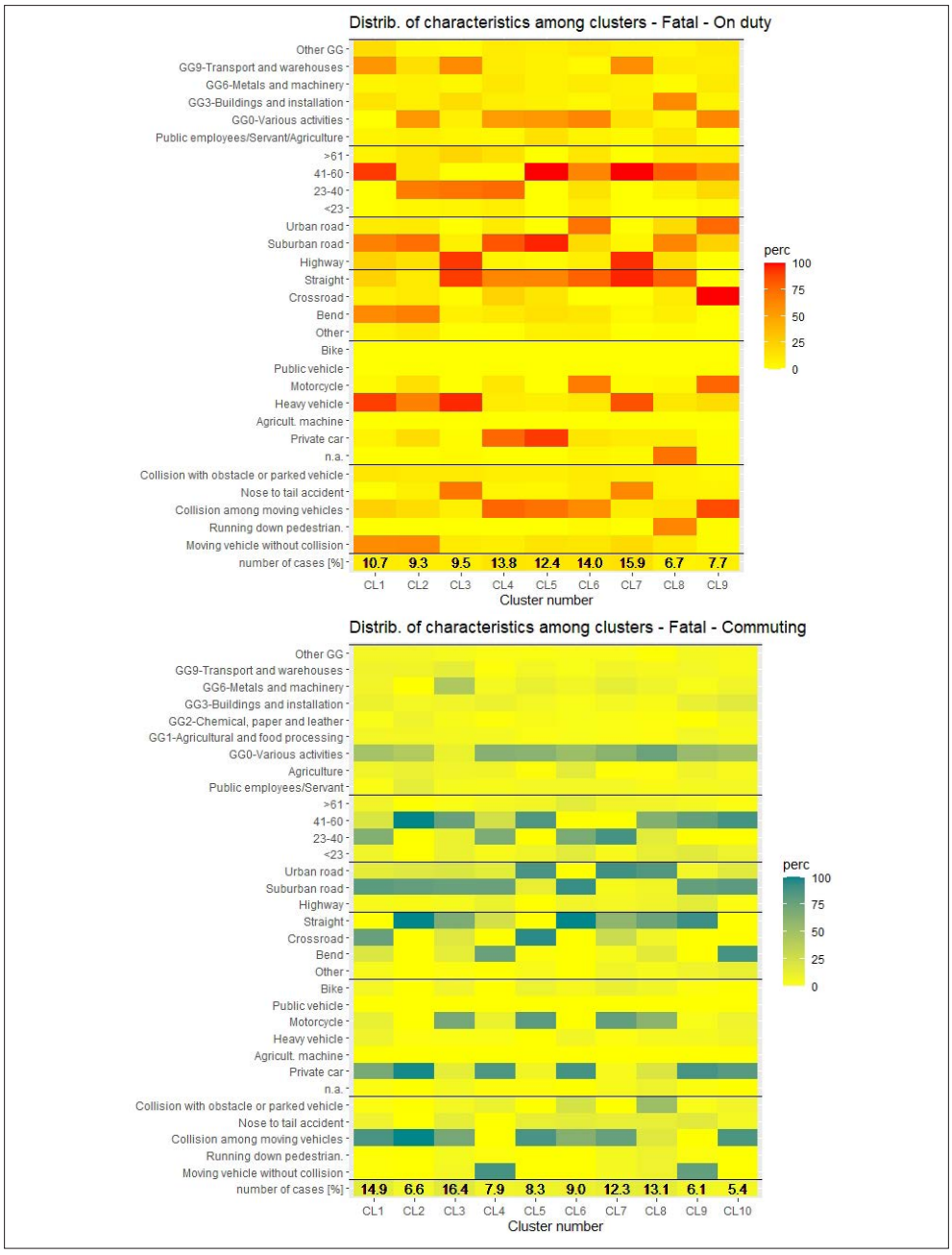
Appendix

Figure A.1 - Time series of the total monthly work-related road accidents occurring in Italy from 2014 to 2018



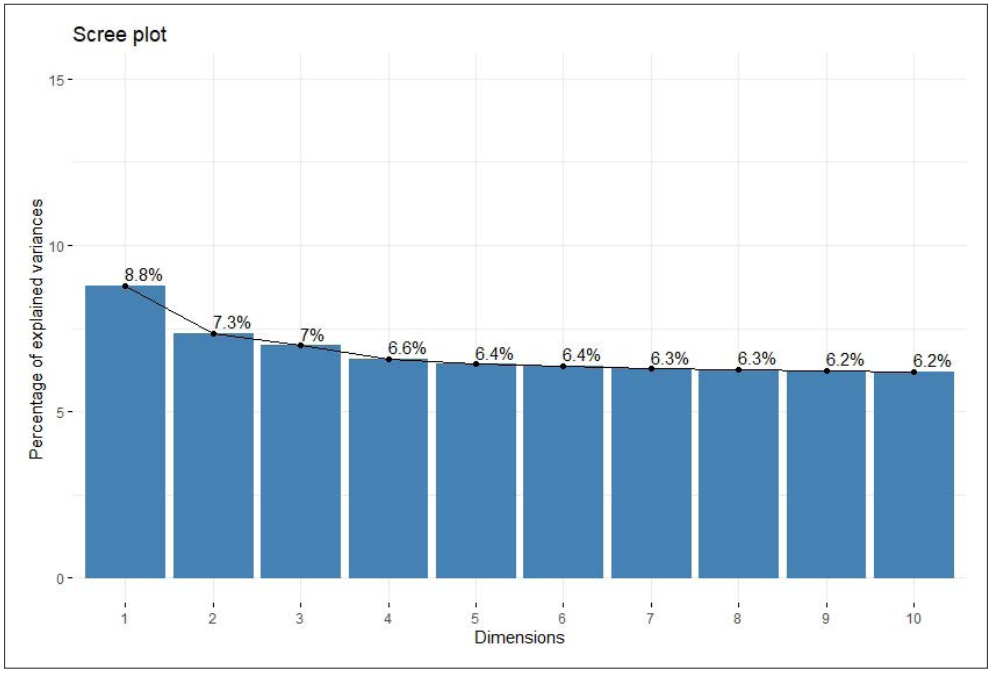
Source: Authors' processing on Inail and Istat datasets

