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" Safety cost estimation : a tool for SMEs "

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Abstract (*ITA*)

L'analisi della letteratura ci rivela che le aziende raramente riescono a riconoscere i costi della non sicurezza e a cogliere l'opportunità di investire denaro per migliorare il proprio sistema di sicurezza. In aggiunta, nella letteratura non si approfonda il problema inerente la quantificazione dei costi della non sicurezza, con maggiore enfasi sulle piccole e medie imprese (PMI). L'attenzione è stata posta su queste tipo di imprese a causa del loro alto numero di infortuni e scarsa attenzione rispetto alle grandi imprese.

Questo studio esplorativo è basato su una precedente ricerca relativa alla riclassificazione e scelta dei costi della sicurezza per le PMI. Conoscendo questi tipi di costo dovuti ad incidenti, l'ulteriore sviluppo sarà impostato su due fasi principali: in una prima parte, si individueranno le formulazioni matematiche delle voci di costo precedentemente selezionate, attraverso la metodologia del Focus Group composto da partecipanti con ampia conoscenza a riguardo; nella seconda parte il processo, atto a raggruppare le aziende attraverso fattori rilevanti, sarà presentato in modo dettagliato al fine di essere applicato nei casi reali.
Nell'ultima parte, un esempio sarà sviluppato per chiarificare e analizzare meglio l'obiettivo del intero processo.

Il risultato ottenuto da questa ricerca è uno strumento in grado di analizzare quali sono i fattori riguardo la sicurezza (e altri fattori relativi) dividendo le PMI in gruppi caratteristici.

PAROLE CHIAVI : OSH; sicurezza; costi; stima; PMI;

Abstract (*ENG*)

The literature analysis reveals that companies rarely recognize the real cost of non-safety and the opportunity to invest in improving their own safety management system. Furthermore, there is a lack of research concerning economic evaluation of non-safety costs, with an emphasis on small and medium-sized enterprises (SMEs). Attention has been focused on these companies due to their higher number of accidents and absence of attention with respect to larger ones.

This exploratory study is based on a previous research regarding the reclassification and selection of relevant non-safety costs for SMEs. Understanding what are the main impacting cost items due to accidents, the further development will be set in two main phases: in the first part, the mathematical formulation of previously identified cost items and relative variables will be detected by a focus group composed of participants with wide knowledge of SME environments; secondly, the process, able to group companies by different relevant factors, will be explained, detailing all the steps needed to be applied to real cases. At the end, an example will be developed in order to have a clear vision of the entire process.

The result derived from this paper is a tool able to understand what are the main factors dividing different SMEs into characteristic groups.

KEYWORDS : OSH; safety; cost; estimation; SME;

1. Introduction

For proper evaluation of the economic performance of an organization, it is clearly evident, from literature, that companies need to comprehend aspects that go beyond the financial dimension to include elements relating to working conditions, employee well-being and work environment. An important contribution to the economic performance of an enterprise is undoubtedly made by the security conditions. Most organizations are unable to systematically calculate work-related costs and are unaware of the economic repercussions associated with non-security.

1.1. General overview of data injuries in Italy

The positive data confirm a downward trend under way for some years; although the decline can be at least partly supported by the reduction in the amount of work arose by the economic crisis, however, a regressive phase of the injury phenomenon must be observed. The positive trend should not be cause for satisfaction: you cannot be forgotten as the public are regularly disturbed by reports of serious accidents events and high drama, sometimes even at the expense of several people at once. When you consider that the complaints received by INAIL of injury are less than 2200 per day, of which about 3 are fatal cases, one realizes how it is still far from achieving the goal of sheltered and safe workplaces.

In Italy Inail, the National Institute for Insurance against Accidents at Work, is a public non-profit entity safeguarding workers against physical injuries and occupational diseases. Inail’s objectives are:

- protecting workers performing hazardous jobs
- facilitating the return to work of people injured at workplace
- reducing the incidence of accidents and occupational diseases.

The insurance - compulsory for all employers hiring subordinate and para subordinate workers in the activities that the law defines as risky - protects workers against damages due to work-related accidents and occupational diseases; this protection, according to the principle of "automatic entitlement to benefits," also includes those cases where the insurance premium has not been paid regularly by the employer.

The insurance releases the employer from liability resulting from the damage caused by his employees, except when he has committed violation of the rules on prevention and safety at work.

The worker protection, even as a result of recent legislative changes, has increasingly taken on the characteristics of an integrated system of protection, ranging from preventive actions at the workplace to medical services and financial assistance; to rehabilitation and reintegration of victims of workplace accidents or professional diseases to social and working life.
Since 2010 Inail's tasks have also included the insurance against accidents at work and occupational diseases of maritime employees and ships crews registered in foreign compartments. Moreover, it is also responsible for research in the field of work accident prevention, safety at workplace, health in the living and working environment.

Table 1.1 : Number of declared injuries from 2012 to 2016 in Italy

	Years				
	2012	**2013**	**2014**	**2015**	**2016**
During the job	*651.443*	*595.717*	*567.264*	*541.639*	*543.494*
		-9%	-5%	-5%	0%
without medium of transport	33.154	24.754	22.064	20.983	20.633
		-34%	-12%	-5%	-2%
with medium of transport	618.289	570.963	545.200	520.656	522.861
		-8%	-5%	-5%	0%
Ongoing	*94.101*	*99.299*	*96.322*	*95.505*	*97.851*
		5%	-3%	-1%	2%
without medium of transport	68.558	73.451	70.986	70.358	71.285
		7%	-3%	-1%	1%
with medium of transport	25.543	25.848	25.336	25.147	26.566
		1%	-2%	-1%	5%
Total	**745.544**	**695.016**	**663.586**	**637.144**	**641.345**
		-7%	-5%	-4%	1%

This choice is based on the fact that it is more difficult to control than the phenomenon of occupational diseases. In fact, as regards the latter, they have been developed evaluation systems to quantify which are the highest levels of exposure to harmful factors for health conditions such as vibration, chemical, manual handling of loads and so on; so in theory, and we also hope into practice, respecting the exposure limit will eliminate the risk to health and related economic loss. On the contrary, the injury phenomenon is removed from complex control, as it is specific to every business reality and includes countless factors to consider.

1.2. Why Small Medium Enterprises ?

"Small firms often appear to be unaware of their legal obligations, do not realize the dangers of poor practice, do not think about the benefits of good health and safety practice and have insufficient resource to devote to health and safety" (McKinney, 2002)

Great attention is focused on this type of firm. In Italy, SMEs comprise a very significant number of companies: of 4,338,766 businesses, 4,335,448 (99.9%) are small and medium-sized enterprises. In addition, almost all SMEs (95%) are made up of companies with fewer than ten employees. The rest consists of enterprises employing 10 to 49 employees (196,090 units, or 4.5%), while the largest enterprises (50 to 249 employees) number only 21,867, or 0.5 per cent of the total.

Membership of the Small and Medium Business category can be defined by different criteria; For the European Union The main factors determining whether an enterprise is an SME are:

- staff headcount
- either turnover or balance sheet total

Table 1.2: SMes characteristics

Company categories	Staff headcount	Turnover	Balance sheet total
Medium -sized	<250	≤ 50 mln	≤ 43 mln
Small	<50	≤ 10 mln	≤ 10 mln
Micro	*<10*	*≤ 2 mln*	*≤ 2 mln*

It should be noted that, while it is compulsory to meet the thresholds for staff, an SME may choose to comply with the revenue criterion or the criterion of the total budget; the company must not meet both criteria and may exceed one of the thresholds without losing its rating.

However, most organizations are unable to systematically calculate work-related costs and, as a proof of this, is unaware of the economic repercussions associated with non-security.
In most of the companies in this category, the human and financial resources available are small compared to large companies involving greater obstacles to the estimation of accident costs.
Investing in safety and health can bring benefits to businesses; even simple adjustments are potentially able to increase the company's competitiveness and profitability, as well as employee motivation.

1.3. Main goals of the research

The aim of this paper is to describe a simple process used to define the shape functions for each cost item, to understand how to group companies coming from different sectors and how to economically evaluate a possible accident at work; such a tool must be used to capture similarities and differences among all types of SME in terms of firm size, production sector and safety organization. Companies with similar characteristics, therefore belonging to the same group, will have an identification parameter different from companies that are placed in different groups.

By defining all groups for each cost function, it is possible to obtain a wider view of the major differences between the classes of company and subsequently analyse the possible interventions that the most loss-making companies will be able to implement in order to improve their safety performance.

The paper is structured in three main sections: section 2 presents the list of non-security costs by defining the shape and the unknown parameters. Section 3 describes the research on cost items and cost functions, defining variables and parameters. Section 4 exposes the process that is used to group companies into clusters through the alpha vector. In the last part (section 5), an example is used to show the application of the model.

2. Background

The literature provides a general picture of the health and safety position for SMEs but most studies focus on the effectiveness of the interaction from a health point of view and rarely consider the financial virtues (Tompa et al. , 2008). As a matter of fact, the related scientific papers are covered by information on costs incurred by the company in the event of an accident, on the nature of them and how it is possible to classify them—all information which, as will be seen, is fundamental to estimating the economic consequences of non-security costs. However, the research and the methods of making such an estimate are lacking, leaving a vacuum that it is vital to fill.

In many scientific papers dedicated to safety costs, the authors divided the costs due to injury into two types: direct and indirect (or 'hidden'). Many researches have affirmed that the indirect costs are much higher than direct ones (Bird, 1974; Dorman, 2000; LaBelle, 2000; Neville, 1998) and found that most managers know the direct costs but have difficulty quantifying the hidden ones (Gavious et al. , 2009; Oxenburgh and Marlow, 2005). Most of these studies use workers' compensation expenses as the only cost measurement, including the value of changes in health outcomes and the value of wages paid for lost time (AIHA, 2008). The indirect costs should be obtained for each situation, or at least for each company, instead of using a blind multiplier (Oxenburgh and Marlow, 2005). Furthermore, it is possible to detect the presence of several classification criteria for cost items; as reported by Dorman (2000), there is frequently an overlap between direct/visible costs and indirect/hidden costs.

More specifically, in most companies categorized as small-medium enterprises, the availability of human and financial resources is minor compared to large companies (Cagno et al., 2013). This gives rise to major obstacles in estimating the cost of injuries: the effort devoted to such estimation is limited and the information on which the estimation is based is sparse; moreover, tracking the data consumes time and money. Other reasons why many companies prefer not to calculate these costs, especially indirect ones, are:

- Difficulty in quantifying them (as their valuation is very often hard and economically costly).
- Overload of managerial work that would be required to monitor such items.

- The lack (or complete absence) of personnel, inside the company, dedicated to health and safety at work with both economic and managerial skills.

It is important to develop a simple and customizable solution because of the informal culture of small enterprises (Champoux and Brun 2003; Hasle and Limborg, 2006) and, most importantly, as guidance to managers (Rickardsson and Impgaard, 2002).

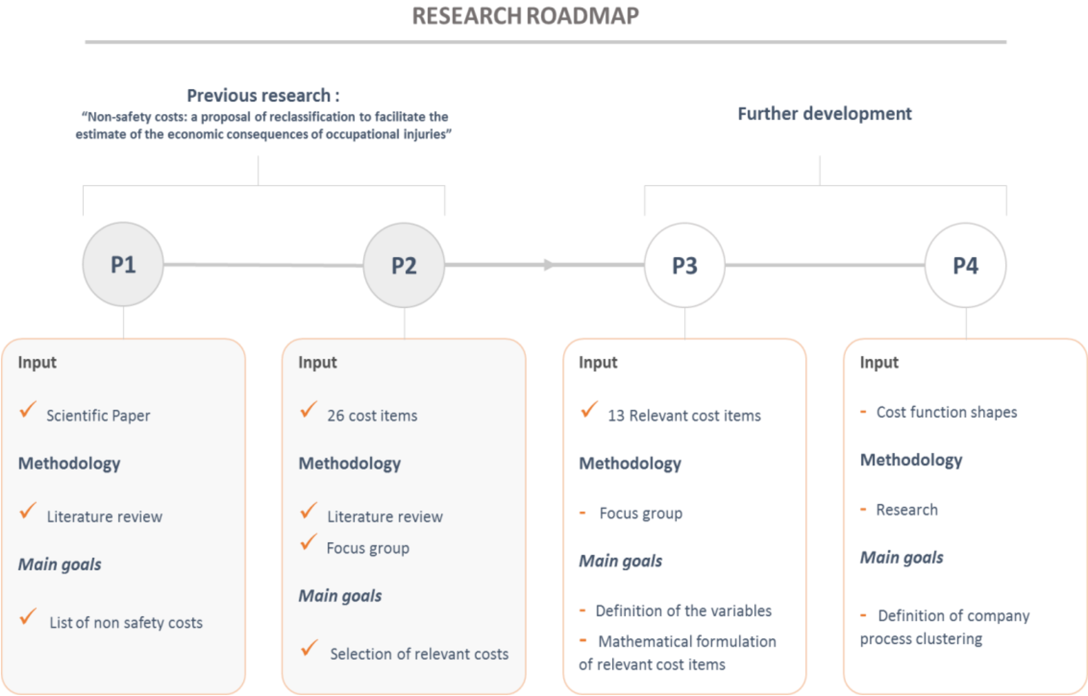
Haslam notes that the most cited costs, such as sick pay/replacement worker cost and lost production/revenue, highly impact performance and management/investigation time (Haslam et al., 2010); additionally, the author explains that "there are several differences in perceived impact of some costs, depending on the size and nature of the respondent business" (Haslam et al., 2010, p. 486).

