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RISK ANALYSIS OF TRACTOR ROLLOVER IN THE NORMAL OPERATION IN FIELD

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1. INTRODUCTION

Tractors are the most widely used machines in agriculture and are responsible for the high number of fatalities related to the use of farm machinery (McCurdy and Carroll, 2000; Nichol et al., 2005). In Italy, data reported by the observatory of Italian Workers Compensation Authority (INAIL) indicate a high number of fatal accidents associated with the use of tractors (Fargnoli et al., 2010). In fact they are a primary cause of death or serious injury in agriculture (Cargioli and Monti, 2004; Myers, 2000; Myers et al., 2009; Pessina et al., 2010) despite the application of the European Commission Directive 74/150 (EEC, 1974) that made tractors Roll Over Protective structures, ROPS, mandatory to provide the driver with a survival volume in case of tractor accident. These devices proved to be effective in reducing fatal injuries to the operator, but the safety margin for the driver is still under evaluation (Guzzomi et al., 2009). Recently, in fact, some questions related to their performance regarding the modern tractor evolutions have been raised (Jarèn et al., 2009; Rondelli and Guzzomi, 2010).

The objective of this research project was the risk assessment of tractor rollover during actual work in field since the theoretical studies based on controlled tests in field or even in laboratory showed the need of actual data to realistically evaluate the problem.

It was therefore decided to monitor tractors in usual operations by fitting a commercial warning device that continuously records the main dynamic parameters so as to collect data on different variables influencing tractor dynamics. The performance of the device was also assessed in order to verify its reliability in improving the operator's risk perception to prevent rollover accidents.

A preliminary territorial statistics investigation was carried out to obtain an overview of the present situation of the accidents related to tractors. A critical approach was adopted to evaluate the data, collected by institutional sources, in order to verify their suitability for statistical safety analysis.

In fact, despite the high number of rollovers, it is not easy to have a correct perception of the phenomenon as the methods of data collection are neither organic nor consistent, so the reliability of accidents databases organization had to be investigated.

In particular, recently, observatories on accidents, collecting information on individual cases from the internet (Arana et al, 2010), have been added to the databases of the insurance institution. Thus it is necessary to evaluate different data from different sources. This approach is likely to become more important as the observatories are intended to spread because of the easiness of downloading accidents information on the web. Therefore it is important to become familiar with an accident data collection system based on the combination of insurance institutions and observatories.

Official statistics related to official work insurance are in Italy, as well as in many European countries, coded according to the European Statistics on Accidents at Work (ESAW) methodology and do not provide a precise definition of the dynamics of the rollover accidents thus making it very difficult to assess the event. Furthermore it does not details the existence of the protection devices, rollover protection structures and seat belts, and their correct installation when the accident occurred.

The different databases available nowadays have different goals and, consequently, a different data collection approach, and none covers the full range of accidents necessary for a complete characterization of the issue. Being this the state of the art, combining data from different sources is necessary to obtain the information on tractor accidents such as the percentage of overturn fatalities compared to total tractor overturns.

Once the most appropriate set of data is selected great attention is required in the statistical evaluation. In the sequent step a territorial evaluation of accidents statistics was used to associate the accidents to the structural characteristics of the territory identifying possible causes of risk. However the analysis of wide geographical aggregates, such as regions or provinces, could have a modest significance as they provide averaged values referred to profoundly different situations. By aggregating more municipalities, instead, on the basis of the type of risk, functional areas of good homogeneity were obtained. Following this approach territorial maps were developed (Brugnoli, 2000).

A model to forecast the level of accident risk was also developed. This was based on the characteristics of the farms activities, the employment and the mechanization.

The maps referred to the municipalities of the Emilia Romagna region, one of the most active areas of Italy in agriculture, with strong geographical differences.

Emilia Romagna region is an important area for the analysis and it could reproduce most of the italian situations. The region is characterized by areas of plain, hill, mountain and different slopes, various forms of enterprise and a quite modern and high agricultural mechanization.

The following research step was to carry out field tests on a group of tractors, operating at the experimental farm of the University of Bologna. These were monitored by using a warning commercial device during two whole vegetative seasons. The evaluation of tractor rollover in working conditions should consider that the rollover is influenced by several factors such as interaction among operator, tractor and environment. Major critical variables reducing tractor stability are slopes and rough terrain; these factors interact in a complex manner in determining the risk of rollover, mainly influenced by the position of the tractor's centre of gravity, forward speed and turning angle. The availability of a commercial low cost device, such as the tested one, offered the advantage of retrofitting it on tractors in use. In European Countries since 1974, according to EC Directive 74/150 (EEC, 1974), tractors are fitted with ROPS as a passive means to minimize the risk of injury for drivers in the event of tractor upset. The approach to fit a ROPS was the consequence of verifying that there was only a little chance of preventing tractors from rolling over (Moberg, 1973). Nonetheless, a commercial warning device capable of informing the tractor operator on the stability of the machine during the operation could greatly contribute to prevent fatal accidents because he can promptly react and consequently decrease dangerous situations.

2. A CRITICAL APPROACH TO DATA EVALUATION

In order to properly assess the entity of rollover injuries, the purpose of the evaluation carried out was essential to clarify the data available for consultation. There are in fact various databases corresponding to different objectives and, consequently, different data. Therefore simply crossing them can lead to errors in such instance even of large scale.

Moreover, information related to the particular case of injury caused by tractor rollovers tends to be incomplete since the rollovers often involve largely retirees and hobby farmers that, not being insured by Italian workers compensation authority (INAIL), are not concerned by official estimates. In addition the accident archives have different encodings and to identify the dynamics of the accident is not always possible, mainly for the rollover cases.

It is thus necessary to analyze the available databases and their different characteristics in order to use the most appropriate for the information to be achieved.

National data are almost exclusively based on the INAIL collection system. The sources of this organization are of three types :

1) Operational archives collecting the allegations, compensated or not. They are therefore related to the workers covered by INAIL insurance protection.

2) Surveillance System of fatal and Serious Injury at Work, whose data are entered by operators of Local Health Units (ASL).

3) The INAIL Observatory realized by the eighth functional unit of the Department of Technologies of Safety, formerly National Institute for Occupational Safety and Prevention (ISPESL), that collects information on fatal accidents in agriculture, with a primary focus on those related to the use of agricultural machinery, and evaluates various sources such as newspapers and websites, and, therefore, considers any possible victim.

In the following paragraphs specificities and differences of these sources of data are described in detail.

2.1 OPERATIONAL ARCHIVES

These are the archives providing official data that are also published in the Annual Reports of INAIL considering a fairly large case series.

Injuries in agriculture are assessed in the insurance management section named Agriculture, that includes agriculture, agricultural or forestry activities that carry out a direct work on land, forestry, animal breeding and related activities.

The following activities are considered in insurance management section named industry, because of the way in which agricultural activities are carried out :

- cooperatives and their consortia that transform, manipulate and sell their products or their members products.
- mechanical and agricultural processing performed exclusively or mainly for third parties.
- the holiday farms if their activity is completely independent from the activities of the farm.

Since 1 June 1993, however, regulars self-employed for which the agricultural activity is not prevalent were excluded from compulsory insurance (Article 14 of Decree-Law May 20, 1993, 155, ratified by Law 243 of 19 July 1993). This resulted in a sharp decline of the recorded data in the INAIL time series, as is evident from the diagrams in Figures 1 and 2.

Therefore there is a substantial portion of injuries that now are outside the field of interest of INAIL estimates.

Considering in particular the data of 1992 and 1994 there is a reduction of 53% of fatalities and of 40% of accidents in agriculture. Such a sudden drop in so a short time period seems justified by the application of the decree rather than by technological improvements for safety.

In particular, when assessing accidents linked to the mechanization, this exclusion was particularly detrimental because the accidents related to the use of machines are especially important in small and medium-sized farms. As an example if considering the year 2007, it results that for the self-employed the accidents, reported by INAIL, due to machinery are 1609 including 10 fatalities, for employees are 668 including 5 fatalities and even lower values for the contractors (INAIL internal report, 2010, personal communication). It is so easy to presume that those who have been excluded from the INAIL archives, mainly pensioners and hobby farmers, are high risk categories.

To get a more specific overview regarding injuries related to tractor rollover it's possible to see the table 1. The data, provided by the Statistical service of INAIL, are divided between fatalities in agriculture and fatalities associated with the use of tractors. The yellow data refer to the years in which data are incomplete due to the lack of encryption, up to 50 % of cases, by the INAIL operators who have not specified the type of event.

The last column relates to an estimation of the rollover cases not reported in the official data, obtained at the INAIL level adopting a specific method of calculation, as reported later, according to Iotti's data (Iotti, 2008).

The current encoding of injury dynamics, established at European level, does not enables to uniquely identify rollovers. The project of harmonizing European Statistics on Accidents at Work, ESAW, started in 1990 with the aim of developing a methodology for the collection of comparable data in the European Union. The project was divided in three phases for data concerning accidents involving absence from work for a period over than three days. The reference years were respectively 1993, 1996 and 2001, where the reference period is defined as the year of the declaration of the accident.

More specifically, the three phases are divided into:

PHASE1

It introduces the variables intended to identify the economic activity of the employer, profession, age and sex of the victim, the type of injury and body part injured, as well as the geographic location, the date and time of the accident.

PHASE2

It integrates these initial data with information on the size of the company, on nationality and professional status of the victim and the consequences of the accident in terms of the number of days lost, permanent disability or death.

PHASE3

The information provided by these variables allow to identify the characteristics of the victim, the injury and its consequences, the date and place of the accident. To promote, however, a more active European policy for the prevention of accidents at work. The phase 3 of the ESAW project introduces harmonized classifications and other variables related to the causes and circumstances of accidents at work which should contribute to the assessment of the situation and the prevailing conditions at the time of the accident, providing useful information for the development of new and more targeted prevention policies.

The variables introduced in this phase can be divided into three levels:

The circumstances immediately before the accident with 4 variables :

Workplace (Optional)

Type of place

Type of work

Specific Physical Activity

The deviation, which is the most recent event occurred in the circumstances described in the previous level, deviating from the standard situation, leading to the accident.

The Contact - Mode of injury, is the action that actually causes the injury due to the deviation in the previous level.

Moreover the system connects, in each of these 3 levels, a material agent associated with each corresponding action:

1) Material Agent associated with the Activity Specific Physical

2) Material Agent associated with the deviation

3) Material Agent associated with the Contact

There are therefore 8 variables, because the first one is optional, to describe the injuries dynamics.

INAIL had therefore to adapt its encoding method previously adopted especially for the cases of road accidents or on public transport.