Figure A.2 - Distribution of characteristics among clusters in fatal work-related road accidents



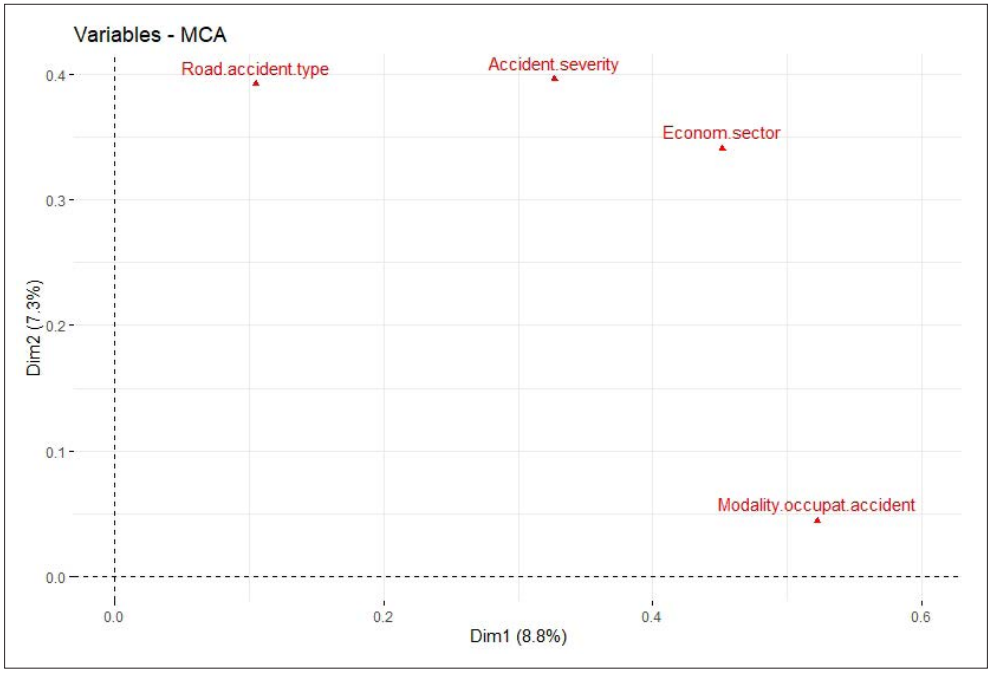
Source: Authors' processing on Inail and Istat datasets

Figure A.3 - Percentage of explained variances by each MCA dimension



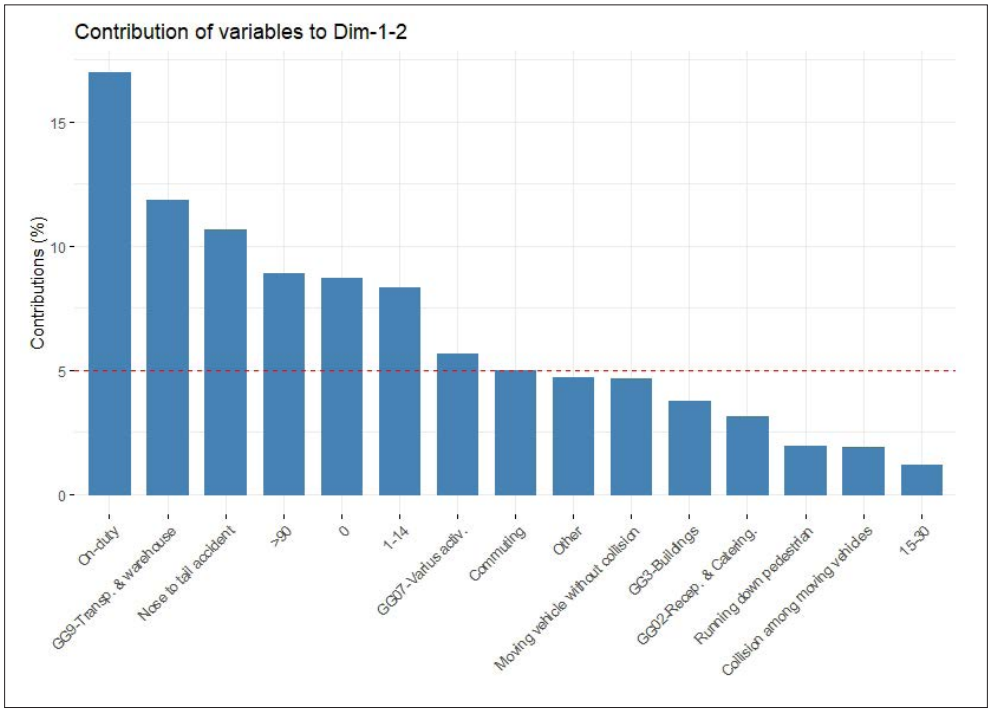
Source: Authors' processing on Inail and Istat datasets

Figure A.4 - Correlation between variables and MCA principal dimensions



Source: Authors' processing on Inail and Istat datasets

Figure A.5 - Contribution of variable categories to MCA principal dimensions. The red dashed line on the graph above indicates the expected average value, if the contributions were uniform



Source: Authors' processing on Inail and Istat datasets

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