2.1 Research roadmap

A schematic diagram of the research roadmap is shown in figure 2.1. The effort so far carried out derives from the paper "Non-safety costs: a proposal of reclassification to facilitate the estimate of the economic consequences of occupational injuries", edited by Micheli et al. (2015).
In the paper, the research is divided essentially into two main parts. In the first part, the authors review the main literature concerning safety costs, obtaining a significant list of all costs sustained by a company in case of an accident. It should be considered that in companies of this size, there is generally low fatality in accidents; therefore, the historical source of information in literature for the quantification of costs turns out to be inconsistent. In the second part, the authors develop a classification of non-safety costs by introducing the need for a quantitative mathematical model suitable for small and medium-sized enterprises.

Starting from this step, it is possible to set the main goals for the development of the authors' work. Two main phases will be analysed: the definition of the shape function for the relevant costs and the clustering process useful for grouping the companies.

Figure 2.1 : Research roadmap



2.2 Resume of previous research

Literature review of costs

In the first part of the aforementioned article, attention was centred on how to classify all the costs items defined by their nature in order to obtain a coherent picture of the economic losses sustained by the companies as a result of accidents. By analysing and reviewing the literature, it emerges that costs comprise a total of 26 entries (Table 2.1), mostly divided into ten categories (Micheli et al., 2015). A method that takes into account this multitude of elements is overly complex to be really applicable in companies where time is a critical resource.

Table 2.1 : List of non-safety costs Adapted from Micheli et al. (2015; Safety and Reliability of Complex Engineered Systems ESREL, p. 3282. Taylor & Francis Group, London.)

LIST OF NON SAFETY COSTS

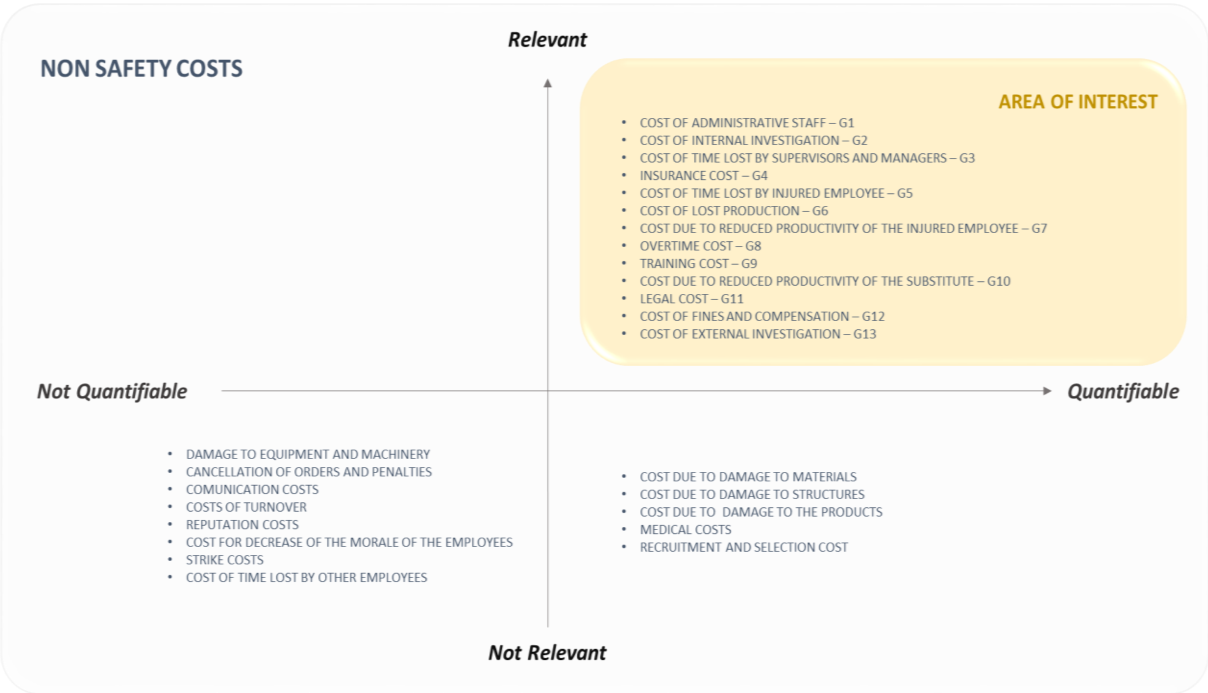
1| COSTS DUE TO DAMAGE TO EQUIPMENT AND MACHINERY	14| COST OF ADMINISTRATIVE STAFF
2| COSTS DUE TO CANCELLATION OF ORDERS AND PENALTIES	15| COST OF INTERNAL INVESTIGATION
3| COMUNICATION COSTS	16| COST OF TIME LOST BY SUPERVISORS AND MANAGERS
4| COSTS OF TURNOVER	17| INSURANCE COST
5| REPUTATION COSTS	18| COST OF TIME LOST BY INJURED EMPLOYEE
6| COST FOR DECREASE OF THE MORALE OF THE EMPLOYEES	19| COST OF LOST PRODUCTION
7| STRIKE COSTS	20| COST DUE TO REDUCED PRODUCTIVITY OF THE INJURED EMPLOYEE
8| COST OF TIME LOST BY OTHER EMPLOYEES	21| OVERTIME COST
9| COST DUE TO DAMAGE TO MATERIALS	22| TRAINING COST
10| COST DUE TO DAMAGE TO STRUCTURES	23| COST DUE TO REDUCED PRODUCTIVITY OF THE SUBSTITUTE
11| COST DUE TO DAMAGE TO THE PRODUCTS	24| LEGAL COST
12| MEDICAL COSTS	25| COST OF FINES AND COMPENSATION
13| RECRUITMENT AND SELECTION COST	26| COST OF EXTERNAL INVESTIGATION

Cost selection

Through a focus group composed of eminent professionals specializing in the field of safety, simplification has been achieved by extrapolating costs that can be estimated ex-ante with a sufficient degree of accuracy (quantifiable costs) and that are considerably more expensive than other (relevant) costs. Specifically, relevant items show the impact of each element on non-safety global costs, whereas ex-ante estimability shows the accuracy in defining cost estimation from a pre-accident perspective.

For the purpose of the research development, which will be explained in the following paragraphs, the relevant quantifiable costs will only be taken into account.

Figure 2.2 : Cost categories. Adapted from Micheli et al. (2015; Safety and Reliability of Complex Engineered Systems ESREL, p. 3284. Taylor & Francis Group, London.)

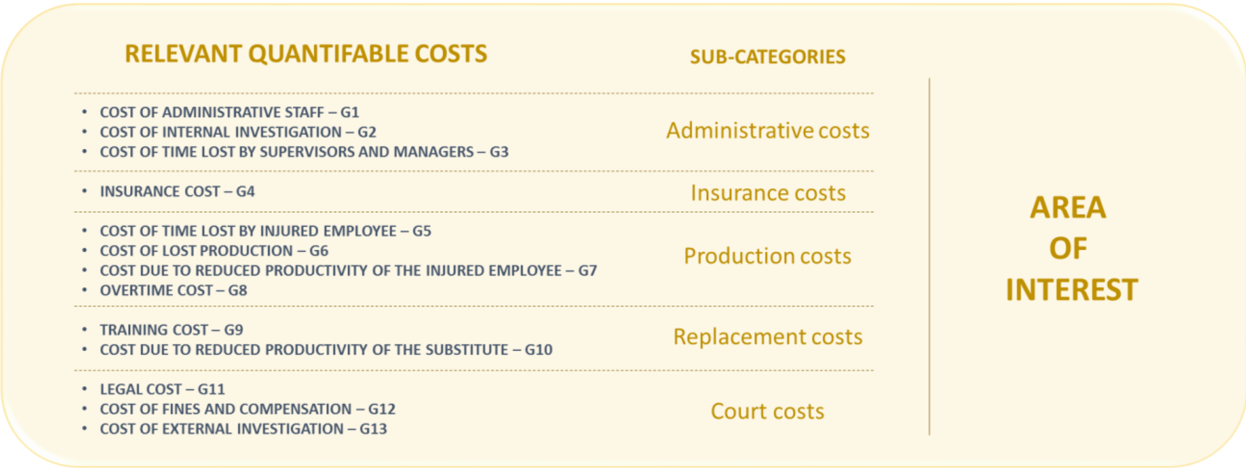


As shown in figure 2.2, half of list is considered by focus group as relevant and quantifiable. This issue is very significant because highlight the high amount of cost incurred by an accident which are not considered by companies. During the focus group, it was also discovered that the relevant quantifiable costs can be divided into five sub-categories (Figure 2.3). The costs are described in table 2.2.

Table2.2 : Description of relevant non-safety costs

G	COST ITEMS	DESCRIPTION
G1	*Cost of administrative staff*	The cost of time spent by administrative staff for handling the case.
G2	*Time lost by supervisors and managers*	Cost of time lost by supervisors and executives to assist the injured worker, reprogram production, hire and train substitutes, attend meetings, and report.
G3	*Cost of internal investigation*	The cost of the time spent by the task force to investigate the causes of the accident; Necessary to complete the administrative documentation. It was considered appropriate to deal in a voice other than the cost of external investigation of the incident since it is tied more to the legal consequences of the event than to its administrative management.
G4	*Insurance costs*	Cost that consists in the growth of the insurance premium due to one or more accidents. From this point of view, what matters is how much the cost increases with respect to a certain sample of events, not how much the company pays in total to protect itself from the consequences of accidents.
G5	*Cost due to reduced productivity of the injured employee*	Remuneration payable to the accident in the accident period not indemnified by INAIL; May include salary additions if they are provided by company policy.
G6	*Cost of lost production*	Cost due to the slowdown in work caused by the accident; This item represents the cost of the production stop that occurs when an employee is involved in an accident.
G7	*Cost of time lost by injured employee*	The employer loses productivity when an employee works below his / her capacity or is assigned to less demanding activities due to the accident; This generates a cost for the company because the amount of output produced will be lower than that of the previous working conditions.
G8	*Overtime cost*	To recover lost production due to the accident, the company may employ extraordinary hours of work, plus regular pay.
G9	*Training cost*	Cost to support to provide the new hired instructions and information that will enable it to perform its duties in a correct and efficient manner.
G10	*Cost due to reduced productivity of the substitute*	Company's lack of profit due to the fact that the new assumption needs a certain amount of time to achieve full productivity due to the poor experience.
G11	*Legal cost*	Costs incurred by the company to defend itself from accusations of liability which, if attributed to it, would result in compensation for the injured party.
G12	*Cost of fines and compensation*	If the incident is due to violations of safety procedures or failure to comply, the organization may be exposed to fines and claim for compensation by the authorities.
G13	*Cost of external investigation*	Costs of time spent by authorities and safety consultant to analyze the injuries and to figure out possible solution to the problems.

Figure 2.3 : Relevant-quantifiable sub-categories costs



2.3 Introduction to further development

Tracking the cost of accidents is very important because often the employers are not able to quantify and predict the economic impact (Biddle et al. , 2005). This is especially true if a company has not been hurt for several years. Furthermore, without evaluation, it is difficult to estimate how investments can impact on benefit by reducing the risk level. This is the case for small and medium-sized businesses where it is difficult to perceive accidents for long periods of time, so it becomes statistically impossible and insignificant to carry out detection in the absence of data. As a result, there may be a distorted perception of the risks and related costs. Consequently, there is a need to create a new way to achieve an accurate estimation of the non-safety costs appropriate for SMEs.

An ex-ante view allows the ability to outline an adaptable approach for any company, a method that does not require a consistent and reliable historian to quantify non-safety costs (Micheli et al., 2015). In practice, it is possible to create from this vision a method which is able to group different companies from different sectors.

Shape functions of relevant costs

As explained above, a historical-based tool is not effectively applicable to companies in this category; for this reason, a method is proposed that allows estimation of the cost of injuries expected on account of the company risk distribution. In order to obtain an economic evaluation, it is necessary to get shape functions for each cost item. The estimation, which will be heavily dependent on the shape of cost functions, may allow deviations in respect of the value that could occur afterwards. This can be refined over time by improving the formulation of functions; in any case, it does not undermine the potential impact of the application that it wants to operate at a strategic level.

The final purpose is to achieve a realistic assessment that gives employers and decision makers the opportunity to understand the economic effect of the injuries they incur.

The main goal of this part will be centred on how to obtain cost functions and which variables will be part of them. The next paragraphs will explain in detail the process used to achieve the mathematical formulation describing the methodology applied.

Clustering process

In the last part of the paper, the clustering process will be detailed, defining all the necessary steps. The approach will use the cost functions found in the previous part and will apply a statistical tool in order to group companies into different clusters. A survey will be done to collect data related to injury and cost forecasts, useful for the clustering process. After the data are obtained, it will be possible to apply the procedure and find clusters characterized by an alpha value.

This final step is crucial for the next project. As a matter of fact, by means of this process, future researches could investigate in a better way the main analogies and differences between enterprises with a small number of employees.