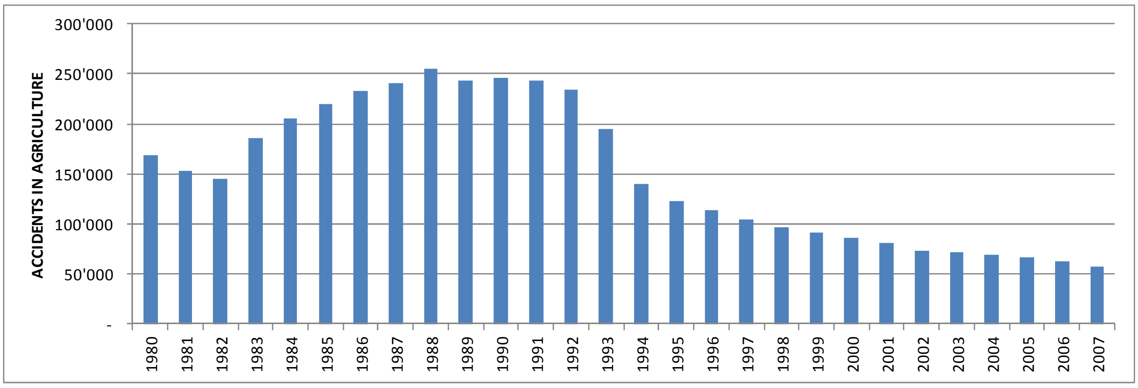


Figure 1. Accidents at work in agriculture (INAIL source).

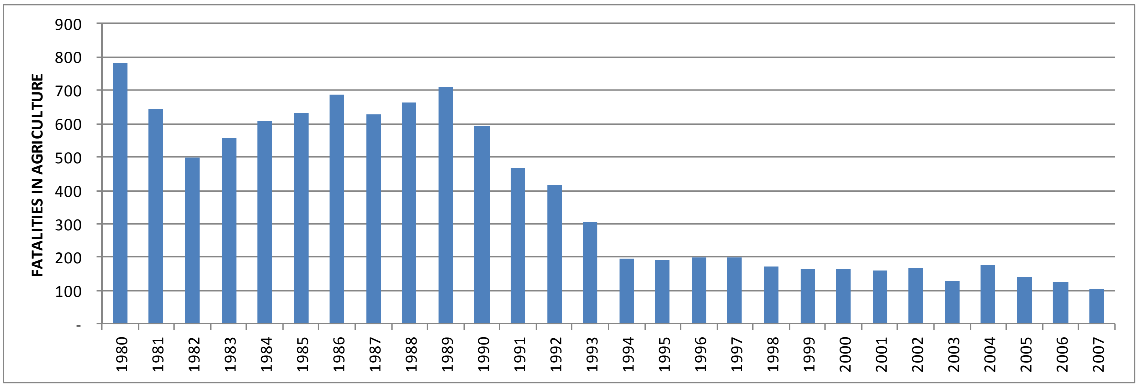


Figure 2. Fatal accidents at work in agriculture (INAIL source).

Unfortunately, as already mentioned, it is not possible to directly extract the series of accidents referring to tractor rollovers in the INAIL databases among those registered with the ESAW system, since this category of accidents is not specifically coded.

However, it is possible to search for the data indirectly crossing a number of characteristics that certainly exist for this type of injury as suggested by Iotti (2008):

• Sector specific AGRICULTURE is the first to be included in the data selection.

• Variable CONTACT and its associated MATERIAL AGENT: as an agent material must necessarily be a TRACTOR, and the contact "crushing under”.

Table 1. Data from the statistic service of INAIL and estimated rollovers.

	STATISTIC SERVICE OF INAIL				Estimated Rollovers (Iotti, 2008)
	Agriculture Accidents	Agriculture Fatalities	Tractor Accidents	Tractor Fatalities	
2000	85618	163	0	0	
2001	80532	159	318	2	
2002	73515	167	3664	16	
2003	71379	128	5758	22	335
2004	69263	175	5753	23	366
2005	66467	141	4817	20	274
2006	63082	124	4705	17	280
2007	57205	105	3524	17	205
2008	53354	125	1790	15	
2009	52665	128	1871	11	
2010	50121	115	1619	15	
Mean	65746	139	4704	19	314
Standard Deviation	11693	23	969	3	44
Standard Deviation %	18	17	21	15	14

With this restrictive selection a very limited and unreliable group of data is obtained. It could improve if focusing on Emilia Romagna region, even if many cases remain "hidden" in the bumps and collisions (depends on what exactly happened in the dynamics, if the operator was knocked out, fell to the ground, collided with the tractor, or is hit by the tractor itself that ends up on tips as on a slope, etc.). So it is reasonable to search for neglected cases in another way.

The variable that allows to do this is the deviation, always with the associated AGENT MATERIAL: whatever happened later, as the final outcome, an injury due to the overturning of a tractor is always determined by a loss of driving control.

• It is necessary then to set the range of deviation "loss of control" and as AGENT MATERIAL associated, TRACTOR.

• By adding, as a further element of selection, CONTACT for "crushing under" (but without specifying the AGENT MATERIAL of contact, otherwise it falls into the above problem). This could result in a small entity of the injuries due to loss of control of a tractor and ended with a crushing of the victim.

2.2 NATIONAL SURVEILLANCE SYSTEM OF FATAL INJURY AT WORK

The surveillance of work-related fatalities is aimed to the study of the causes, and was launched in 2002 jointly by ISPESL, regions, autonomous provinces and INAIL.

Operators Services for Prevention and Safety at the workplace of the local health units (ASL) reconstruct the accident occurred and send the information into the National Archives.

The coordination is entrusted to the Ministry of Health and the National Center for Disease Control and Prevention.

Since 2005 the system has been consolidated through a continuous monitoring, particularly in the first two years, 2005-2006, a transition period between experimental phase and continuous monitoring. Data have been included related to investigations conducted by the Accident Prevention Services of ASL of 12 regions and autonomous provinces, while for the years 2007 onwards, the coverage has been extended on a national scale with quality checks on new cases of injury progressively inserted in the database in order to publish the new data. The technicians of the prevention service cooperate in police investigations for the recognition of the causes and responsibility for the most serious cases of accidents and occupational diseases. Focus is mainly on the professional workers. In detail the subjects of surveillance are:

• Cases investigated by the Prevention Services of ASL regardless of their conditions of possible indemnity.

• Cases not investigated by the Prevention Services of the ASL if they are reported to INAIL (mainly the so-called injuries " related to the street ").

• A limited number of cases where investigations are carried out by the Provincial Departments of Work.

• There are also cases of work-related fatalities, but not detected by the institutions, mainly related to irregular workers.

The main objective of the system consists in the investigation of injury dynamics aimed to provide guidance to enforcement actions to control the phenomenon through a homogenous standard of intervention, collection of information and interpretation by the structures of investigation, namely the prevention services of ASL and INAIL offices. This goal is divided into:

• Development of the National Directory of Fatal Accidents including the reconstruction of the causes and dynamics of the injuries.

• The improvement of the skills of analysis and interpretation of events through the method “Mistakes are teachers”.

• Upgrading means for communication.

• Implementation of Operational Tools (Recommendations, Guidelines, "risk profiles "...) based on the cases studied.

• Promotion of initiatives aimed at prevention.

The "Mistakes are teachers" method is one of the models of tree of the causes for the analysis and description of the injury dynamics.

"Injury dynamics" means the sequence of events and circumstances that, when the accident occurred, can be recognized through appropriate methods of investigation and that can explains the injury. The accident dynamics is then formed by all the elements that the analyst recognizes as relevant to the interpretation of that particular case investigated. The reconstruction process follows the path "backwards" in use in the judicial investigative process, then starting from the last event in chronological order, the damage, with its qualitative aspects (location and nature of the lesion) and quantitative (severity) non- difficult to detect, and proceeds looking for the cause of that particular injury, the exchange of energy, then where did the energy comes in the interpretation of the accident, ie, what are the factors that have determined the event (determinants) and those which have a bearing on the seriousness of its consequences (modulators).

With this method it is possible to obtain a highly detailed description of injuries and fatalities in the archive available online through the web tool INFORMO. In table 2 fatalities are visible and it is possible to isolate the cases of tractor rollovers contained within the item "Change in the run of a vehicle/transport (leaving from the intended path, rollover...)" that are confirmed as the leading cause of death in agriculture. Because the elements that have an impact on the severity of the consequences are also specified, the modulators, it is possible to get, by reading the report of each case, a tractor statistics about tractors, if they were equipped with ROPS or seat belt at the time of the injury, as shown in Figure 3 that confirms the extreme importance of the use of these safety devices.

The results displayed indicate that the database of the surveillance system is essential in studies where a thorough understanding of the dynamics of events, is needed but insufficient in cases where it is required a complete picture of all fatal accidents, because databases collect a reduced number of data and, in the case of fatal accidents in agriculture, even lower than the ones provided by INAIL operational archives.

Table 2. Agricultural fatalities in the period 2002-2010.

AGRICULTURE FATALITIES 2002-2010	Frequency	Percentage
Total	675	100.00%
TRACTOR ROLLOVERS	168	24.89%
Fall from a height or depth of the injured	107	15.85%
Weight fall	73	10.81%
Contact with other objects, vehicles or vehicles in motion (in their usual venue)	66	9.78%
Contact with other objects, vehicles or vehicles in motion (in their usual venue)	60	8.89%
Change in the run of a vehicle/transport (leaving from the intended path, ~~rollover~~....)	57	8.44%
Accidental starting of the vehicle, machine, equipment, etc..	51	7.56%
Projections of solids	19	2.81%
Other... (var. interface)	19	2.81%
Direct electrical contact	14	2.07%
Unespected movement of animals	13	1.93%
Indirect electrical contact	9	1.33%
Fall in the plane of the injured	7	1.04%
Other... (var. energy)	7	1.04%
Uncoordinated movement of the injured (causing collision with...)	3	0.44%
Flames	2	0.30%
Movement of the injured with effort of excess	0	0.00%
Leakage of gas, vapor and liquid hot	0	0.00%
Leakage of gas, vapor and liquid at very low temperatures	0	0.00%
Leakage of gases, vapors and corrosive liquid	0	0.00%
Move unexpected or aggressive of another worker or a third one	0	0.00%
Contact with hot objects or materials, open flames, etc.. (in their usual venue)	0	0.00%
Contact with hot liquids or corrosive (in their usual venue)	0	0.00%
Contact with objects at very low temperatures (in their usual venue)	0	0.00%
Missing data	0	0.00%
Total	675	100.00%

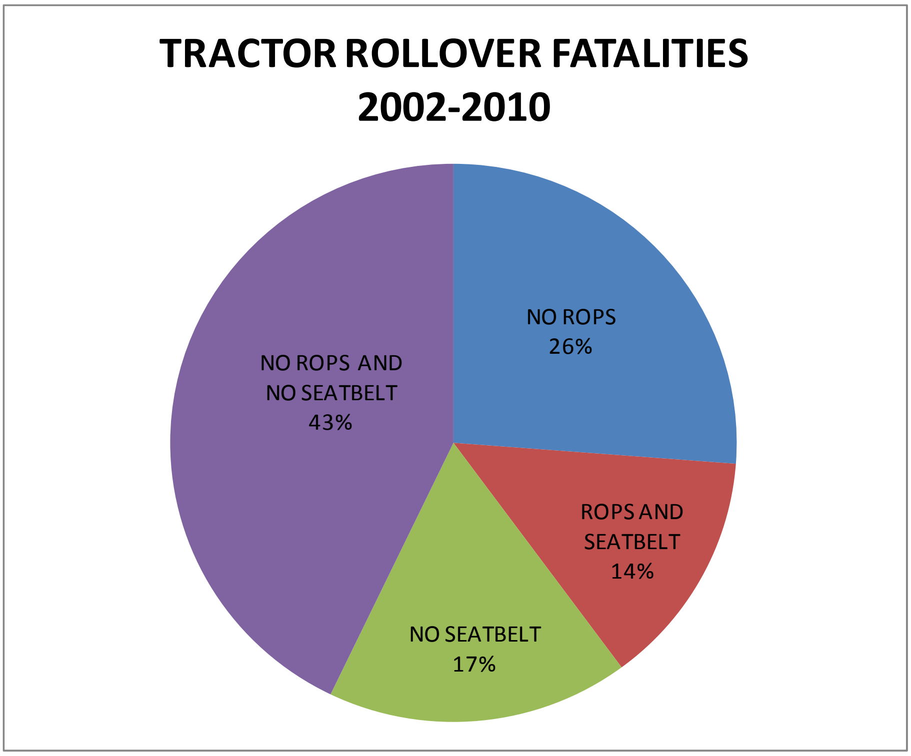


Figure 3. Tractor safety devices in Rollover fatalities in the period 2002-2010.