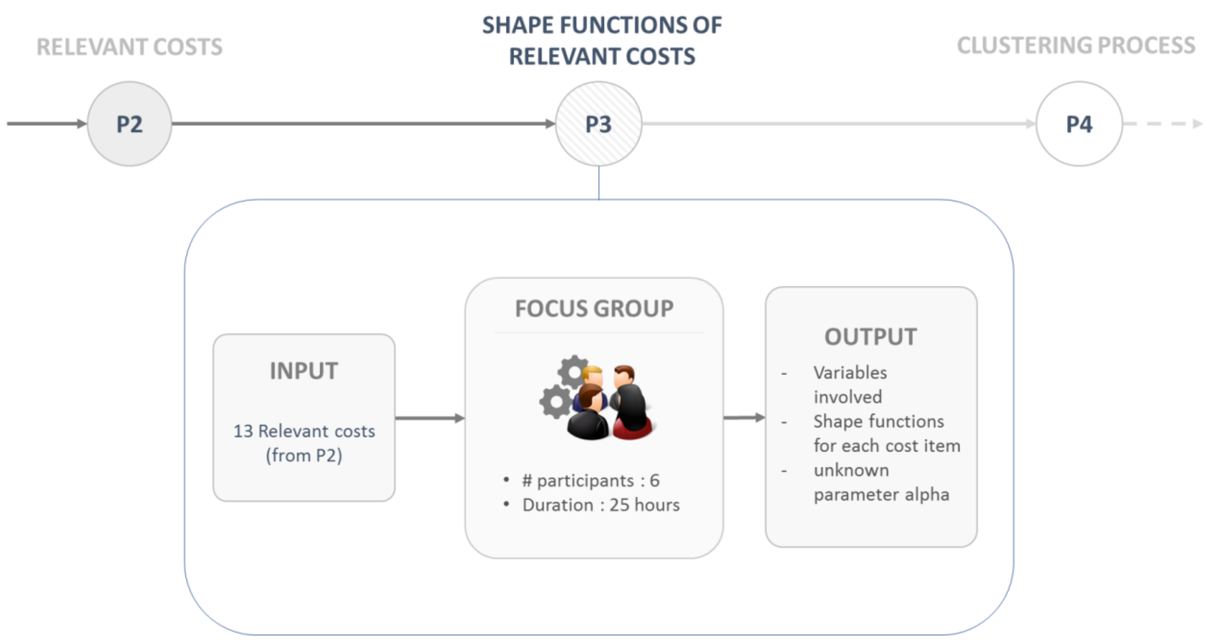
3. Research method: shape functions of relevant costs

In the previous research, starting from a literature review on the specific subject, all the cost items were identified and then categorized. The output is a list of costs which are categorized as relevant and quantifiable. Thus, the results from the literature review have been used as a basis for the focus group, to define the shape functions and input variables.

A focus group is a team approach in which a group of specialists discuss the subject matter under the guidance of moderators; this method is characterized by a structured meeting which allows recreating a situation similar to ordinary opinion, focusing on the exchange of information in a free communication style. The group is composed of an expert panel including a meeting facilitator and some informal participants with the necessary in-depth and wide knowledge of the SME environment.

The total amount of time that has been spent in meetings is approximately 25 hours. The purpose of the debate is to discover the cost item variables involved in an injury situation that characterize the SME, the shape functions for each relevant quantifiable cost, and the alpha value unknown for each cost items. Figure 3.1 below represents the input and output of the focus group, the core process of this part of the research.

Figure 3.1 : Input/output Focus Group



3.1 Cost computation:

After determining which cost items should be considered, particular emphasis was placed on the selection of parameters and the shape of cost functions. For the company, the cost of non-safety is given by collecting the costs of accidents related to each accident. A non-safety cost related to injuries I is given by the sum of costs Gj due to consequences:

$$I = \sum_{j=1}^{n} G_j$$

Each cost item G_j can be represented as function of different independent variables Z_i and parameters θ_i :

$$G_j = f(Z_i, \theta_i)$$

3.2 Description of variables and parameters:

It is necessary to find estimators, easily found in any company, able to represent each factor within the function; it should be considered that the recorded data in SMEs is reduced compared to those available in large enterprises.

In the literature, several factors have already been identified that act on the various voices:

- Number of injuries;
- Duration of absence of the injured person;
- Occupation of the injured worker;
- Company size;
- Productive sector of the company.

The first two are distinguished by the fact that the cost is linked to the characteristics of an event or even the general injury situation, represented by the cumulative events (frequency index) and the accumulated absences (severity index).

The task of the injured worker comprises two distinct elements: the wages of the injured employee and the degree of complexity of the task.

In the following, the selected estimators will be presented to characterize the factors considered.

Variables:

- ***Z1 = number of events****.* The number of injuries should be considered according to two different views: the first considers the number of events by itself and is functional by estimating the costs depending on the characteristics of the event; it is implicit that in order to calculate the total size of a cost item, you need to know how many events you are referring to. The second view concerns what has been defined as an accident situation, which is unimaginable by the sheer number of events that tell little about the business reality: the weight of an accident changes between an enterprise with ten employees and one that has 200. An indicator that allows comparison of data between companies is the frequency index, defined as the ratio between the number of events and the total of worked hours.

  Input variables obtained from Z1 are:

  - n (Number of injuries)
  - FI (Frequency index)

- ***Z2 = Duration of absence.*** The duration of the absence associated with an injury is also revealed in two ways: the first one is simply the average duration (AD) of absence following an accident in the company; this parameter is calculated based on the number of accidents, making it unsuitable for a comparison between different companies. In fact, the weight of an accident changes from an enterprise with ten employees to one who has 200: for example, if the average duration is ten days, the first must deal with a total of 20 days of absence, the second 80. An indicator used to compare the severity of the consequences of accidents is the severity index (IG), defined as the ratio between total days of absence and total hours worked.

Input variables obtained from Z2 are:

- AD (average days of absence)
- AD_{org} (days of absence that make convenient to take over a replacement)
- AD_{rif} (average reference duration that is assumed to be 15 days)
- SI (severity index)

Parameters:

- ***Θ1 = Firm size*****.** As for the size, there are two possibilities—using the number of employees, or turnover. The number of employees has been chosen rather than turnover because it represents the availability of personnel of the company.

- ***Θ2 = Manufacturing sector – Insurance fee.*** This is an important factor for the category of insurance costs. This parameter is defined as the level of risk associated with a particular production sector, because the type of industry is a generic predictor that can account for the major differences in terms of benefits and policies. Depending on the risk of the production activity, a policy with certain general characteristics is stipulated: at the beginning of the activity, in the absence of safety data, reference is made to the production sector in which it belongs; afterwards, the prize is adjusted, also taking into account the actual injuries that occur year after year. It is possible to use as an indicator the rates provided by the appropriate INAIL premium taxes, which essentially take into account the different hazards of each individual process; in fact, the tariffs consist of a technical classification of the works, which correspond to differentiated rates depending on the specific job risk.

- ***Θ3 = Salary of the injured worker.*** This parameter is represented by the gross daily pay of the injured employee.

- ***Θ4 = Complexity of the job – Training days.*** It can be assumed that more complex tasks require greater training time, so the estimator of this parameter is precisely the number of days needed to learn and properly perform the activities related to the role of the injured worker.

3.3 Shapes of cost functions and initializing unknown parameters

Finally, the shape function that best denotes the trend of each cost (Table 3.1) has been supposed by the focus group with particular attention to the variables and the parameters. The factors are represented using estimators: the number of events is characterized by the number of injuries or the frequency index; the length of absence by the average duration of an injury or the severity index; the business size by the number of employees; the field of activity by the INAIL tax rates; the injured worker's salary by the daily net salary; and the job's grade of difficulty by the training days. Each function is associated with one unknown parameter required to measure the cost. A simple and accurate way to initialize the alpha parameters is transforming them into the unknown of the function; for this purpose, it is useful to use the ISO 31000 technique: this is a standardized 'what-if' technique that, by creating various scenarios, allows us to obtain the starting values of the parameters to be estimated (Figure 3.2). Specifically, assuming certain values of an independent variable, the company interlocutor will have to suppose what cost can be expected.

Figure 3.2: Process diagram to initialize unknown parameters

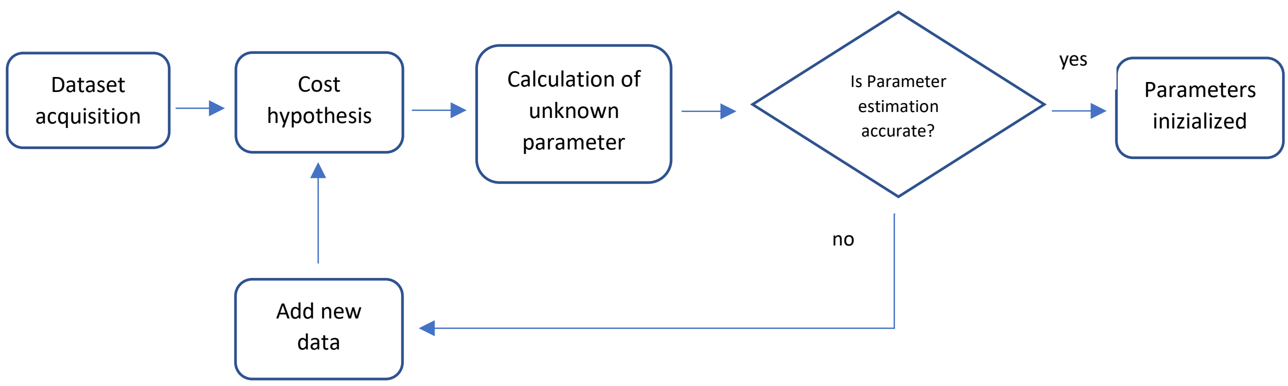


Table 3.1: List of cost item and cost functions

COST CATEGORY	COST ITEMS	COST FUNCTIONS	VECTOR UNKNOWN PARAMETERS
Administrative cost	Cost of administrative staff	$G_1 = \alpha_{pa} * n * \theta_1$	α_{pa}
	Cost of internal investigation and time lost by supervisors and managers	$G_{2+3} = \alpha_{tsi} * n$	α_{tsi}
Insurance cost	Insurance cost	$G_4 = \alpha_a * FI * SI * \theta_2$	α_a
Production cost	Cost of time lost by injured employee	$G_5 = \alpha_{ti} * n * AD * \theta_3$	α_{ti}
	Cost of lost production	$G_6 = \alpha_{mp} * n * AD^2 * (\theta_1)^{-1}$	α_{mp}
	Cost due to reduced productivity of the injured employee	$G_7 = \alpha_{rpi} * n * AD * \theta_4$	α_{rpi}
	Overtime cost	$G_8 = \alpha_s * n * AD * \theta_3$; for AD ≤ ADorg	α_s
Replacement cost	Training cost	$G_9 = \alpha_{as} * n * AD^2 * \theta_4$; for AD ≥ ADorg	α_{as}
	Cost due to reduced productivity of the substitute	$G_{10} = \alpha_{rps} * n * AD * \theta_4$; for AD ≥ ADorg	α_{rps}
Court cost	Legal cost	$G_{11+12+13} = \alpha_g * n * (\frac{AD}{ADrif})^2$	α_g

4 Alpha value estimation: the framework

4.1 Alpha value computation and company clustering

The expected outcome of the process is to compute the alpha value for every cluster of each cost item, highlighting what are the main input parameters that affect cluster division.

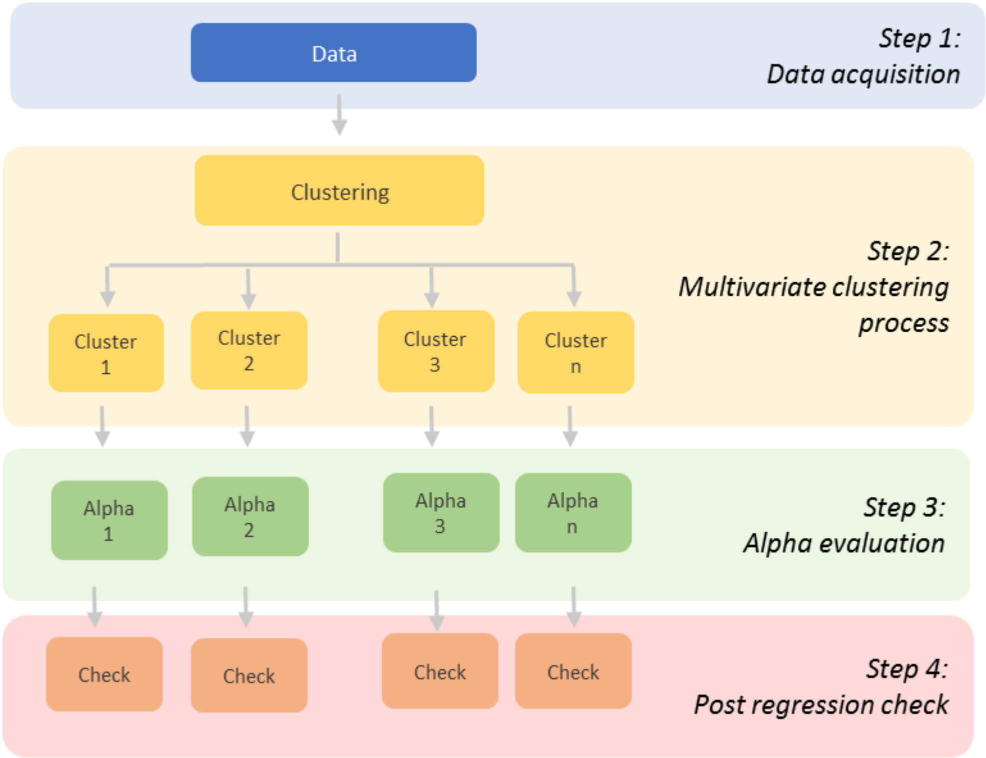
Figure 4.1 depicts the evaluation process for a single cost item. The process is composed of four steps and is briefly described in the following. The process starts with the acquisition of the parameters needed to define the most frequent and economically impacting injuries for the company. This first step is done through interviews with employers and safety managers; interviewees are asked to quantify financially, for each cost item, an injury that is significant to the company. When this information is obtained from each company, it provides a dataset consisting of input parameters for each cost function and related costs. To break the data into groups of similar companies, a cluster analysis is applied to observations achieved previously. The attained groups will be analysed in order to find similarities between companies belonging to the same group and differences between companies that are part of different clusters. Finally, using multiple linear regression, the unknown alpha value can be computed for each cluster. Before considering the value obtained, it will be necessary to consider the goodness of the statistical model. The statistical values outgoing from each MLR will be analyse by checking that:

1. $p\_value < 0.05$
2. $R2 \geq 80\%$

Should it become clear that either of the two above conditions no longer holds, significant outliers in the cluster will be identified and removed from the cluster. At the end of the process, it will be evident which parameters most affect the division into clusters and to obtain the alpha parameter for each group for each cost item.The steps of the evaluation process are described below:

- Step 1: Data acquisition
- Step 2: Multivariate cluster observation
- Step 3: Alpha computation
- Step 4: Post-regression data check

Figure 4.1 : Process steps



Step 1: Data acquisition

In order to start the implementation of the process, we need to acquire a minimum of 15–20 observations, one for each company. The aim of the process is to highlight the differences from diverse types of companies and to find out the parameters that most impact the division.