2.3 INAIL OBSERVATORY OF ACCIDENT IN AGRICULTURE

The main problem in accidents assessments is that the information concerns a small number of injuries related to the field of interest of the institution collecting the data. It has been created then an INAIL observatory on accidents in agriculture at the VIII functional unit of the department of security technologies, former ISPESL, with the aim of providing a complete picture of the situation accident in the Italian agriculture.

Therefore, to obtain data on all those engaged in agricultural activities, information was gathered from :

- Reports of the Territorial Local Health Units ASL
- Collection of data on the major media (newspapers, press agencies...)
- Observatory " Il centauro " Asaps (Association of Supporters Friends of the Traffic Police)

This method allows to certainly obtain the complete series, but the data collected concern mainly injuries related to the use of machines and thus not sufficient to assess the impact that these cases have on the full range of accidents in agriculture.

But it must be emphasized that the activities of the observatory began in 2007 and that the systematic collection of data was consolidated only since 2009, so it is reasonable to assume that there will be an increase of information in a short time.

Because the data come from different sources often the information is not provided by technical experts and the technical aspects are not always clearly reported.

It has, however, been established that, in the context of the National Plan for Prevention in Agriculture and Forestry since May 1 2011, all accidents recorded at the observatory are validated by a on-site supervisory organ of ASL that shall complement the information by filling a special survey form (INAIL internal report, 2010, personal communication).

Nevertheless, these data certainly provide the most complete picture regarding fatalities associated with the use of the tractor, as visible in Table 3. It is clear how the overturning of tractors represents almost the main type of accident and that the victims are often over sixty, exactly the type of person who can be neglected by the statistics of the operational archives. By crossing these data with those found in the INAIL archives (Tab. 4) it is possible to assess how operational archives underestimate the phenomenon (INAIL internal report, 2010, personal communication).

Table 3. Fatalities related to tractors in the period 2009-2010.

ACCIDENT	**2009**	**2010**
Rollover	123	116
Collision	10	9
Falling from tractor	10	8
Ground tractor ignition	1	-
Undefined	2	2
TOTAL	**146**	**135**
Operator age≥65 years	67	63

Table 4. Observatory data and operational archives data comparison.

	RECORDED ACCIDENTS INAIL OBSERVATORY	RECORDED ACCIDENTS INAIL OPERATIONAL ARCHIVES
2009	**146**	**40** (19 INAIL Indemnified and 21 Cases reported to INAIL, but rejected as uninsured person)
2010	**135**	**47** (18 INAIL Indemnified and 29 Cases reported to INAIL, but rejected as uninsured person)

Therefore this is a database that considers almost exclusively fatal cases related to the use of agricultural machinery, but indicates, even not in detail, the dynamics and considers almost all the events.

2.4 COMPARISON OF DATA

In order to have a quantitative comparison of the different databases it is reasonable to consider the annual values of the data calculated for the last available year (Table 5).

To obtain the average values of the monitoring system the years from 2002 to 2010 were considered, because, despite the organizational evolution that has characterized it, the annual data have not had big changes.

The number of rollover for operational archives consists of the assessment that was described previously.

In the last column of the table are inserted values that consider the underestimation of official data due to exclusion from compulsory insurance of self-employed for whom farming is not prevalent (Decree-Law May 20, 1993, 155, ratified by Law 243 of 19 July 1993) and has been calculated on the basis of the variation of the historical series of accidents for the years 1992 and 1994, estimated at 40% for accidents in agriculture, and 53% for fatal accidents.

It has been also calculated an increase in the estimated rollover, equal in percentage, to that of injuries in agriculture, since, in this case, we consider generically all accidents, not only fatalities.

Table 5. Values of accidents per year according to the database.

ANNUAL VALUES	SURVEILLANCE SYSTEM	OBSERVATORY	OPERATIONAL ARCHIVES	Adjusted OPERATIONAL ARCHIVES
Agriculture Accidents			65746	109576
Agriculture Fatalities	75		139	296
Tractor Accidents			4704	
Tractor Fatalities		141	19	
Rollover Accidents			314	523
Rollover Fatalities	19	120		

Focusing on the fatalities related to tractors it is possible to state that the data available in the operational archives underestimate the phenomenon of 86%, while the surveillance system underestimates of 84% the fatal rollovers.

It's also clear the noticeable difference between fatalities in agriculture operating archives and surveillance system that is completely inappropriate for a comprehensive evaluation of the problem.

In order to assess how many rollovers are fatal and how many fatal accidents are rollovers is necessary to pay great attention. Using data from the various sources allows to get the results shown in Table 6.

In the last column, referred to the operational archives, the approximation Tractor Fatalities number equal to Rollover Fatalities number is considered.

The most accurately calculated values are those in the third column and give an indication of the impact of the problem of overturning tractor more plausible. They are also consistent with the results of a similar observatory activated at the University of Navarra (Arana et al., 2010)

Just for reference purpose the second column was included, that compares values from databases with a level of reliability in the assessment of the problem totally different.

Table 6. Percentage of rollover fatalities compared to total rollovers and fatalities in agriculture.

	SURVEILLANCE SYSTEM	OBSERVATORY/ OPERATIONAL ARCHIVES	OBSERVATORY/ adjusted OPERATIONAL ARCHIVES	OPERATIONAL ARCHIVES
% Rollover sfatalities compared to total rollovers		38	23	
% Rollover fatalities compared to fatalities in agriculture	25	86	40	14

In conclusion, the main characteristics of the databases were summarized in Table 7.

Table 7. Observations on assessed databases.

DATA BASE	ADVANTAGES	CRITICAL ASPECTS
OPERATIONAL ARCHIVES	Includes fatal and non fatal accidents	Only INAIL insured workers are considered. It's impossible to identify cases of tractor rollover. For many recent data it has been not provided information about the type of accidents, such as if a tractor was involved or not.
SURVEILLANCE SYSTEM	It is possible to identify rollover cases. It is possible to verify the presence of safety devices (ROPS, seatbelts)	Only fatalities are included. Not all fatalities are included, data related to agricultural fatalities are even lower than the ones of operational archives.
OBSERVATORY	It's possible to identify the rollover cases and also all cases related to the use of self-propelled agricultural machines.	Data related to fatalities in agricolture are not available yet. Only fatalities are considered.

3. TERRITORIAL ACCIDENTS RESEARCH

A survey on the region of Emilia Romagna has been carried out, one of the most active regions in the agricultural sector, in order to understand the work accident situation in a perspective oriented to the territory, its peculiarities and its use, including assessment of how it affects the frequency and severity of accidents with particular attention to those that involve tractors, and comparing these accidents to accidents to the total accidents in agriculture.

The study, therefore, is not intended to provide a general overview of farming in the region, as has been done in previous studies (Brugnoli, 2000), but to assess the elements affecting tractor work.

3.1. DESCRIPTION OF AGRICULTURAL ACTIVITY

Data considered useful to evaluate the intensity of farming management characteristics were selected, releasing thus the information from the territorial extension. The territorial unit chosen as reference was the municipal area. For this reason, data are presented either as provincial averages, divided according to the altimetric areas, and maps with local detail at the municipal level.

3.1.1 STRUCTURAL CHARACTERISTICS

To describe the general characteristics of the farm management the data of the archives of 2010 agricultural census carried out by ISTAT have been used.

As expected land use is closely related to altitude, nevertheless it is possible to find strong differences even within the same altimetric area.

<u>Arable land per hectare of Utilised Agricultural Area (UAA)</u>

The highest concentration is found in plain, especially in Piacenza and Parma provinces, which have remarkable values also in the hilly area, followed by Ferrara and Bologna.

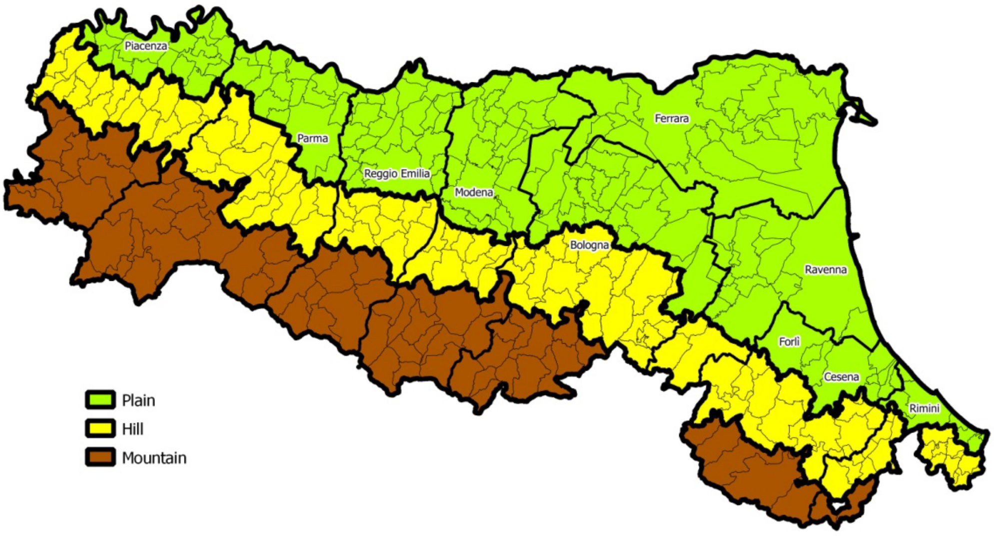


Figure 4. Map of municipalities, provinces and altimetric areas in Emilia Romagna.

<u>Grassland per hectare of UAA</u>

In this case the effect of the altitude is the opposite because the values increase with altitude, particularly in the mountainous areas of Forlì-Cesena and Parma.

<u>Forestry area – Municipal area ratio</u>

The forests are mainly situated, obviously, in the mountainous and hilly areas with the highest concentration in Romagna. In the map, however, are visible areas with high rates even in the west. These areas could not be evident by examining the table of provincial averages.

<u>Percentage livestock farms</u>

It was decided to consider this value rather than the livestock concentration because the interest is focused more on the activity carried out in the farms rather than on the intensity of production. Obviously, the results are completely different because in this case areas traditionally most productive, such as the plain of Modena, Reggio, and Parma are not pointed out, while it appears a strong link between the livestock farms and the altimetric area. However a clear distinction between the east and west of the plain remains.

UAA per farm

The surface of the farm is one of the most characteristic elements and of great interest for a study on agricultural mechanization. Table 8 shows that the most extended farms are located mainly in the plain, in particular in Piacenza, followed by Ferrara and Parma. Observing the map in figure 9 is evident that the Ferrara value is the provincial average resultinf from two very different values referred to the east and west locations.