- *The Risk Evaluation Document (R.E.D.):*

The R.E.D. is a mandatory report that must be present within the work place and must be available for a possible examination by the control bodies; its function is to identify the risks present in the working environment that may cause damage to health, such as the use of machinery or toxic substances. This document prepares and suggests appropriate measures to prevent and control identified risks such as periodic maintenance of facilities and equipment or the preparation of an intervention program in order to reduce them over time and increase safety levels; In addition, it specifies that all workers must be equipped with appropriate means of prevention, such as personal protective equipment (helmets, safety shoes ...), information and training.

The RED lists the tasks performed by the company's staff and the activities that characterize them; for each activity, the possible risks that can lead to an injury or occupational disease are identified. Each of them is assigned a degree of probability and severity of damage by the RSPP Responsible Service Provider. The probability scale (P) table is based on three factors: more or less direct causality between risk and damage, existence of previous episodes, and the fact that the event is more or less expected. Severity scale (D) is based on the severity and reversibility of the effects. Knowing the value of P and D it is possible to quantify the risk (R) by applying the following formula:

$$R = P * D$$

Table 4.1: Probability scales and Severity scales

Probability Scales (P)

Level	*Type*	*Definitions*
4	Highly probable	The occurrence of damage to the detected failure would not provoke any amazement (in other words the event the event would be widely widely expected).
3	Probable	Already it is known, within the production unit, some episode in which the lack detected has done a result of damage;
2	Not Probable	Only very rare episodes are known;
1	Unlikely	No episodes are known

Severity Scales (S)

Level	*Type*	*Definitions*
4	Extremely serious	Accident or episode of acute exposure with letal effect or total invalidity effects;
3	Serious	Accident or episode of acute exposure with partial invalidity effects;
2	Average	Chronic exposure with reversible effects.
1	Soft	Chronic exposure with rapidly reversible effects.

- *Input dataset*

The RED (risk evaluation document) gives a complete picture of the risk distribution in the company; this allows identification of the risk associated with the tasks by supporting the definition of the scope of action: decision makers can focus their attention on the riskiest tasks in order to speed up the procedure, or possibly on what they feel most critical—for example, tasks where there are the largest number of employees. At this point, the RSPP (person responsible for prevention and protection), or a company referent who has a clear and comprehensive view of the company's safety condition, is called upon to determine the value of parameter variables and estimators. With these data, it is possible to carry out an estimation of associated costs. The input data to acquire for each company are:

- *Injury parameters and company data: n , AD , FI , GI , θ1 , θ2 , θ3 , θ4*
  These parameters denote data related to accident that are most impacting and most frequent on company; the research of these accident data is done by analyzing risk assessment documents.

- *Forecasted costs items: G1, G2, …, Gn*
  An audit with each company's owner (and/or health and safety manager) is needed to obtain reliable input data concerning cost estimation for most risky type of accident.

Table 4.1 summarizes all input dataset related to each company (observation C1, C2, …, Cn).There is also a need to further clarify how to acquire some data on companies, due to the need to obtain reliable values to put into the process. The INAIL rate (θ2), the frequency and gravity indexes (FI and GI) and salaries (Θ3) are easily obtained as described below:

- *Θ2* (*Insurance fee*) : from INAIL table it is easy to find the rate (%) associated to the company sector

- *Θ3 (Salaries)* : weighted average of the daily net wages of workers classified in skilled worker (net salary around 15.74 € per day), qualified worker (net salary around 13.65 € per day) and general worker (net salary around

11.57 € per day). Knowing exactly the number of worker per each group, it is possible to evaluate the daily net wages as :

$$\theta_3 = \frac{\#\, skilled\ worker * €_{skilled\ worker} + \#\, qualified\ \ worker * €_{qualified\ \ worker} + \#\, general\ worker * €_{general\ worker}}{\#\, skilled\ worker + \#\, qualified\ \ worker + \#\, general\ worker}$$

- *FI and GI (Frequency and Gravity indexes):* defined as the ratio of injured accidents to the number of exposed persons for FI and ratio between the consequences of compensated injuries and the number of exposed persons for GI (all types of consequences are expressed in lost days). The data can be obtained by INAIL web database; all values are listed in specific table and can be extracted by knowing the firm size and sector of the company.

Figure 4.2 : Data acquisition

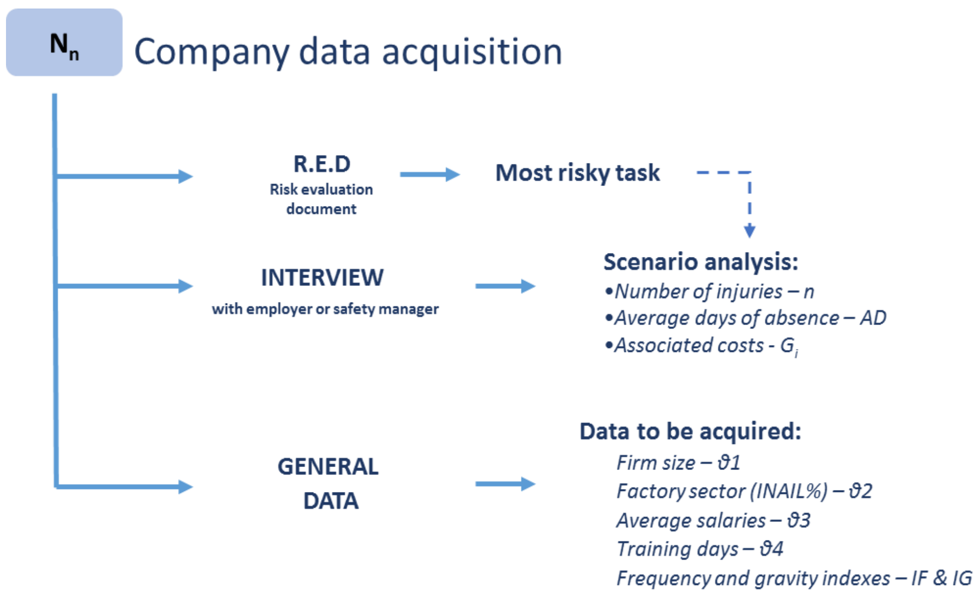


Table 4.2: Input dataset:

COMPANY	SCENARIO DATA	GENERAL DATA	FORECASTED COSTS
N_1	n_1 , AD_1, FI_1, GI_1	$\Theta_{1,1}$; $\Theta_{2,1}$; $\Theta_{3,1}$; $\Theta_{4,1}$	$G_{1,1}$; $G_{2,1}$; $G_{3,1}$; …; $G_{n,1}$
N_2	n_2 , AD_2, FI_2, GI_2	$\Theta_{1,2}$; $\Theta_{2,2}$; $\Theta_{3,2}$; $\Theta_{4,2}$	$G_{1,2}$; $G_{2,2}$; $G_{3,2}$; …; $G_{n,1}$
…	…	…	…
N_n	n_n , AD_n, FI_n, GI_n	$\Theta_{1,i}$; $\Theta_{2,i}$; $\Theta_{3,i}$; $\Theta_{4,i}$	$G_{1,i}$; $G_{2,i}$; $G_{3,i}$; …; $G_{n,i}$
…	…	…	…

Table 4.3 : Input dataset for cost item $- G_1 = \alpha_1 * n * \theta_1$

COMPANY (observations)	SCENARIO DATA (number of injuries)	GENERAL DATA (firm size)	FORECASTED COSTS G1
N_1	n_1	$\Theta_{1,1}$	$\mathbf{G_{1,1}}$
N_2	n_2	$\Theta_{1,2}$	$\mathbf{G_{1,2}}$
…	…	…	**…**
N_n	n_n	$\Theta_{1,i}$	$\mathbf{G_{1,i}}$
…	…	…	**…**

Step 2: Multivariate cluster observation

The second step of the process is based on the cluster analysis. At this stage, all the cost item datasets are separated and studied individually to try to find clusters.

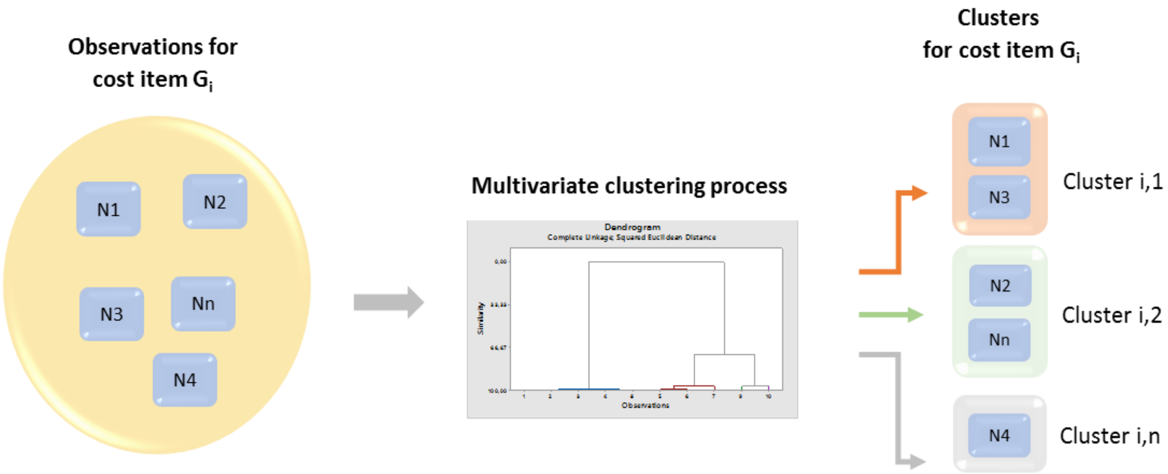
Cluster analysis is a data investigation tool for separating a multivariate dataset into 'natural' clusters (groups). This method is used to discover whether previously indeterminate groups may exist in the dataset.

This type of clustering method, known as a hierarchical agglomerative clustering method, starts out by pushing each datum into its own distinct cluster. It then computes all the distances between all the observations and couples the two closest to obtain a new cluster. So, finding the first cluster to form simply means looking for the smallest number in the distance matrix and joining the two observations that the distance corresponds to into a new cluster.

For a hierarchical grouping approach, the dendrogram is the key graphical tool to gain insight into a cluster solution and it can be seen by passing the result of the clustering to the plot function. From the dendrogram plot, the observations are grouped by fixing a minimum level of similarity.

The clustering process is represented in the figure 4.3

Figure 4.3: Multivariate clustering process



Step 3: Alpha computation

In this type of research, the shapes of cost functions are already defined by the focus group. A linear relationship is assumed between the dependent variable and the independent variables. The basic shape of cost function is:

$$G_i = \alpha_{i,j} * f(Z_i, \theta_{m,i})$$

where:

i = cost item type "i"

j = cluster "j" of cost function "i"

The unknown parameter value α , which is the relationship between cost and input variable, is computed by applying a multiple regression in each cluster for all cost function.