Table 8. Indicators of structural caracteristic for provincial altimetric area.

Province	Altimetric Area	Arable land per hectare of UAA	Grassland per hectare of UAA	Forestry Area to Municipal area ratio	Average UAA per farm	Livestock Farms to Farms Ratio
Piacenza	Mountain	49	49	15	11	29
	Hill	79	10	8	15	19
	Plain	97	2	1	33	27
Parma	Mountain	33	66	15	12	37
	Hill	83	16	10	17	30
	Plain	96	3	1	22	27
Reggio Emilia	Mountain	65	34	14	15	54
	Hill	75	18	8	11	26
	Plain	77	12	1	14	21
Modena	Mountain	54	43	13	11	43
	Hill	64	21	8	9	25
	Plain	82	1	1	13	11
Bologna	Mountain	53	43	11	9	31
	Hill	71	15	12	14	19
	Plain	89	2	2	18	7
Ferrara	Mountain					
	Hill					
	Plain	91	0	0	23	5
Ravenna	Mountain					
	Hill	40	13	20	12	15
	Plain	68	1	1	13	6
Forlì Cesena	Mountain	42	55	18	21	47
	Hill	66	20	20	13	19
	Plain	63	3	3	6	6
Rimini	Mountain	72	27	19	17	35
	Hill	78	9	9	9	19
	Plain	79	2	2	6	9

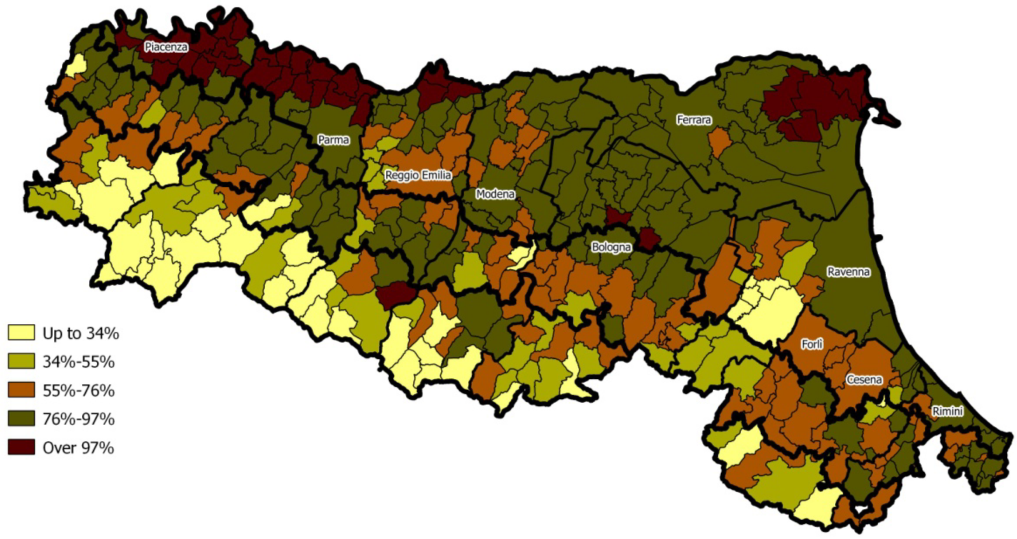


Figure 5. Percentage of arable land with respect to UAA.

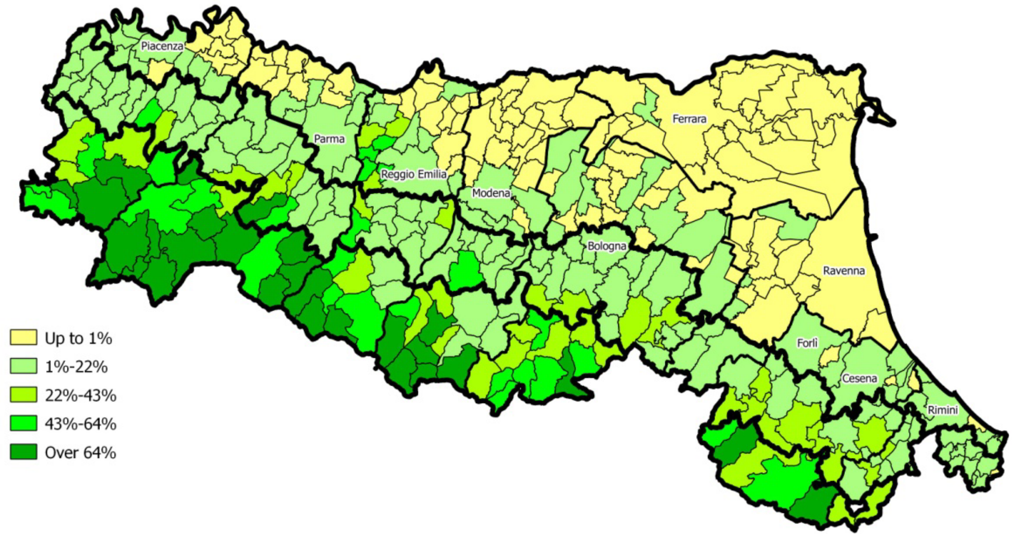


Figure 6. Percentage of grassland with respect to UAA.

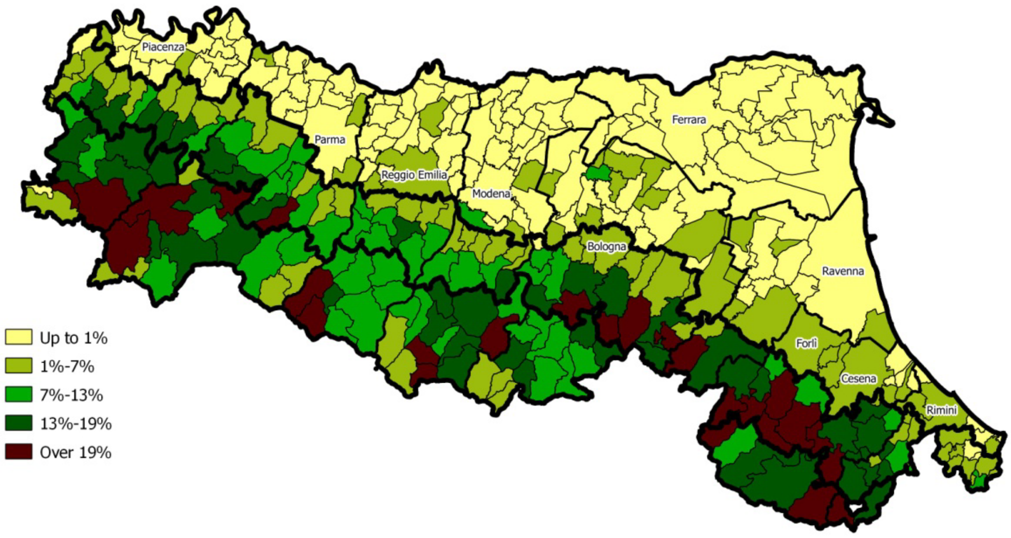


Figure 7. Percentage of forestry area with respect to municipal area.

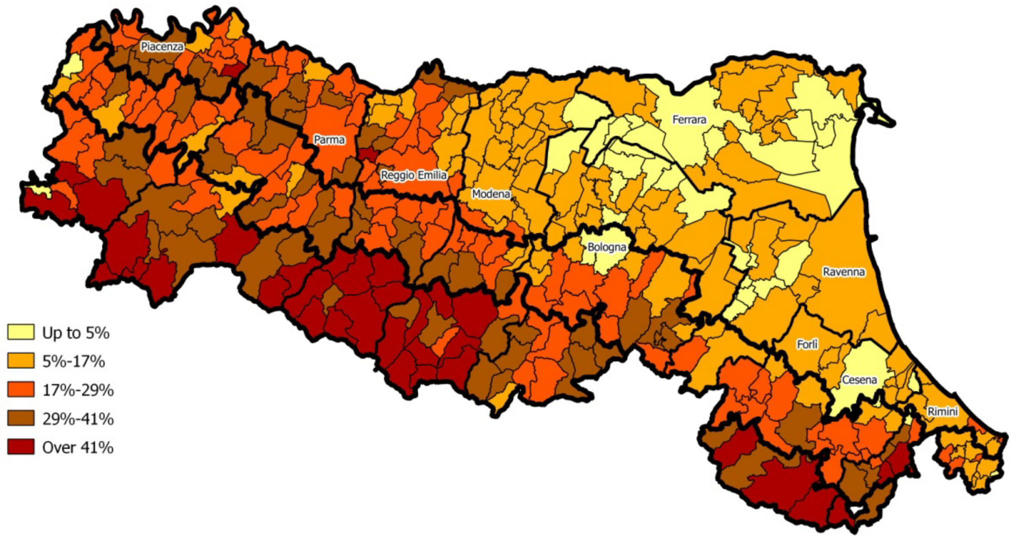


Figure 8. Percentage of livestock farms with respect to total farms.

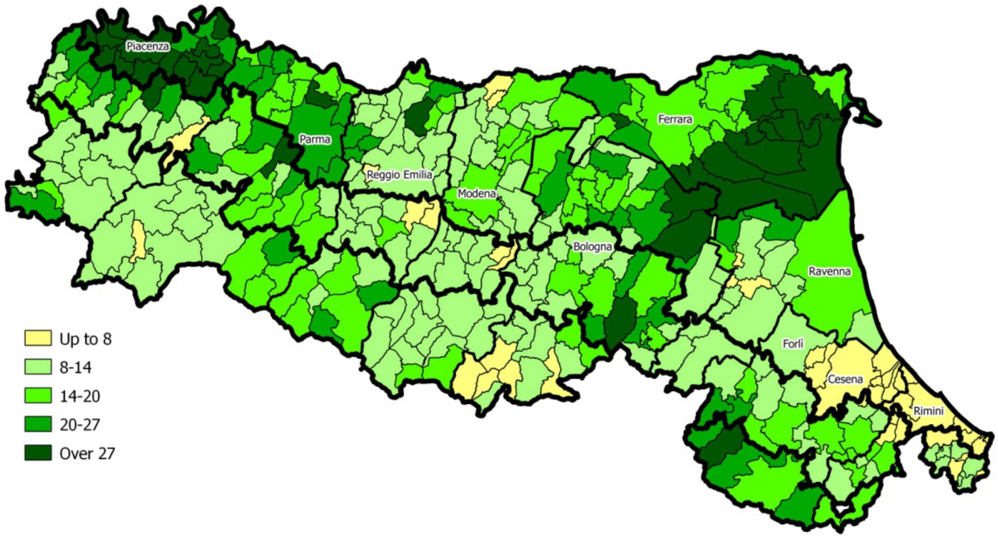


Figure 9. Average UAA per farm.

3.1.2. MECHANIZATION

To evaluate the levels of agricultural mechanization the data from the Archive Agricultural Machinery Users (UMA) of the Emilia Romagna region agriculture department were analized.

Because this survey is mainly aimed to the analysis of tractor accidents it seemed important to identify some aspects considered particularly significant.

<u>Tractors per farm</u>

The highest values are in plain with a peak at Piacenza followed by Parma and Ferrara. The farms in plain area of these cities presents also other similarities: large territorial dimension and high use of the arable land. The lowest values are in Romagna, consistently with the low use of the land as arable.

<u>Percentage of tractors before 1994</u>

To define a time threshold of obsolescence 1994 was chosen, twenty years after the European Commission Directive , 74/150/ECC, introducing the ROPS as mandatory on the tractors.

The overall trend shows a higher density of tractors registered before to 1994 in plain, although the differences between altimetric zones are not particularly marked, except for Piacenza, with opposite trend, and Parma where there is a great uniformity among the values of the different altimetric areas.

This could be explained with the need to renew the tractors in the mountains for the more demanding conditions in the slopes.

Percentage of tractors with Power over 60 kW

High values in the plain areas of Parma and Piacenza are noticeable, and in the Romagna mountains too. Linking the power of tractors to altimetric area is difficult, this is probably due to the balance between two different needs: the need of powerful tractors in the mountains, where the conditions are more difficult, and in areas of intensive arable land.

Figure 13 (b) shows that in the mountains there is a higher amount of four-wheel drive tractors, while the track laying tractors are present in similar percentages in the mountains and hills. In the plain there are many wheeled tractors.

In figure 13 (c) the old tractors are more than two and a half the new ones, while in figure 13 (d) The four-wheel drive tractors replace the wheeled ones and, in part, track laying tractors.

Figure 13 (f) shows that wheeled tractors and track laying tractors have mainly a reduced power, while the high-powered tractors are mainly four-wheel drive. This is reasonable considering that the new tractors, many of which have four-wheel drive, have gradually increasing the engine power over time.

However there is a lack of information in some data because for some tractors is not specified the type of drive system and for the others sometimes is not specified the engine power. The summary table, table 10 and 11, has three columns: for power less than 60KW, higher or equal to 60 kW, and a third that shows the total, not necessarily equal to the sum of the first two for the lack of data. The same situation is in the year of registration.

Only the data with the correct information of interest were used to calculate percentage values.

Table 9. Indicators of agricultural mechanization per provincial altimetric area.

Province	Altimetric Area	Number of tractors per farm.	Percentage of tractors before 1994	Percentage of tractors with power over 60 kW.
Piacenza	Mountain	2.1	73	17
	Hill	2.7	65	27
	Plain	4.7	64	38
Parma	Mountain	2.1	72	19
	Hill	2.8	70	26
	Plain	3.6	73	29
Reggio Emilia	Mountain	2.3	70	32
	Hill	1.8	76	27
	Plain	2.7	75	26
Modena	Mountain	1.9	65	24
	Hill	2.0	69	20
	Plain	2.5	70	23
Bologna	Mountain	1.4	60	28
	Hill	2.0	64	25
	Plain	2.7	69	23
Ferrara	Mountain			
	Hill			
	Plain	3.0	71	25
Ravenna	Mountain			
	Hill	2.0	63	20
	Plain	2.5	72	19
Forlì Cesena	Mountain	1.6	57	34
	Hill	1.6	62	28
	Plain	1.8	73	17
Rimini	Mountain	1.6	40	27
	Hill	1.4	53	24
	Plain	1.3	63	15

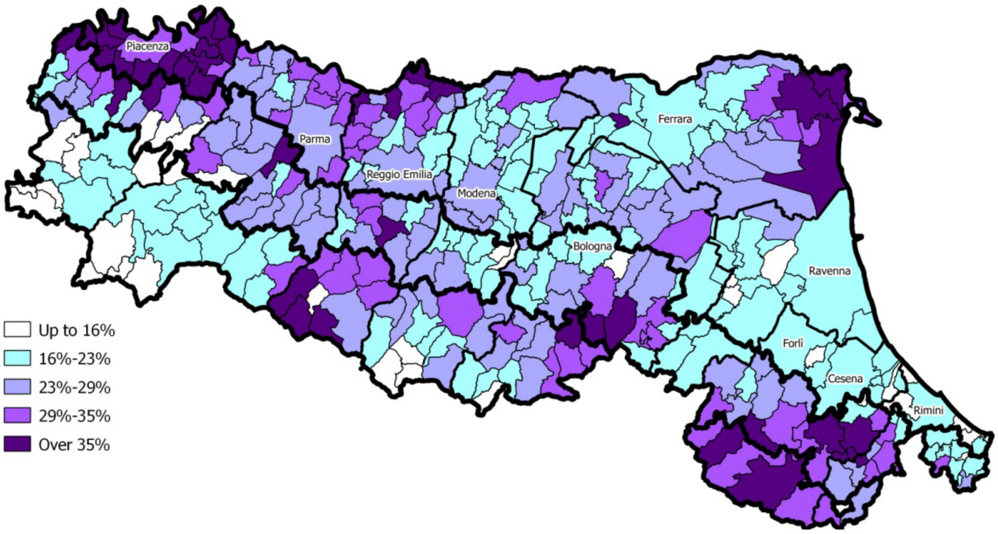


Figure 10. Percentage of tractors with power over 60 kW.

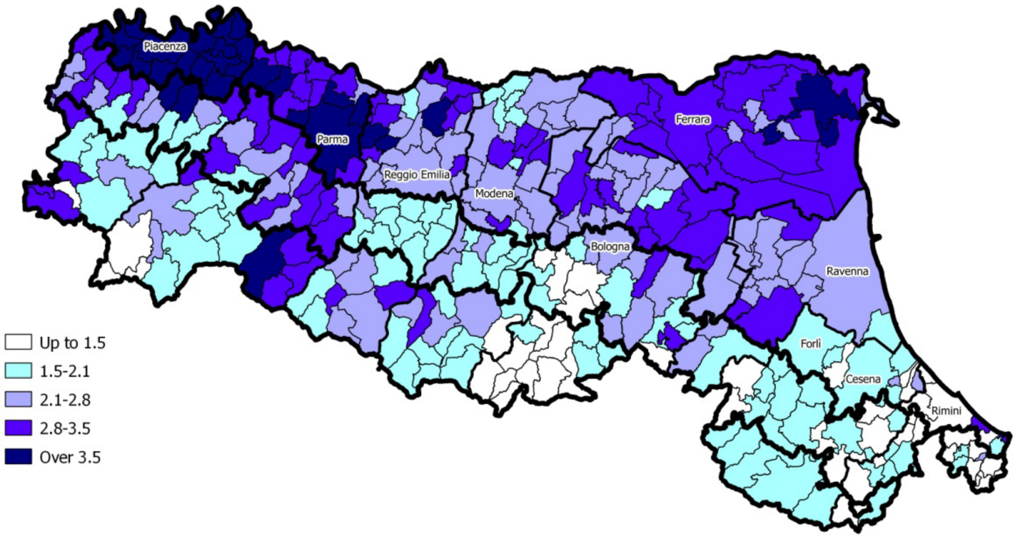


Figure 11. Tractors per farm.

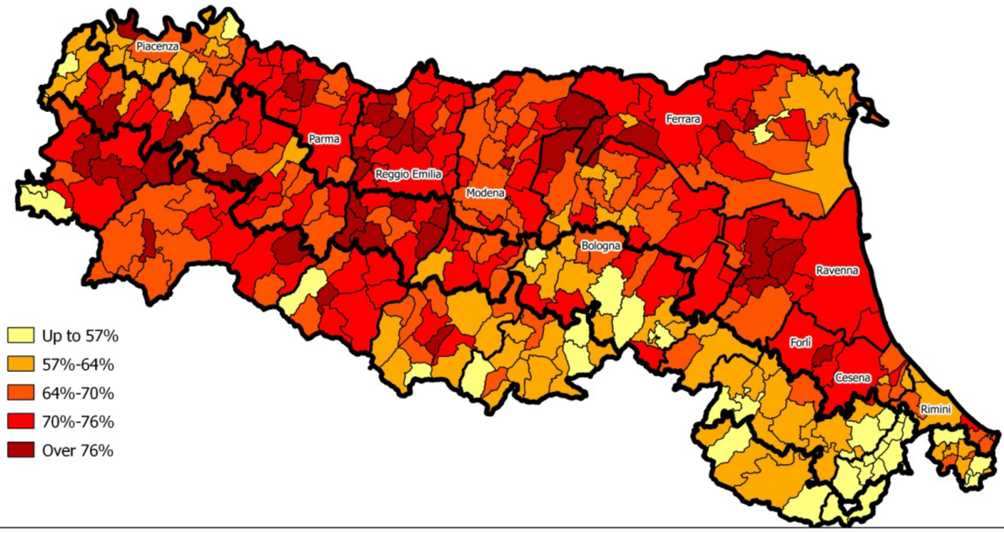
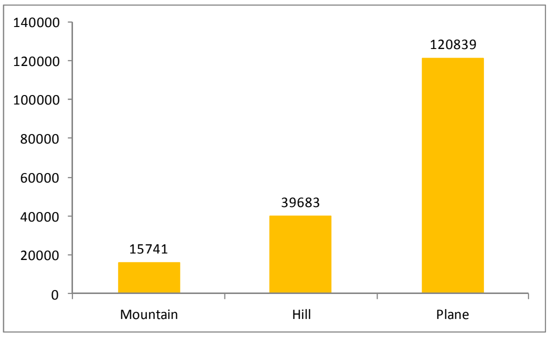
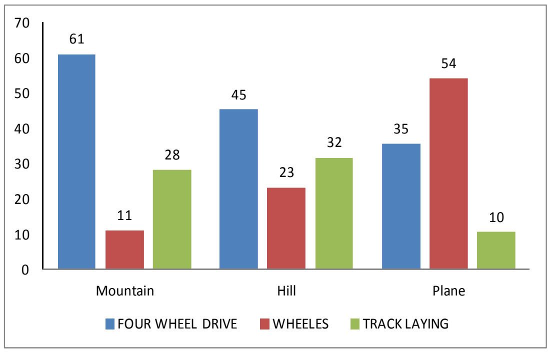


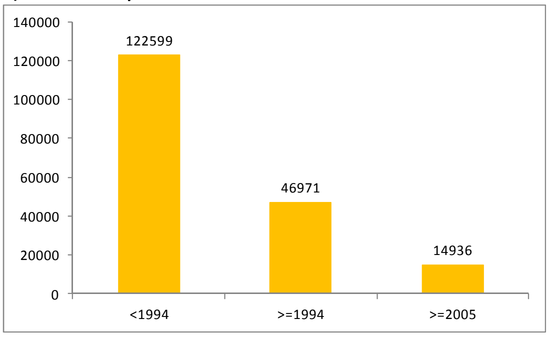
Figure 12. Percentage of tractors registered before 1994.



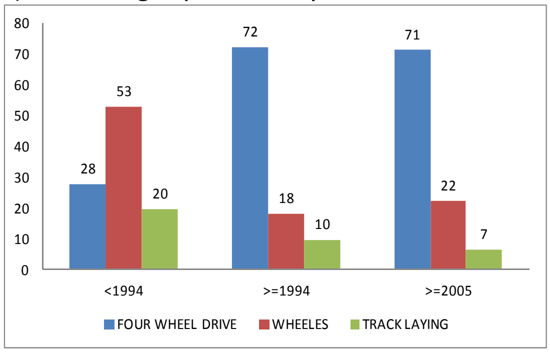
a)Tractors per altimetric area.