Multiple regression is used to forecast the value of a dependent variable (also known as result variable) subject to the value of two or more independent variables (also known as predictor variables).:

- Multiple variables are stared as the predictors or independent variables: Z_i = n, DM, IF, IG ; θ_k

- The other variable, denoted G, is regarded as the cost, outcome, or dependent variable: G_i

Multiple linear regression analysis makes several key assumptions:

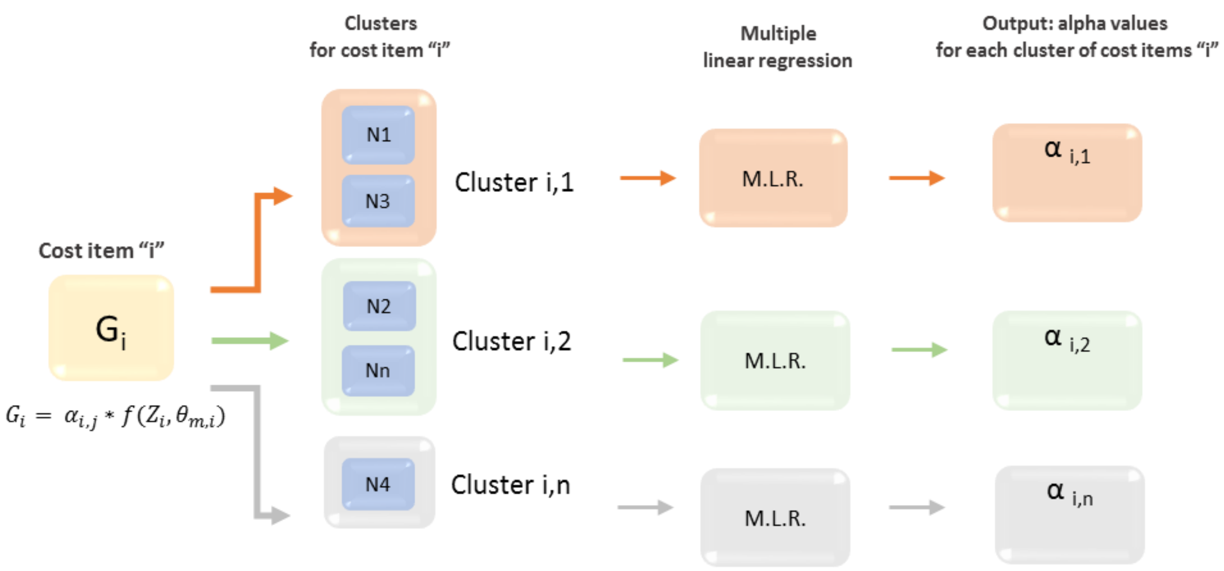
- *A* Linear Relationship between the outcome variable and the independent variables.

- Multivariate Normality: multiple regression assumes that the variables are normally distributed.

- Sample size: the number of observations must be greater than number of predictors; in this case the predictors is always one due to the multiplication of independent variables.

If, in a particular case, a cluster has only one data row, the multiple regression is not applied and consequently the alpha value is computed by inverting the cost function. Figure 4.4 below represents the schematization of the process for the cost items *i*.

Figure 4.4: Alpha computation process



Step 4: Post regression data check

In the final step, we check linear regression for each cluster. Verification is based on the statistical validity of P-value and R2.

In order to test hypotheses, the p-value is the probability for a given statistical model wherein, when the null hypothesis is true, the statistical summary (such as the sample mean difference between two compared groups) will be the same as, or more extreme than, the actual observed results. The reference value chosen for the test is 0.05: a valid model should have a p-value of less than 0.05.

On the other hand, the coefficient of determination, denoted R2, is a number that indicates the proportion of the variance in the dependent variable that is predictable from the independent variables. It is a statistical parameter used in the context of mathematical models whose main purpose is the prediction of future outcomes. A valid model should have an R2 higher than 80 per cent.

The non-passing of one of these two tests indicates the presence of outliers, defined in statistic as an observation point that is distant from others in the cluster. In the figures below (Figure 4.5 and Figure 4.6), are represented possible cases of outliers.

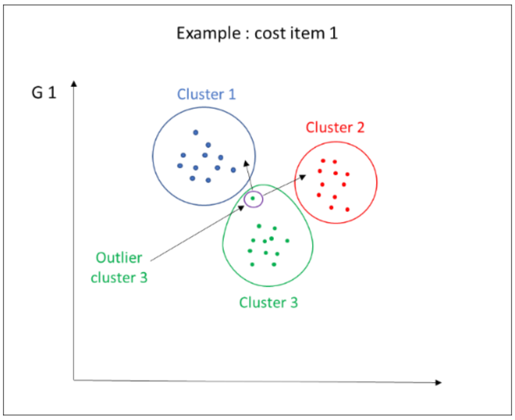


Figure 4.5: Outliers of cluster 3 added to other clusters

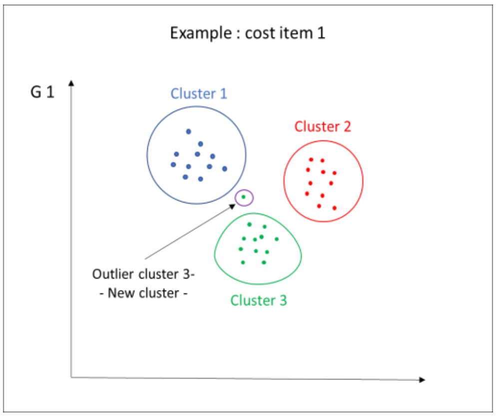


Figure 4.6: New cluster formed by outlier

Once the outliers are detected in the clusters, they will be removed and inserted into different clusters (figure 4.5). Subsequently, the new p-value and R^2 values will be recalculated to choose the best fit. If no cluster passes the test then it will create a new group composed exclusively by the outlier (figure 4.6).

4.2 Update and convergence of alpha parameter

Update process:

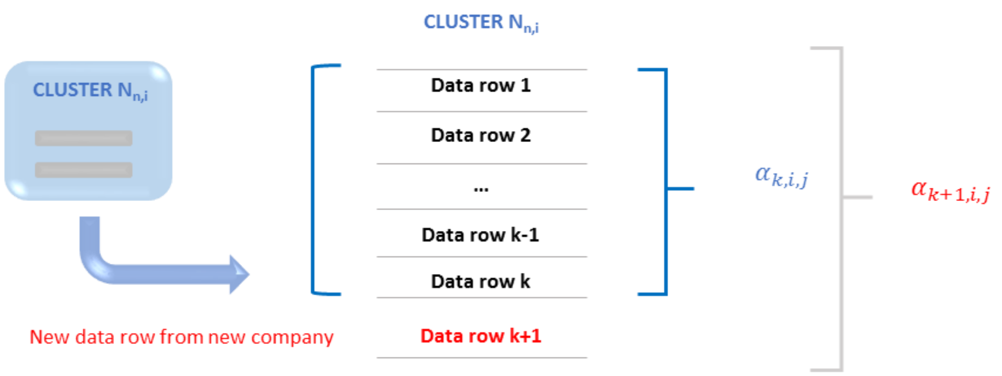
Having defined the clusters and initialized alpha parameters, this section will show how alpha values are updated, explaining how new data have to be inserted in a suitable cluster of cost item Gi.

To choose the best cluster, the new set of data must be added in all groups and linear regression applied to each to calculate the new alpha parameter. Once values are obtained from regression, statistical data such as p-value and R2 are analysed. From here, there are three possible cases:

1. *No cluster has a p-value <0.05 and $R^2 \geq 80\%$:* in this case a new cluster has to be created for the cost item under consideration.
2. *Only one cluster has a p-value <0.05 and $R^2 \geq 80\%$:* in this other case, the new data will be included in this cluster. The alpha value for this cluster will be updated with the new data entry.
3. *More than one cluster has a p-value <0.05 and $R^2 \geq 80\%$:* in this latter case, we proceed to a qualitative cluster selection by analyzing in detail the characteristic parameters.

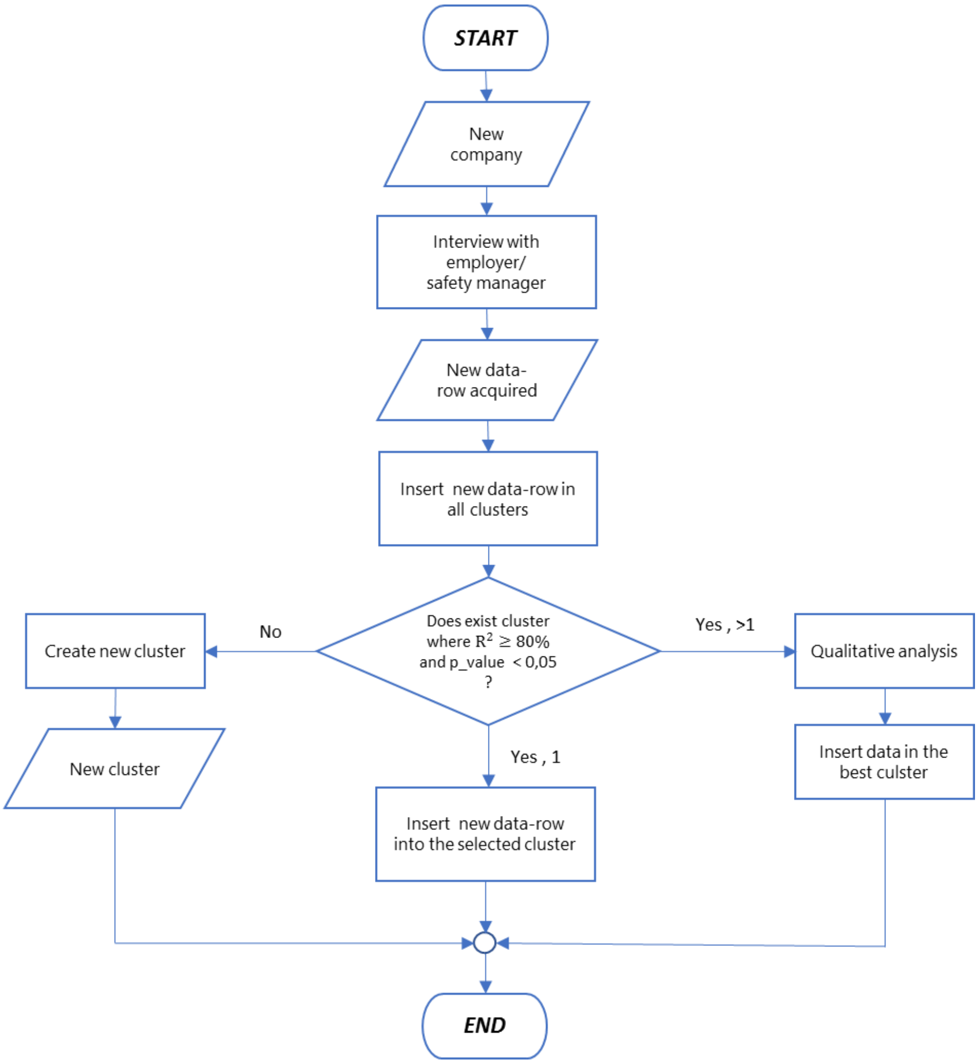
Figure 4.7 depicts the addition of new data row to cluster Nn,i instead, in figure 4.8, the update process for the alpha parameter is detailed graphically.

Figure 4.7: Addition of new data row to cluster $N_{n,i}$



Where:
i = cost item type "i"
j = cluster "j" of cost function "i"
k = row "k" of cluster "j"

Figure 4.8: New data cluster selection process



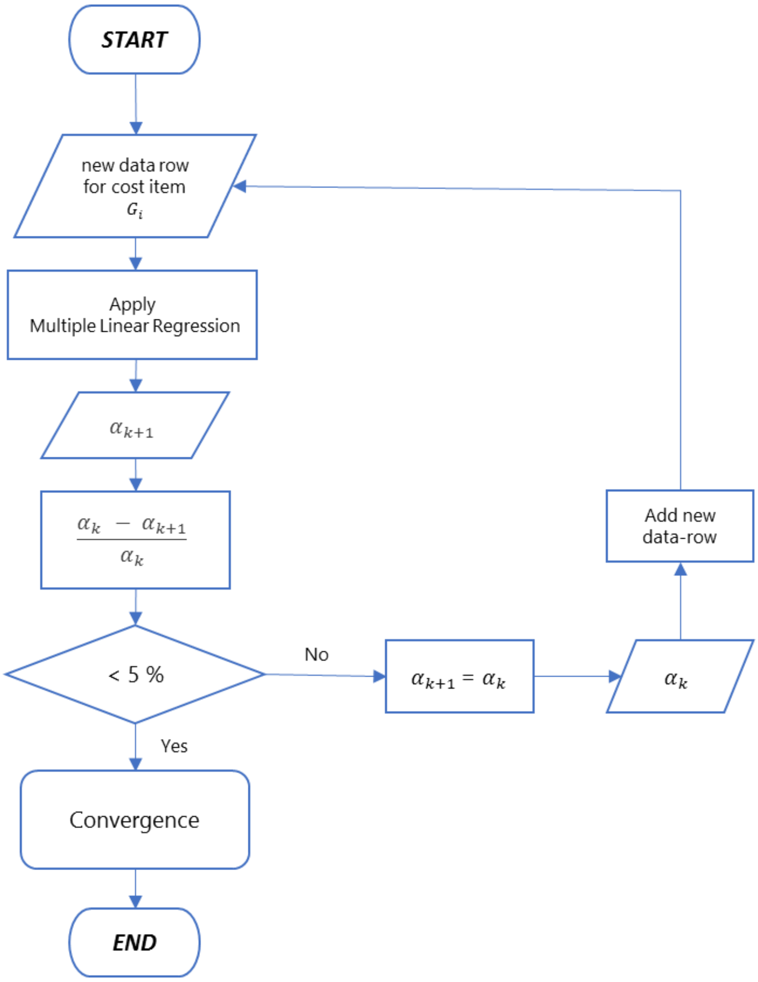
Convergence process:

In this part, we describe the process to obtain the converged alpha parameter considering the cluster already composed of a k data row.

By inserting the k + one line of data, you will get a new alpha named alpha k + 1. If the difference between alpha k and alpha k + 1 is less than five per cent, then the new alpha parameter can be considered to have arrived at convergence. Conversely, if the result is larger than five per cent, we have to continue adding new data to converge.

In figure 4.8, the convergence process for the alpha parameter is detailed.

Figure 4.9 : alpha update process.



5 Exemplification

In this last part, the attention is focused on an exemplification of the process. These are just a couple of proposals to give some focus to this debate and its framework, rules and basic conditions. The chosen target is companies coming from the manufacturing sector. This choice is dictated by many factors, among which are a great presence in the territory and a high number of accidents at work.

We suppose the acquisition of data from ten manufacturing companies (N1, N2, …, N10). The subsectors are detailed in Table 5.1.

Table 5.1: Sub categories and firm size for each company acquired

COMPANY #	MANUFACTURING SUB - SECTORS	NACE CODE	FIRM SIZE
N1	Manufacture of electrical equipment	C27	20
N2	Manufacture of machinery and equipment	C28	24
N3	Manufacture of electrical equipment	C27	15
N4	Manufacture of machinery and equipment	C28	68
N5	Manufacture of motor vehicles, trailers and semi-trailers	C29	50
N6	Other manufacturing	C32	90
N7	Manufacture of basic metals	C24	20
N8	Manufacture of machinery and equipment	C28	70
N9	Manufacture of motor vehicles, trailers and semi-trailers	C29	13
N10	Manufacture of basic metals	C24	120

After defining the action field, it is possible to proceed with the detection of the data necessary for the estimation (table 5.2): the value of the variables, the value of the parameter estimators and starting with the initialization of the unknown parameters. The R.E.D. (risk evaluation document) coming from all companies is used to understand what are the most impacting activities, in economic terms, on companies. Having a complete view of how risk is distributed among the tasks, it offers the possibility to estimate the non-security costs related to those who accumulate more risks; this allows to preserve company's resources without compromising the significance of the estimation, assuming the riskiest tasks as the ones that generate more costs. The frequency index and severity index are taken by INAIL database crossing sector and firm size of each company (table A2-A3-A4) .

Table 5.2: Data acquired from 10 companies

			N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
Input data	n	NUMBER OF INJURIES	2	3	2	2	10	9	12	5	13	10
	AD	AVG DAYS OF ABSENCE	6	4	4	5	20	21	20	4	15	25
	FI	FREQUENCY INDEX	15,21	26,82	14,12	27,17	37	33,92	41,63	27,17	38,41	48,2
	SI	SEVERITY INDEX	1,25	1,66	0,97	1,69	2,08	1,9	3,4	1,69	3,92	3,24
	θ1	FIRM SIZE	20	24	15	68	50	90	20	90	13	120
	θ2	INSURANCE FEE	25	32	21	35	45	40	80	35	90	130
	θ3	SALARY	16,00	14,00	16,00	19,00	13,00	15,00	18,00	14,00	20,00	16,00
	θ4	TRAINING DAYS	40	30	45	60	30	50	60	20	80	42
Predicted costs in 10 years	G1	ADMINISTRATIVE STAFF	200,00 €	150,00 €	130,00 €	180,00 €	1.500,00 €	1.600,00 €	1.900,00 €	600,00 €	2.600,00 €	2.000,00 €
	G2+3	INTERNAL INVESTIGATION	500,00 €	450,00 €	300,00 €	800,00 €	4.000,00 €	3.500,00 €	3.000,00 €	820,00 €	5.000,00 €	6.000,00 €
	G4	INSURANCE	8.000,00 €	7.500,00 €	5.000,00 €	10.000,00 €	35.000,00 €	30.000,00 €	40.000,00 €	13.000,00 €	45.000,00 €	55.000,00 €
	G5	LOST TIME	600,00 €	450,00 €	490,00 €	530,00 €	6.000,00 €	6.300,00 €	8.000,00 €	480,00 €	9.100,00 €	9.500,00 €
	G6	LOST PRODUCTION	2.000,00 €	2.100,00 €	1.800,00 €	1.500,00 €	35.000,00 €	30.000,00 €	50.000,00 €	1.000,00 €	55.000,00 €	60.000,00 €
	G7	REDUCED PRODUCTIVITY	850,00 €	900,00 €	700,00 €	650,00 €	8.500,00 €	9.000,00 €	10.000,00 €	400,00 €	9.000,00 €	12.000,00 €
	G8	OVERTIME	400,00 €	350,00 €	280,00 €	360,00 €	6.000,00 €	6.500,00 €	8.000,00 €	400,00 €	7.000,00 €	8.500,00 €
	G9	TRAINING	300,00 €	320,00 €	420,00 €	300,00 €	9.000,00 €	8.500,00 €	10.000,00 €	500,00 €	9.500,00 €	12.000,00 €
	G10	REDUCED PROD.SUBSTITUTE	450,00 €	600,00 €	700,00 €	650,00 €	4.500,00 €	5.600,00 €	6.000,00 €	350,00 €	8.000,00 €	9.000,00 €
	G11	LEGAL COSTS	250,00 €	260,00 €	400,00 €	350,00 €	18.000,00 €	20.000,00 €	25.000,00 €	500,00 €	15.000,00 €	26.000,00 €
		TOTAL COST (for each company)	**13,550.00 €**	**13,080.00 €**	**10,220.00 €**	**15,320.00 €**	**127,500.00 €**	**121,000.00 €**	**161,900.00 €**	**18,050.00 €**	**165,200.00 €**	**200,000.00 €**

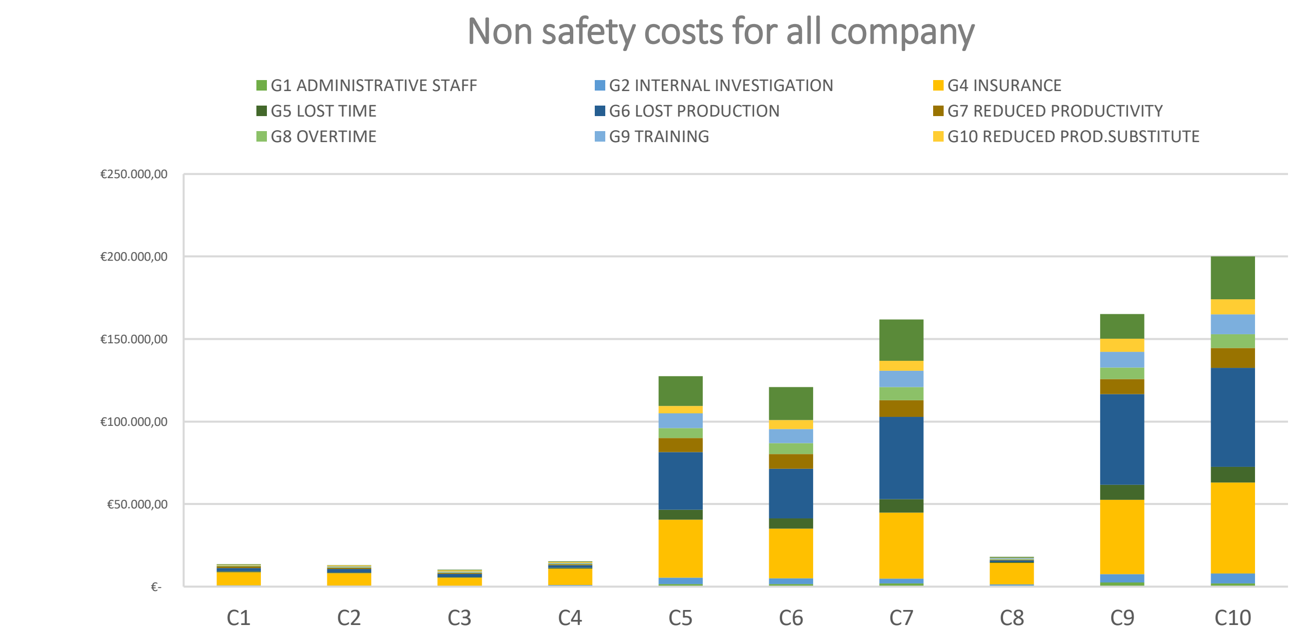
5.1 Description analysis of sample

The pre-analysis of data enables us to roughly understand what are the main differences among the companies. In order to do this, a bar chart has been used to plot the predicted costs, showing the main differences between company in an economic term. Moreover, to have a complete vision before analyzing the data, it has been deployed a level input table drawing a distinction between three different grades:

- *Low value :* defined as one or more of the characters with the lowest position in the input data row (↓)
- *Medium value:* defined as one or more of the characters with a median position in the input data row (→)
- *High value :* defined as one or more of the characters with the highest position in the input data row (↑)

In figure 5.1 it is represented the bar charts and level table

Figure 5.1 : Non safety costs analysis - bar charts and level table



		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Number of injuries	N	↓	↓	↓	↓	→	→	↑	↓	↑	→
Avg days of absence	AD	↓	↓	↓	↓	→	→	→	↓	→	↑
Frequency index	FI	↓	→	↓	→	→	→	↑	→	↑	↑
Severity index	SI	↓	→	↓	↓	→	↑	→	→	↑	↑
Firm size	Θ1	↓	↓	↓	→	→	→	↓	↑	↓	↑
Insurance fee	Θ2	↓	↓	↓	→	→	→	↑	→	→	↑
Salary	Θ3	→	↓	→	↑	↓	↓	→	↓	↑	→
Training days	Θ4	↓	↓	→	→	↓	→	→	↓	↑	→

5.2 Process example for cost item G1 " Cost of administrative staff "

Step 1: Data acquisition

Shape of cost functions: ($G_1 = \alpha_{pa} * n * \theta_1$).

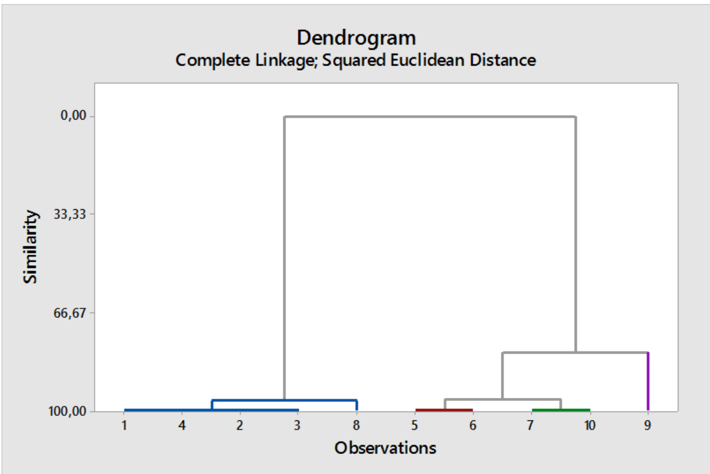
Table 5.3 : Data acquired from all companies for cost item G1:

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
Number of injuries (n)	2	3	2	2	10	9	12	5	13	10
Firm size (θ1)	20	24	15	68	50	90	20	90	13	120
Administrative staff (G1)	200,00 €	150,00 €	130,00 €	180,00 €	1.500,00 €	1.600,00 €	1.900,00 €	600,00 €	2.600,00 €	2.000,00 €

Step 2: Multivariate cluster observation for cost item G1

Using statistical software, it is easy to compute the clustering observation.

Figure 5.2 : Dendrogram plot



The dendrogram plot highlights the presence of four main clusters in all the observations. The clustered data are stated in the table 5.3.

Table 5.4: Cost item G1 - Data clustered

CLUSTER	COMPANY	N	AD	Θ1 (FIRM SIZE)	G1
	N3	2	4	15	130,00 €
	N2	3	4	24	150,00 €
1,1	N4	2	5	68	180,00 €
	N1	2	6	40	200,00 €
	N8	2	5	70	600,00 €
	N5	10	20	50	1.500,00 €
1,2	N6	9	21	90	1.600,00 €
	N10	10	25	120	2.000,00 €
1,3	N7	12	20	20	1.900,00 €
1,4	N9	13	15	13	2.600,00 €

Step 3 and 4: Alpha computation and statistical check for cost item G1

For each cluster, we apply the MLR in order to obtain the alpha value.

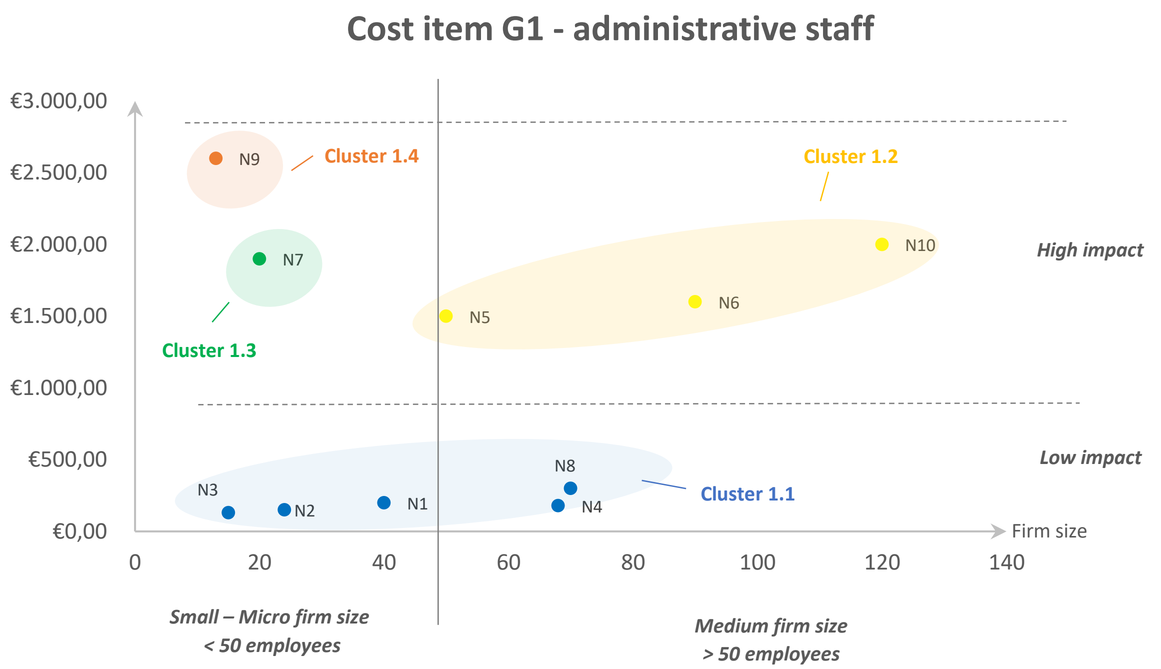
In the final step, the statistical values, which come from the linear regression, must be checked for all groups.