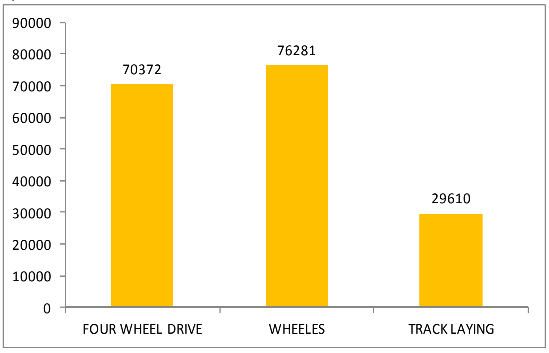
b) Percentages per drive system.



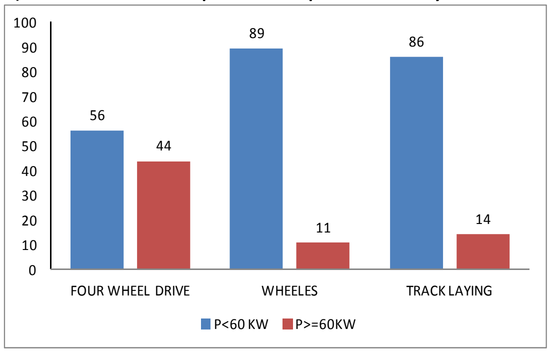
c) Obsolescence of tractors.



d) Obsolescence percent. per drive system.



e) Tractors per drive system.



f) Percentages per Power.

Figure 13. Statistics of drive system of tractors.

Table 10. Summary table of tractors per provincial altimetric area (source UMA).

		<1994									>=1994								
		FOUR WHEEL DRIVE			**WHEELS**			**TRACK LAYING**			**FOUR WHEEL DRIVE**			**WHEELS**			**TRACK LAYING**		
		P<60 KW	P>=60KW	TOT P	P<60 KW	P>=60KW	TOT P	P<60 KW	P>=60KW	TOT P	P<60 KW	P>=60KW	TOT P	P<60 KW	P>=60KW	TOT P	P<60 KW	P>=60KW	TOT P
Piacenza	Mountain	819	185	1007	92	13	108	999	8	1011	296	224	525	17	4	22	40	12	52
	Hill	1211	645	1867	1625	253	1884	2214	91	2314	733	1182	1949	92	28	123	340	112	459
	Plain	258	515	781	2705	504	3217	462	119	582	388	1207	1624	135	28	166	43	97	142
Parma	Mountain	1112	191	1312	230	19	255	963	17	987	324	320	664	43	44	99	29	23	54
	Hill	1242	481	1726	1685	194	1900	1538	82	1623	460	811	1290	156	151	336	83	58	144
	Plain	405	623	1033	5147	616	5825	208	60	272	438	1084	1545	353	198	586	26	26	55
Reggio Em	Mountain	836	240	1076	176	17	196	307	7	314	178	454	637	20	14	34	5	4	9
	Hill	826	319	1145	865	54	919	381	20	401	246	461	710	36	18	54	11	8	19
	Plain	1147	1005	2154	7071	511	7584	147	87	235	1070	1783	2874	300	94	397	10	23	34
Modena	Mountain	1285	276	1584	320	28	365	630	23	667	280	420	768	111	161	354	36	19	64
	Hill	939	182	1133	859	53	939	600	48	662	221	270	559	157	161	411	34	32	80
	Plain	1364	877	2254	7756	581	8442	371	158	533	975	1260	2435	951	615	1773	26	47	82
Bologna	Mountain	501	111	614	25	3	29	400	30	431	155	237	403	17	40	64	49	43	93
	Hill	1162	310	1473	1072	34	1113	1233	128	1365	468	667	1165	125	126	297	162	161	332
	Plain	1905	727	2636	7752	280	8056	1180	255	1439	1221	1794	3077	520	513	1129	66	136	208
Ferrara	Mountain																		
	Hill																		
	Plain	2589	1455	4067	10613	773	11452	668	314	985	1717	2575	4684	559	342	1070	31	79	132
Ravenna	Mountain																		
	Hill	434	54	492	106	2	110	721	28	749	156	211	385	51	38	98	98	62	164
	Plain	2598	536	3142	8374	325	8733	2400	117	2521	1327	2110	3578	456	477	1022	121	98	227
Forlì Cese	Mountain	152	57	209	26	5	31	287	13	301	99	176	284	6	2	9	34	71	106
	Hill	683	168	869	197	7	205	1571	94	1666	346	583	979	30	20	58	261	343	620
	Plain	1754	268	2028	2800	88	2895	3028	127	3160	975	1026	2082	130	52	194	368	363	749
Rimini	Mountain	48	11	59	10	2	12	61	3	64	37	53	90	27	10	37	58	12	71
	Hill	430	148	580	114	8	122	892	63	958	381	344	854	98	41	147	288	145	460
	Plain	619	72	692	252	2	254	739	39	780	371	192	716	45	14	68	86	80	190

Table 11. Summary table of tractors per provincial altimetric area (source UMA).

		>=2005									TOTAL								
		FOUR WHEEL DRIVE			WHEELS			TRACK LAYING			FOUR WHEEL DRIVE			WHEELS			TRACK LAYING		
		P<60 KW	P>=60KW	TOT P	P<60 KW	P>=60KW	TOT P	P<60 KW	P>=60KW	TOT P	P<60 KW	P>=60KW	TOT P	P<60 KW	P>=60KW	TOT P	P<60 KW	P>=60KW	TOT P
Piacenza	Mountain	53	84	140	6	0	7	8	4	12	1181	441	1632	113	18	134	1111	24	1138
	Hill	176	532	725	14	11	25	53	47	106	2086	1953	4088	1858	297	2163	2788	216	3015
	Plain	75	495	590	13	12	26	8	41	50	712	1865	2617	3150	584	3743	537	233	773
Parma	Mountain	32	93	131	6	20	30	7	4	11	1489	527	2045	300	79	399	1026	40	1073
	Hill	52	253	317	37	53	99	17	15	35	1790	1352	3164	1955	400	2405	1694	144	1843
	Plain	62	318	388	45	50	106	3	7	13	881	1799	2708	5744	901	6729	245	92	340
Reggio Em	Mountain	17	126	144	1	3	4	0	0	0	1015	696	1716	196	31	230	313	11	324
	Hill	32	160	192	2	4	6	0	2	2	1076	785	1864	906	72	978	393	28	421
	Plain	207	728	945	16	24	40	2	10	12	2233	2819	5077	7408	612	8026	157	112	271
Modena	Mountain	37	119	179	28	69	118	7	3	15	1620	727	2448	456	193	770	692	45	761
	Hill	32	51	112	49	83	171	11	10	27	1194	468	1752	1046	220	1402	664	83	778
	Plain	132	452	658	240	316	632	9	17	30	2400	2213	4851	8958	1239	10560	406	213	634
Bologna	Mountain	31	93	132	5	17	27	13	12	26	701	376	1099	49	49	118	481	83	570
	Hill	127	294	440	60	68	148	40	48	91	1749	1048	2835	1255	170	1487	1486	315	1817
	Plain	264	784	1082	203	324	587	13	35	53	3276	2635	5990	8643	859	9690	1279	413	1704
Ferrara	Mountain																		
	Hill																		
	Plain	530	1009	1811	125	172	415	16	18	46	4452	4183	9087	11569	1152	13048	720	415	1165
Ravenna	Mountain																		
	Hill	18	54	82	29	28	65	9	24	35	626	283	932	165	47	224	871	93	969
	Plain	174	689	947	217	382	673	14	26	45	4093	2749	6996	9149	832	10130	2616	230	2861
Forlì Cese	Mountain	14	71	92	4	1	5	4	19	24	254	234	497	32	7	40	326	86	413
	Hill	58	173	282	10	6	21	17	88	113	1033	696	1853	230	24	266	1834	441	2292
	Plain	287	395	741	40	20	64	32	96	140	2734	1297	4118	2932	142	3095	3397	490	3911
Rimini	Montagna	2	9	11	3	2	5	0	2	3	86	64	150	37	12	49	119	15	135
	Collina	65	109	242	9	14	27	13	35	59	812	496	1439	214	49	271	1184	210	1425
	Pianura	67	77	242	15	8	29	2	13	33	992	266	1414	298	16	324	830	120	977

3.1.3. ENGAGEMENT IN AGRICULTURE

To evaluate the characteristics of engagement in the agricultural field data from the 2010 ISTAT agricultural census have been collected then used to calculate seven indicators.

Percentage of farm holders older than 65

These are fairly distributed over the altimetric zones with a slight increase in the hilly area, the lower concentration occurs in the eastern plains of Ferrara, Ravenna, Forlì. This indicator, as it could be expected, is not particularly related to altimetry.

Farm managers with diploma or degree and farms ratio

Data on the qualifications of the farm manager, rather than the holder were published and the ratio between the number of those with a high school diploma or degree and the number of farms has been calculated. The results showed a fairly homogeneous distribution between the different altimetric areas even if the concentration is a bit lower in the mountains. The most notable areas are the plain in Piacenza and the hills in Bologna and, at a distance, Ferrara and the hills in Ravenna. It is notable, however, that the concentration is higher in the provincial capitals.

Continuous manpower per farm

This decreases with increasing altimetry, with higher values in the plain of Parma and Piacenza and the hills in Ravenna.

Occasional manpower per farm

The census data obviously do not consider illegal work even if this kind of work could be very probable for occasional manpower. The highest values related to occasional manpower are in the eastern plain of Ferrara, Ravenna and Modena, while it is not present in highly developed areas of the plain of Parma and Piacenza, where a continuous manpower instead of the occasional one seems preferred.

Percentage of not Italian continuous manpower

The largest concentrations are in Rimini hills and plains, this information is even more significant when compared to the continuous manpower in general.

Percentage of not italian occasional manpower

It's probably the most questionable information due to the nature of this kind of work that tends to illegal recruitments. It is only possible to evaluate the official data that generally have higher values in the plain and in particular Piacenza, Bologna and Ravenna, while a high value is found in a mountainous area in the province of Reggio Emilia.

Employed workers and family members ratio

This is a kind of data closely related to the altimetry.

Table 12. Engagement Indicators.

Province	Altimetric area	% holders over 65	Farm managers with diploma or degree and farms ratio	Averaged Continuous Manpower per farm	Averaged Occasional Manpower per farm	% not Italian Continuous Manpower	% not Italian Occasional Manpower	Employed workers and family members ratio
Piacenza	Mountain	49	19	0.07	0.05	3	10	0.07
	Hill	50	30	0.17	0.73	34	37	0.50
	Plain	46	37	0.31	0.61	35	55	0.53
Parma	Mountain	48	23	0.07	0.02	37	41	0.05
	Hill	51	27	0.20	0.11	39	39	0.18
	Plain	52	26	0.29	0.14	38	45	0.26
R. Emilia	Mountain	45	18	0.19	0.04	29	50	0.13
	Hill	52	21	0.19	0.27	19	19	0.26
	Plain	51	24	0.20	0.69	38	32	0.49
Modena	Mountain	47	17	0.11	0.09	24	31	0.10
	Hill	52	23	0.16	0.47	25	26	0.32
	Plain	50	29	0.21	1.11	30	43	0.72
Bologna	Mountain	52	21	0.10	0.08	27	26	0.10
	Hill	54	34	0.23	0.49	26	47	0.38
	Plain	52	23	0.21	0.64	25	50	0.46
Ferrara	Mountain							
	Hill							
	Plain	41	28	0.18	1.50	12	43	0.99
Ravenna	Mountain							
	Hill	46	27	0.37	1.07	37	47	0.70
	Plain	42	22	0.24	1.43	40	51	0.84
ForlìCesena	Mountain	49	22	0.26	0.44	25	42	0.43
	Hill	47	23	0.22	0.55	18	44	0.44
	Plain	41	17	0.19	0.79	35	43	0.51
Rimini	Mountain	43	12	0.05	0.03	9	0	0.05
	Hill	50	20	0.18	0.16	48	20	0.17
	Plain	47	18	0.24	0.23	55	48	0.25

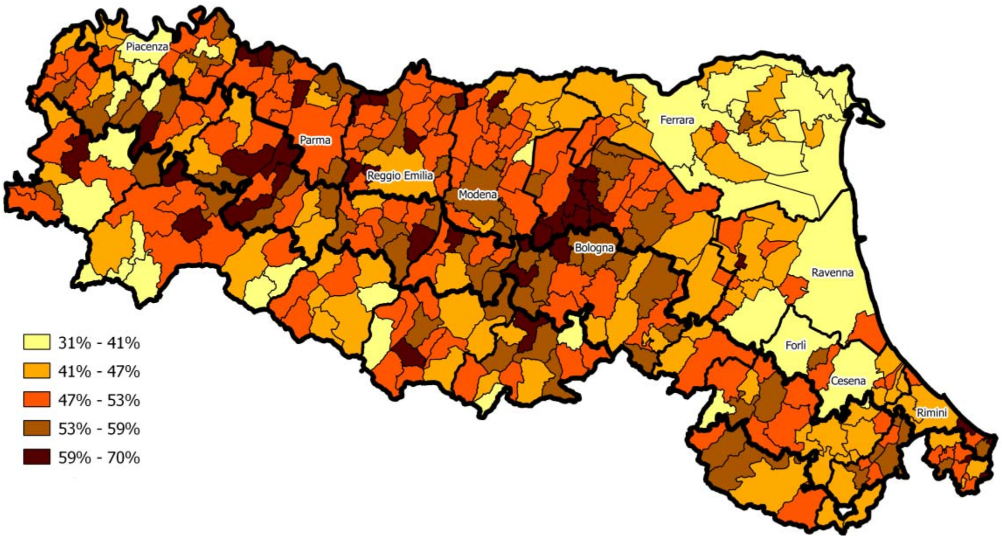


Figure 14. Percentage of holders over 65.

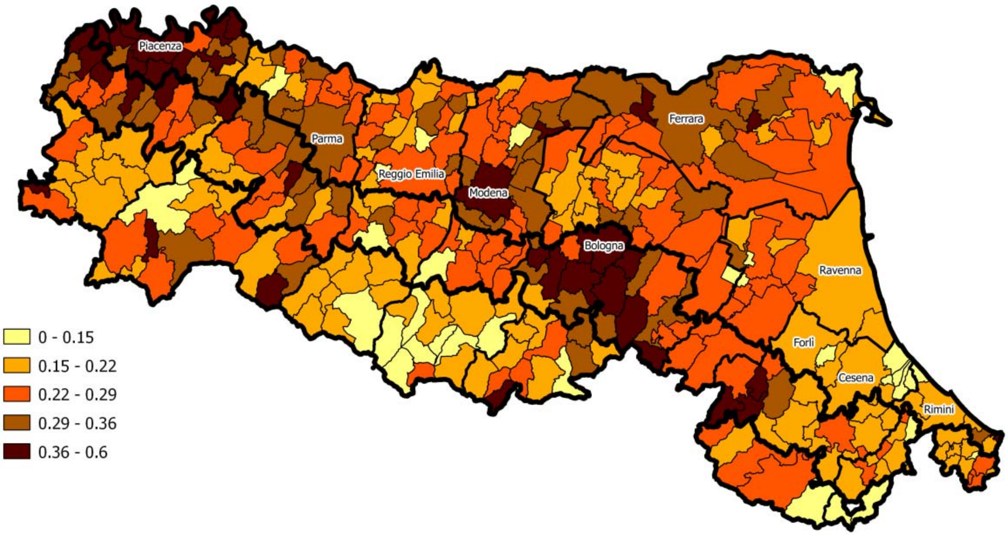


Figure 15. Farm managers with diploma or degree and farms ratio.

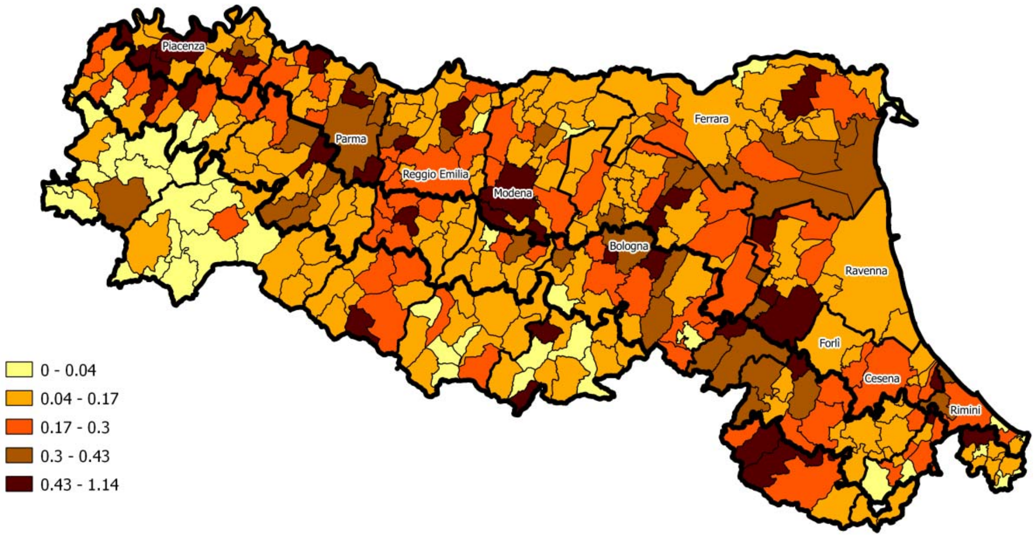


Figure 16. Continuous Manpower per farm.

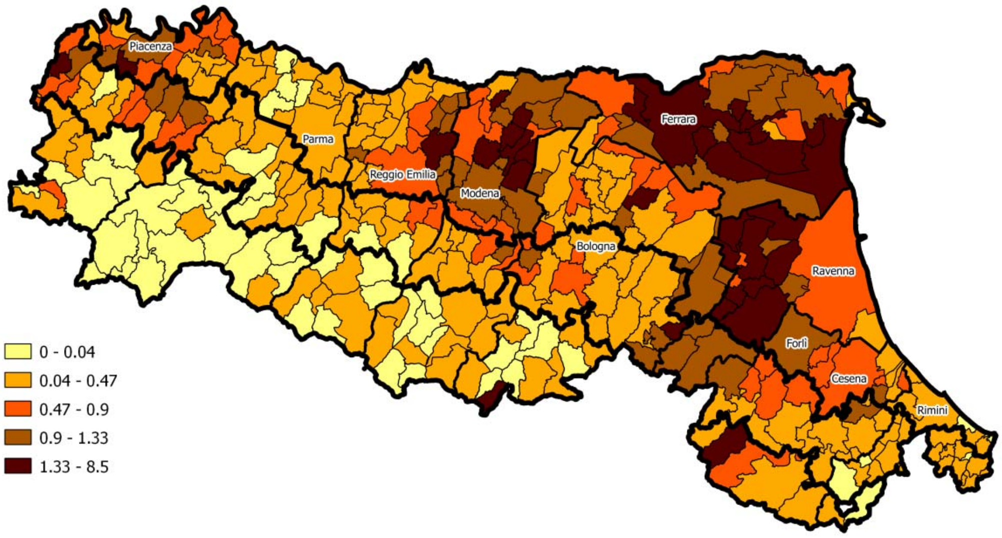


Figure 17.Occasional Manpower per farm.

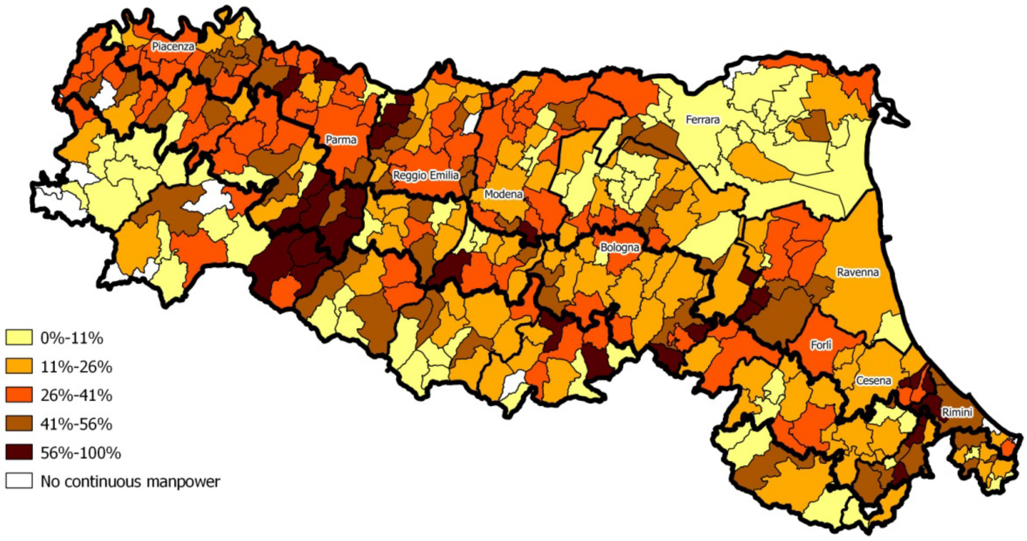


Figure 18. Percentage of not italian continuous Manpower.

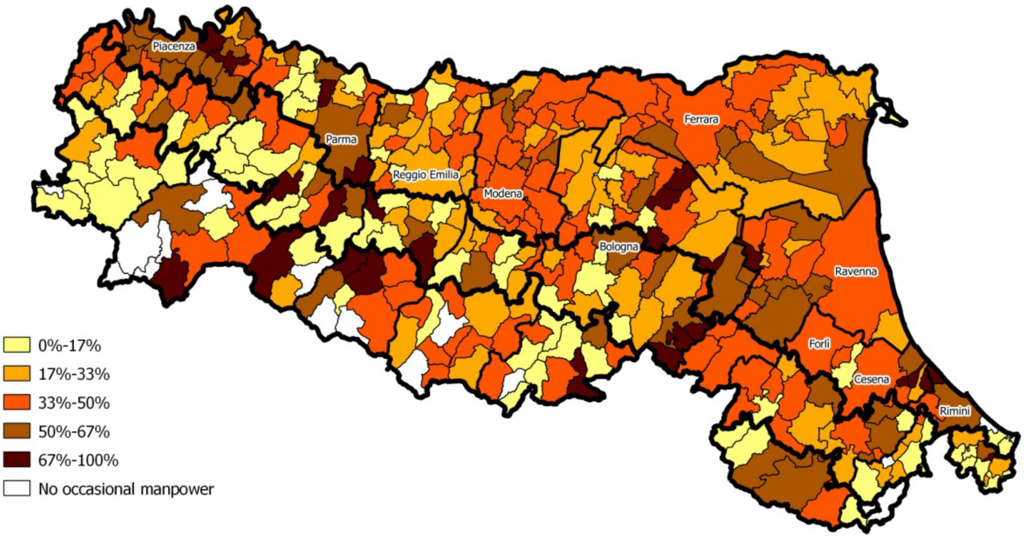


Figure 19. Percentage of not italian occasional Manpower.