For clusters 1.1 and 1.2, the R^2 values are higher than 80 per cent and p-values are lower than 0.05. For clusters 1.3 and 1.4, multiple linear regression could not be applied due to the presence of one single value. The alpha values are evaluated by simply inverting the cost function. Future research must be focused on these particular clusters in order to increase the dataset and improve the evaluated alpha value.

Table 5.5: Alpha computation and statistical check

CLUSTER	COMPANY	N	AD	Θ1 (FIRM SIZE)	G1	ALPHA VALUE	R^2 (≥80%)	P_VALUE (≤0.05)	CHECK
	N3	2	4	15	130,00 €				
	N2	3	4	24	150,00 €				
1,1	N4	2	5	68	180,00 €	**1.387**	**85%**	**0.02**	✓
	N1	2	6	40	200,00 €				
	N8	2	5	70	600,00 €				
	N5	10	20	50	1.500,00 €				
1,2	N6	9	21	90	1.600,00 €	**1.895**	**90%**	**0.02**	✓
	N10	10	25	120	2.000,00 €				
1,3	N7	12	20	20	1.900,00 €	**0.13**	\	\	
1,4	N9	13	15	13	2.600,00 €	**0.07**	\	\	

Figure 5.3 : Post - Process graph



Repeating the process used for cost item G1, it is easy to find clusters for each cost items (table 5.5).

Table 5.6: Alpha values and cost item clusters

G	COST ITEMS	CLUSTERS	COMPANIES	CHARACTERISTICS	ALPHA VALUE
G1	*Administrative staff*	*1,1*	N1,N2,N3,N4,N8	Low number of injuries, All firm size	*1,39*
		1,2	N5,N6,N10	medium number of injuries, large firm size	*1,90*
		1,3	N7	medium number of injuries, small firm size	*0,13*
		1,4	N9	High number of injuries, large firm size	*0,07*
G2+3	*Time lost by supervisors and*	*2,1*	N1,N2,N3,N4,N8	Low number of injuries, All firm size	*188,00*
		2,2	N5,N6,N7	High number of injuries, medium firm size	*330,80*
		2,3	N9	High number of injuries, small firm size	*384,60*
		2,4	N10	High number of injuries, large firm size	*600,00*
G4	*Insurance costs*	*4,1*	N1,N2,N3,N4,N8	Low number of injuries, low severity index, low S.I./F.I.	*7.05*
		4,2	N5,N6	All injuries, medium severity index, med. S.I./F.I.	*10,65*
		4,3	N7,N9	High number of injuries, large days of abs., high S.I./F.I., Small firm size	*3,41*
		4,4	N10	High number of injuries, large days of abs., high S.I./F.I., Large firm size	*2,71*
G5	*Cost due to reduced productivity of the injured employee*	*5,1*	N1,N2,N3,N4,N8	Low number of injuries, low days of abs., med. salary	*2,49*
		5,2	N5,N6	High number of injuries, large days of abs., low salary	*2,26*
		5,3	N7,N9,N10	High number of injuries, large days of abs., high salary	*2,16*
G6	*Cost of lost production*	*6,1*	N2,N3,N5,N7,N9	Low number of injuries, low days of abs., all firm size	*237,10*
		6,2	N1,N4,N6,N8	High number of injuries, med.- large days of abs., small-med. firm size	*680,00*
		6.3	N10	High number of injuries, large days of abs., large firm size	*9,60*
G7	*Cost of time lost by injured employee*	*7,1*	N1,N2,N3,N4,N8	Low number of injuries, low days of abs., med. training days	*1,52*
		7,2	N5,N6,N7,N9	High number of injuries, med. days of abs., med-high training days	*0,75*
		7.3	N10	High number of injuries, med. days of abs., med training days	*1,14*
G8	*Overtime cost*	*8,1*	N1,N2,N3,N4,N8	Low number of injuries, low days of abs., all salary	*1,80*
		8,2	N5,N6,N9	High number of injuries, med. days of abs., med-high salary	*2,04*
		8.3	N7,N10	High number of injuries, med. days of abs., med salary	*1,98*
G9	*Training cost*	*9,1*	N1,N2,N3,N4,N8	Low number of injuries, low days of abs., med. training days	*0,15*
		9,2	N5,N6,N7,N9	High number of injuries, med. days of abs., med-high training days	*0,04*
		9.3	N10	High number of injuries, med. days of abs., med training days	*0,05*
G10	*Cost due to reduced productivity of the substitute*	*10,1*	N1,N2,N3,N4,N8	Low number of injuries, low days of abs., med. -low training days	*1,20*
		10,2	N5,N6,N7	High number of injuries, med. days of abs., med training days	*0,50*
		10,3	N9,N10	High number of injuries, med. days of abs., med-high training days	*0,62*
G11	*Legal costs*	*11,1*	N1,N2,N3,N4,N8	Low number of injuries, low days of abs.	*1302,00*
		11,2	N5,N6,N9	High number of injuries, med. days of abs.	*1089,90*
		11,3	N7,N10	High number of injuries, med. days of abs.	*1024,00*

5.3 Update and convergence of alpha parameter for cost item G1

Alpha update process

Once all the clusters are defined, a new dataset from company 11 is acquired. The next step of the process is to select the group in which to insert the newly acquired data and to obtain a more accurate alpha value.

In table 5.6 are listed all the new data coming from company 11.

Table 5.7: New dataset from company 11

N11 Construction of various instruments and appliances	n	AD	FI	GI	Θ1	Θ2	Θ3	Θ4	NACE CODE	
	4	5	21	1.15	70	21	18	35	C33	
	G1	G2+3	G4	G5	G6	G7	G8	G9	G10	G11
	400,00 €	900,00 €	8.500,00 €	730,00 €	3.500,00 €	850,00 €	540,00 €	450,00 €	850,00 €	550,00 €

The schematization of the process is represented in the figure below (figure 5.5):

Figure 5.4 : Cluster selection process for G1

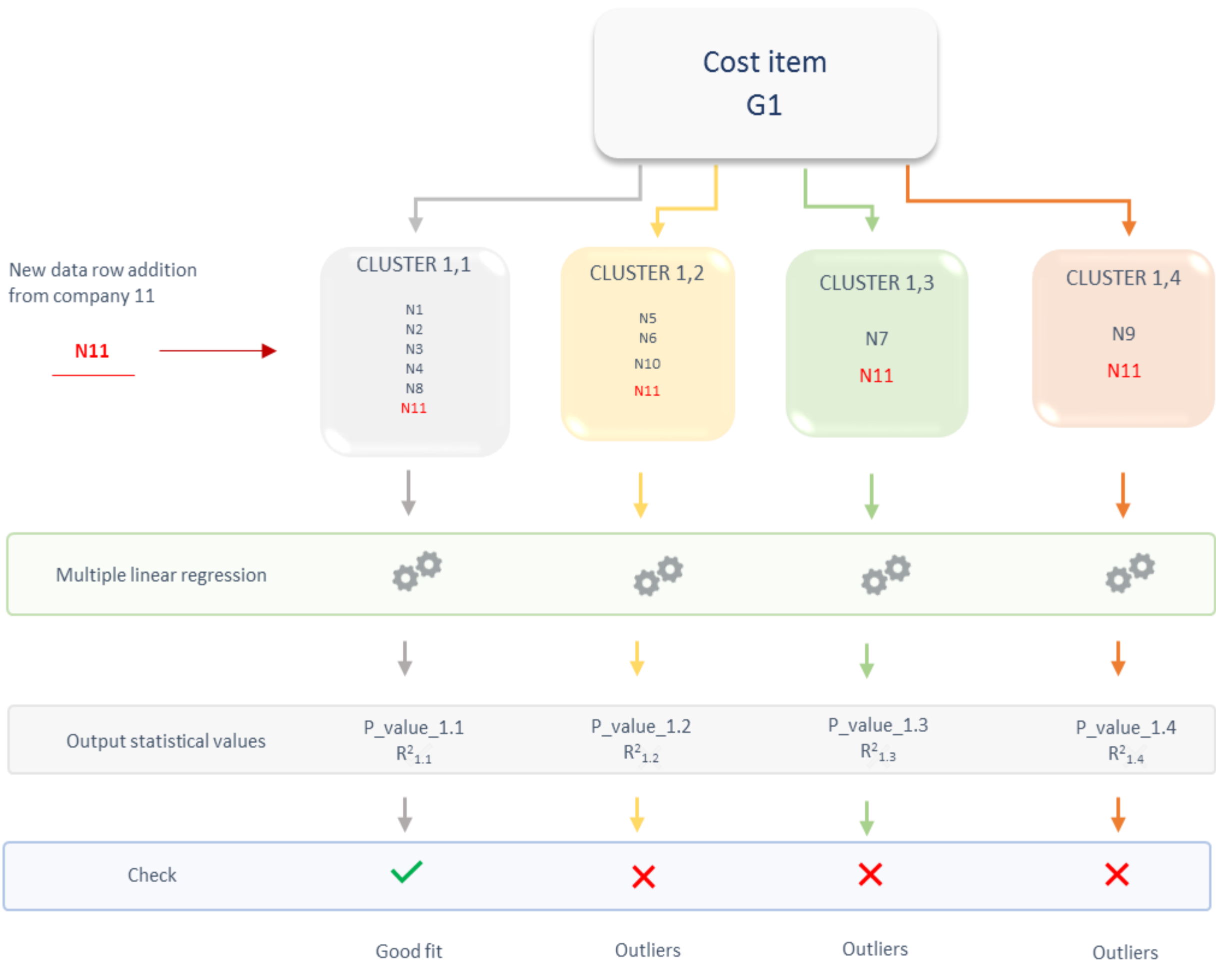
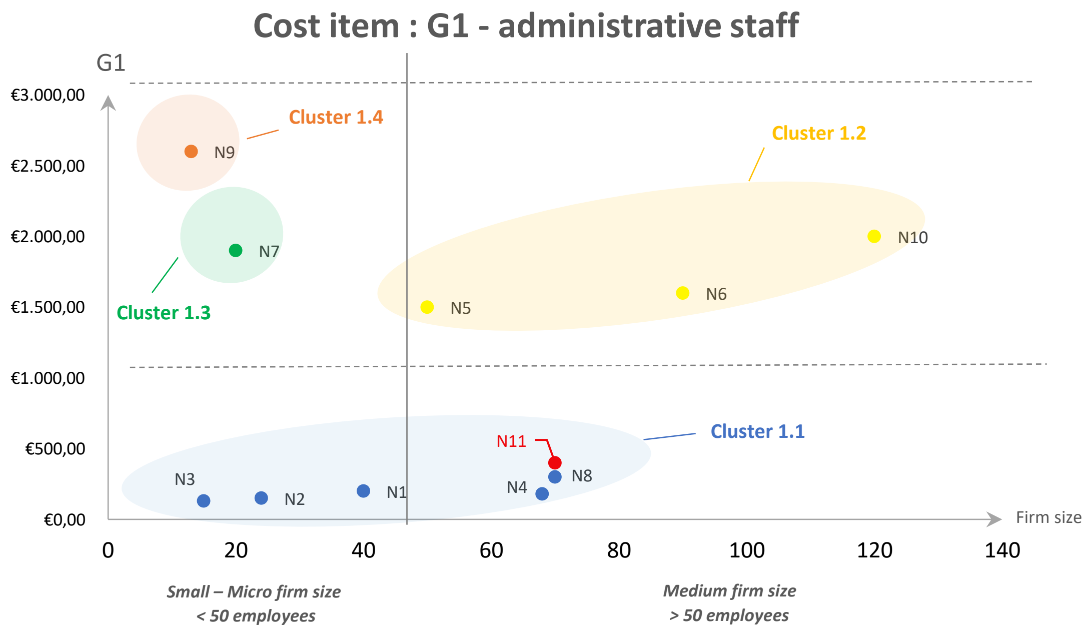


Table 5.8: Alpha computation and statistical analysis with new data

CLUSTER	COMPANY	N	AD	Θ1 (FIRM SIZE)	G1	NEW ALPHA VALUE	R² (≥80%)	P_VALUE (≤0.05)	CHECK
1,1	N3	2	4	15	130,00 €	0,3232	88%	0,001	✓
	N2	3	4	24	150,00 €				
	N4	2	5	68	180,00 €				
	N1	2	6	40	200,00 €				
	N8	2	5	70	300,00 €				
	N11	4	5	70	400,00 €				
1,2	N5	10	20	50	1.500,00 €	0,0797	74%	0,041	✗
	N6	9	21	90	1.600,00 €				
	N10	10	25	120	2.000,00 €				
	N11	4	5	70	400,00 €				
1,3	N7	12	20	20	1.900,00 €	0,56	0%	0,411	✗
	N11	4	5	70	400,00 €				
1,4	N9	13	15	13	2.600,00 €	0,853	33%	0,224	✗
	N11	4	5	70	400,00 €				

Figure 5.5: Plot analysis with new data N11



Alpha value convergence

Considering the updated alpha value, it is possible to evaluate the differences between new and old value:

$$\Delta\propto^{1,1} = \frac{\alpha_2^{1,1} - \alpha_1^{1,1}}{\alpha_1^{1,1}} = \frac{0.32 - 1.39}{1.39} = -76\% \geq \pm 5\%$$

As the value of the difference is major than five per cent the new value ($\alpha_2^{1.1}$) refereed to cluster 1,1 has not arrived at convergence yet. It means that additional data are needed for this particular cluster.

6. Conclusion

We opened this paper by noting that there is a gap in literature about economic evaluation of the cost of industrial accidents for organizations. The previous research provided a reclassification of non-safety costs, establishing the most relevant ones.

The further development of the previous research in this research is twofold. On the one hand, it provides a mathematical formulation for all the relevant cost items, using the focus group methodology; the variables of the shape functions are related to the kind of injury and the type of company. Specifically, the factors considered are:

- Injury related: number of injury, days of absence, frequency and gravity index
- Company related: firm size, salary, insurance fees, training days

On the other hand, the foregoing discussion has attempted to expose a process for clustering the companies through these factors. Considering SMEs' interests and their peculiarities, a reliable tool for the cost of industrial injuries is important for finding what factors are more relevant to different groups of companies from microenterprises to small-medium sized. By understanding what the main factors that affect non-safety costs are, it is possible to avoid putting together micro-, small-, and medium-sized enterprises as considered by literature, which tends to study those three different kinds of enterprise as a whole. In order to give this kind of output, the process needs a reliable set of data to be estimated. This can be a limitation when the owners/general managers of these companies are not able to give a good estimation of an injury during the first step of the process. This problem leads to many outliers that could affect the process itself.

Furthermore, a reliable tool can help to detect clusters that require great investment in safety measures and lead managers/owners to highlight the importance of safety actions from an economical point of view.

Our study serves as a window to an understanding of a clustering process that allows the grouping of different companies using OSH factors and economic parameters. From here, further research could implement the clustering process, testing different companies from different typologies of small-medium enterprises and ascertaining the major groups of interest for an in-depth analysis.

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Appendix

Table A1: Number of enterprises in Italy - firm size vs activity sector (INAIL database)

	Firm size				
Activity sector (NACE)	**from 1 to 9**	**from 10 to 49**	**from 50 to 249**	**equal/larger-than 250**	**Total**
A Agriculture, forestry and fishing	28.328	523	104	51	**29006**
B Mining and quarrying	1.945	426	57	7	**2435**
C Manufacture	388.345	43414	8948	1590	**442297**
D Electricity, gas, steam and air-conditioning supply	2.782	369	142	66	**3359**
E Water supply, sewerage, waste management and remediation	5.987	1375	434	132	**7928**
F Construction	638.909	13692	1190	143	**653934**
G Wholesale and retail trade, repair of motor vehicles and motorcycles	643.711	24718	3034	615	**672078**
H Transportation and storage	126.135	8504	1437	278	**136354**
I Accommodation and food service activities	282.562	7117	571	94	**290344**
J Publishing,Telecomunication and IT	63.284	4973	1012	216	**69485**
K Financial and insurance activities	31.806	1620	597	290	**34313**
L Real estate activities*	75.579	1094	154	19	**76846**
M Scientific research and development	168.854	6520	1257	287	**176918**
N Administrative and support service activities	103.141	5440	1195	255	**110031**
O Public administration and defence, compulsory social security	3.678	3893	1397	406	**9374**
P Education	29.916	2287	542	98	**32843**
Q Human health services and Residential care/social work activities	73.157	4301	1625	435	**79518**
R Arts, entertainment and recreation	38.817	1505	291	45	**40658**
S Other services	217.396	3112	497	62	**221067**
T Activities of households as employers;	2.372	32	3	0	**2407**
U Activities of extra-territorial organisations and bodies	171	78	21	2	**272**
X Not determined	247.128	2.331	328	83	**249870**
Total	**3.174.003**	**137.324**	**24.836**	**5.174**	**3.341.337**
	133811%	**5789%**	**1047%**	**218%**	

Table A2 : Severity index (SI) - Manufacturing sectors NACE 2011 vs firm size (INAIL database)

Activity sector (NACE code)	Sub-division - NACE 2011	Autonomous	01-05	06-15	16-49	50-99	100-249	> 250	TOTAL
C - Manufacturing	C10 - MANUFACTURE OF FOOD PRODUCTS	2,01	3,14	2,68	2,52	2,16	2,1	1,79	**2,31**
	C13/14 - MANUFACTURE OF TEXTILES	1,11	1,14	0,82	0,99	1,17	0,94	0,67	**0,99**
	C15 - MANUFACTURE OF LEATHER AND RELATED PRODUCTS	1,4	1,08	1,09	1,12	0,7	1,07	0,64	**1,06**
	C16 - MANUFACTURE OF WOOD AND OF PRODUCTS OF WOOD	5,34	6,11	4,51	3,76	4,55	5,08	2,96	**5,03**
	C17/18 - MANUFACTURE OF PAPER AND PAPER PRODUCTS	1,5	1,39	1,53	1,67	1,79	1,74	1,18	**1,52**
	C19 - MANUFACTURE OF COKE AND REFINED PETROLEUM PRODUCTS	\	2,25	1,77	1,62	1,92	0,86	0,44	**0,97**
	C20/21 - MANUFACTURE OF CHEMICALS AND CHEMICAL PRODUCTS	1,67	1,57	1,21	1,2	1,2	0,82	0,68	**0,92**
	C22 - MANUFACTURE OF RUBBER AND PLASTIC PRODUCTS	2,56	2,12	2,55	2,66	2,78	2,16	1,73	**2,39**
	C23 - MANUFACTURE OF OTHER NON-METALLIC MINERAL PRODUCTS	3,3	6,18	5,05	4,56	4,81	3,11	2	**4,21**
	C24/25 - MANUFACTURE OF BASIC METALS	3,65	4,62	3,76	3,4	3,39	3,24	3,02	**3,64**
	C28 - MANUFACTURE OF FABRICATED METAL PRODUCTS, EXCEPT MACHINERY AND EQUIPMENT	3,64	2,9	2,48	1,66	1,69	1,43	1,15	**1,84**
	C26/27 - MANUFACTURE OF ELECTRICAL EQUIPMENT	1,7	1,44	0,97	1,25	0,94	0,78	0,49	**1**
	C29/30 - MANUFACTURE OF MOTOR VEHICLES, TRAILERS AND SEMI-TRAILERS	1,91	4,08	3,92	2,39	2,08	1,99	1,25	**1,79**
	C31/32 - OTHER MANUFACTURING	2,89	3,41	2,9	2,34	1,9	1,65	1,96	**2,62**
TOTAL		**2,76**	**3,23**	**2,65**	**2,28**	**2,16**	**1,83**	**1,28**	**2,25**

Table A3 : Frequency index (FI) - Manufacturing sectors NACE 2011 vs firm size (INAIL database)

Activity sector (NACE code)	Sub-division - NACE 2011	Autonomous	01-05	06-15	16-49	50-99	100-249	> 250	TOTAL
C - Manufacturing	C10 - MANUFACTURE OF FOOD PRODUCTS	12,46	24,54	25,99	29,34	30,91	36,21	34,73	**26,41**
	C13/14 - MANUFACTURE OF TEXTILES	8,83	8,59	8,82	12,98	17,85	15,74	13,55	**11,68**
	C15 - MANUFACTURE OF LEATHER AND RELATED PRODUCTS	8,15	9,03	11,68	12,58	12,93	16,83	15	**11,84**
	C16 - MANUFACTURE OF WOOD AND OF PRODUCTS OF WOOD	34,45	42,87	39,85	39,41	42,26	55,07	47,72	**39,47**
	C17/18 - MANUFACTURE OF PAPER AND PAPER PRODUCTS	7,63	11,48	14,34	20,27	24,92	26,54	19,31	**18,02**
	C19 - MANUFACTURE OF COKE AND REFINED PETROLEUM PRODUCTS	\	21,67	17,76	12,8	9,46	8,6	3,17	**7,87**
	C20/21 - MANUFACTURE OF CHEMICALS AND CHEMICAL PRODUCTS	8,24	12,03	12,86	15,26	16,32	13,73	8,71	**11,76**
	C22 - MANUFACTURE OF RUBBER AND PLASTIC PRODUCTS	10,04	19,5	24,5	33,27	39,43	38,09	34,52	**30,89**
	C23 - MANUFACTURE OF OTHER NON-METALLIC MINERAL PRODUCTS	21,05	36,53	39,5	43,75	49,57	42,34	33,39	**38,11**
	C24/25 - MANUFACTURE OF BASIC METALS	23,15	40,34	40,31	41,63	46,14	48,2	50,85	**40,36**
	C28 - MANUFACTURE OF FABRICATED METAL PRODUCTS, EXCEPT MACHINERY AND EQUIPMENT	22,97	27,95	28,76	26,82	27,17	27,6	23,78	**26,4**
	C26/27 - MANUFACTURE OF ELECTRICAL EQUIPMENT	8,85	13,74	14,12	15,21	15,95	15,98	10,02	**12,94**
	C29/30 - MANUFACTURE OF MOTOR VEHICLES, TRAILERS AND SEMI-TRAILERS	17,79	36,21	38,41	33,53	37,02	37,45	21,7	**27,48**
	C31/32 - OTHER MANUFACTURING	18,97	26,03	26,72	28,32	33,92	31,1	31,8	**26,52**
TOTAL		**2,76**	**17,43**	**26,07**	**26,94**	**28,23**	**30,62**	**30,33**	**22,92**

Table A4 : Insurance fees - Manufacturing sectors (INAIL database)

Activity sectors	Tax value
Iron and Steel Metallurgy (Steel). Production of semi-finished products and iron and steel.	
Treatment and processing of raw materials and production of cast iron to the blast furnace.	83
Refitting, casting, finishing of cast iron or steel products	83
Thread, bar and tube drawing.	73
Cold refilling of steel products. Coating and cutting of coils.	53
Treatment and processing of raw materials (minerals or chemical compounds) for the production of metals and their alloys.	60
Refit, cast; Die Casting; extrusion; first processing to mills, mops, presses.	62
Processing of metallurgical products and machining of metallic materials.	
Cutting, bending, welding of laminates and strips, metal carpentry construction and metalworking	100
Production of tools for arts and crafts and hardware, generally obtained by forging	77
Production of cutlery, surgical instruments, weapons.	53
Construction of furniture and furniture made of metallic material, safes, armored lockers, locks and locks of safety, of chandeliers, of prams and strollers for children, of seats for lifting installations.	44
Production of screws and bolts obtained by forging or stamping	47
Construction and repair (including any scaling operations, picketing and the like) of tanks, reservoirs, tanks, gas tanks, containers and generally large containers.	115
Manufacture of metal bodywork for motor vehicles or parts thereof. Repair of car bodywork for motor vehicles.	48
Machining of sheet metal molding. Production in series of metal products made with prevailing molding operations.	73
Production, not in series, pipes, channels, tanks, hoppers, hoods, signs and the like; promiscuous working plumbing and boiler assembly.	81
Production of cables and wire ropes in general, bare electrical wires and coated.	31

Production of canvases and metallic networks.	74
Production of springs of any type obtained from wire or ribbon.	33
Machining with machine tools for the removal of material: turning, milling, drilling, etc.	35
Silver processing	30
Goldsmiths and Jewelery	18
Production of dies for photomechanical printing, zincotype, gravure, stereo, and the like.	9
Production of coins, medals and the like.	18
Production of different objects made from steel strip and wire.	37
Rolling and cleaning	69
Painting	52
Enamelling, metallization	75
Chromolithography.	36
Welding	65
Demolition of machinery and metal equipment	130
Construction, transformation and repair in workshop of machines and mechanisms	
Liquid, gas, compressed air engines; hydraulic motors and wind	44
Electric motors, alternators, dynamo, transformers, converter machines.	29
Pumps and compressors	39
Operating machines	40
Sewing machines and threshing machines for industrial and domestic use.	18
Elevators and hoists.	66
Small weapons	18
Heavy weapons	60
Torpedoes, missiles and the like	37
Mechanical industry in general.	61

Means of transport	
Construction of motor vehicles and trailers	30
Repair of vehicles	42
Building, repair, maintenance of movable equipment for railways and tramways	100
Construction work and construction, carried out both on board, both on land and in the shipyard, ships, boats, barges, pontoons, docks and floating platforms and the like, of naval carpentry, buoys, buoys.	115
Transformation, repair, maintenance of ships, boats, floating and part of it, svolte was on of board or to earth in the field of the shipyard navale; works of carnage.	130
Air transport: aeronautical constructions	28
Different instruments and appliances. Construction	
Machines for writing, copying and duplicating of all types, cash registers, telechargers, issuers and ticket validators, and the like.	10
Measurement tools	20
Scientific equipment	12
Musical instruments and accessories mainly in metallic material	15
Optical instruments	13
Components of electrical systems	21
Measurement and control instruments	14
Telephone and telegraphic equipment.	10
Cathodic tubes, vacuum or gas tubes for light or special radiation, bulbs; illuminated signs	20
Lighting fixtures in any material	22
Hydraulic and hygienic equipment	41
Thermal equipment: steam production, heating, refrigeration, air conditioning	55
Home appliances	32
Other instruments and apparatus	31