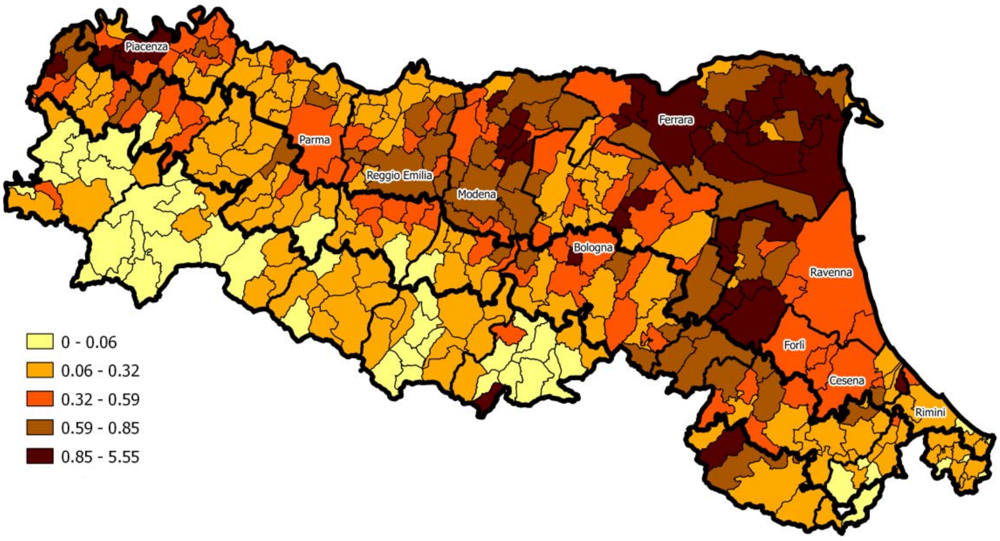


Figure 20. Employed workers and family members ratio.

3.2. WORKPLACE ACCIDENTS SITUATION

To assess the incidence of accidents in the region, data by INAIL operational archives have been used. Despite the limitations of these sources, already pointed out, in particular related to a certain inadequacy in giving an accurate picture of the tractor accidents, however, these archives enable the evaluation of a larger number of data than the other databases.

The focus therefore was on accidents in agriculture in general and accidents related to tractors, in particular in the 348 municipalities of the region, that were evaluated primarily according to two criteria, defined according to the international conventions, reflected in the technical standard UNI 7249 of 2007 which deals with accidents at work: frequency and severity. The significant indicators useful to evaluate the frequency of accidents resulting from the ratio between the number of accidents and a measure of exposure to the risk are defined according the first two formula:

1) $I_f = \frac{N}{O_L}$

Where N=number of accidents and O_L=worked hours.

2) $$I_f = \frac{N}{A} \cdot 10^3$$

Where A=number of employed.

This second index is also called Index of incidence.

The field considered is of course the agricultural one, the territorial unit is the municipal one and the considered time interval from 2008 to 2010. The indicators are then adapted for a three years period by adjusting the exposure to risk so that it was possible a comparison with the number of accidents occurred in that time period.

The number of employees was obtained from the 2010 ISTAT agricultural census as well as the number of days worked, which was calculated by multiplying per 8 the number of days worked. The data required for the calculation of the indices then come from different sources, and are therefore to be considered as indicative.

Accidents indicators enable to make a spatial, temporal and sectorial comparison. To evaluate the specific case of accidents related to tractors, it must be considered the relationship between the number of these accidents and the same measure of risk exposure used for accidents in agriculture in general, since it is not possible to quantify the workers using tractors.

To compare the severity of injuries resulting from different events it is used a severity index obtained by the ratio of disabling consequences, and a measure of exposure to the risk. The global severity index is derived from the contribution of three different indexes dividing the injuries on the basis of the consequences: temporary, permanent and mortal.

For temporary injuries, the lost working days until clinical recovery are considered. In the case of permanent injury it is considered the sum of the degrees of disability that have determined a compensation of not less than minimum degree of indemnification.

Also a conversion factor for these accidents is used: 75 days lost for each conventional degree of disability, because it was determined that a fatal accident has a severity corresponding to 7500 days lost in a conventional working life. Indeed a whole working life corresponds to 30 years with 250 days per year. So a permanent injury, 100 degrees of disability, corresponds to 7500 days lost as in the case of a fatal accident.

The formula to calculate these indices are:

3) $$Ig_T = \frac{T}{O_L} \cdot 10^3$$

With T=number of lost days.

4) $$Ig_P = \frac{75 \cdot P}{O_L} \cdot 10^3$$

With P=sum of degrees of inability related to the considered injuries.

5) $$Ig_M = \frac{7500 \cdot M}{O_L} \cdot 10^3$$

With M=number of fatalities.

6) $$Ig_G = \frac{T + 75 \cdot P + 7500 \cdot M}{O_L} \cdot 10^3$$

The total severity index is thus the sum of the three partial indices of severity and is also expressed in conventional lost days per thousand hours worked.

In the data provided there were not the degrees of disability, but the lost days already tabulated. It's possible assuming that they were already calculated as set out in the standard.

In table 13 are indicated the values of indices for provincial altimetric areas of the Emilia Romagna region calculated for accidents in agriculture and for accidents related to the use of the tractor. There is, however, the disadvantage, as already mentioned, of the impossibility of evaluating the number of employees driving the tractors. It was therefore tried to obtain indices that could provide a more reliable picture. It was then added the ratio between the number of accidents and the number of tractors and moreover another index calculated according to the formula 7) which takes into account the intensity of work.

7) $$I_W = \frac{N}{Tr} \cdot \frac{G_L}{A}$$

With Tr=number of tractors and G_L=worked days.

Comparing the table with maps in figure 21, 22, 23, 24 and 25 it is evident as the lowest values are found in areas of high altitude and this is in contrast to what would expectable, and the results obtained in other similar evaluations (Brugnoli, 2000) carried out with data relating to the nineties.

This is probably due to the current data collection system that is focused almost exclusively on professional workers, rather than on the actual distribution of accidents.

By comparing between the table and the maps it is also evident a remarkable consistency of the values with regard to the frequency, severity, and the other two indexes added.

Also a map is inserted, Figure 26, with the cases of rollover, selected with the method described in paragraph 2.1. Despite these are only indicative data, due to the small number of cases considered, there is a concentration of accidents in the provincial capitals.

Table 13. Accidents indicators per provincial altimetric area.

		INCIDENCE		FREQUENCY		TEMPORARY SEVERITY		PERMANENT SEVERITY		MORTAL SEVERITY		TOTAL SEVERITY		ACCIDENTS/ TRACTORS		WORK INTENSITY	
		AGRIC	TRACT	AGRIC	TRACT	AGRIC	TRACT	AGRIC	TRACT	AGRIC	TRACT	AGRIC	TRACT	AGRIC	TRACT	AGRIC	TRACT
Piacenza	Mountain	22.7	2.2	29.3	2.8	0.88	0.12	0.46	0.12	0.00	0.000	1.33	0.24	0.057	0.0055	5.5	0.53
	Hill	21.1	2.1	26.5	2.6	0.73	0.08	0.36	0.01	0.68	0.340	1.77	0.43	0.063	0.0061	6.3	0.61
	Plain	59.2	5.8	57.7	5.6	1.53	0.20	0.78	0.12	0.59	0.000	2.90	0.32	0.102	0.0099	13.1	1.28
Parma	Mountain	32.3	1.3	34.9	1.4	0.94	0.05	0.66	0.05	0.00	0.000	1.60	0.09	0.085	0.0034	9.9	0.39
	Hill	37.4	3.2	34.4	3.0	0.82	0.08	0.51	0.02	0.00	0.000	1.33	0.10	0.082	0.0071	11.1	0.96
	Plain	42.9	3.9	36.9	3.3	0.98	0.11	0.49	0.06	0.38	0.000	1.84	0.17	0.074	0.0067	10.8	0.97
Reggio Emilia	Mountain	71.3	2.2	55.1	1.7	1.39	0.05	1.08	0.08	0.98	0.000	3.46	0.13	0.185	0.0057	29.9	0.93
	Hill	26.7	1.0	32.1	1.2	0.80	0.05	0.83	0.06	0.00	0.000	1.62	0.10	0.097	0.0037	10.1	0.38
	Plain	37.0	1.7	44.8	2.1	0.97	0.06	0.71	0.05	0.22	0.000	1.91	0.11	0.113	0.0053	11.6	0.55
Modena	Mountain	43.2	1.9	46.2	2.0	1.39	0.08	0.57	0.04	0.61	0.000	2.56	0.12	0.141	0.0062	16.5	0.72
	Hill	28.3	1.0	33.1	1.2	1.02	0.05	0.42	0.03	0.00	0.000	1.45	0.08	0.113	0.0040	12.0	0.43
	Plain	23.9	1.0	35.2	1.5	0.81	0.04	0.36	0.03	1.27	0.182	2.44	0.25	0.090	0.0038	7.6	0.32
Bologna	Mountain	18.4	0.8	27.1	1.1	0.59	0.02	0.45	0.00	0.00	0.000	1.04	0.02	0.081	0.0033	6.9	0.28
	Hill	31.6	1.1	38.8	1.4	0.88	0.04	0.74	0.02	1.47	0.368	3.09	0.42	0.128	0.0045	13.0	0.46
	Plain	23.9	1.4	30.7	1.8	0.69	0.05	0.45	0.03	0.76	0.000	1.89	0.08	0.069	0.0042	6.7	0.41
Ferrara	Mountain																
	Hill																
	Plain	23.3	1.9	38.6	3.2	1.00	0.11	0.57	0.08	0.95	0.158	2.51	0.34	0.078	0.0065	5.9	0.49
Ravenna	Mountain																
	Hill	30.1	2.1	47.8	3.3	1.15	0.08	0.46	0.10	0.00	0.000	1.61	0.19	0.156	0.0107	12.3	0.84
	Plain	31.6	1.8	49.1	2.8	0.96	0.07	0.49	0.06	1.06	0.000	2.51	0.13	0.138	0.0079	11.1	0.64
Forlì Cesena	Mountain	52.3	0.0	69.6	0.0	1.33	0.00	0.85	0.00	0.00	0.000	2.17	0.00	0.220	0.0000	20.7	0.00
	Hill	32.6	0.5	43.0	0.6	1.02	0.01	0.41	0.01	0.93	0.000	2.36	0.02	0.157	0.0023	14.9	0.21
	Plain	33.5	0.5	45.2	0.6	0.92	0.01	0.47	0.00	0.19	0.187	1.58	0.20	0.163	0.0022	15.1	0.21
Rimini	Mountain	28.1	1.9	34.3	2.3	0.68	0.08	0.67	0.00	0.00	0.000	1.35	0.08	0.090	0.0060	9.2	0.61
	Hill	19.3	0.8	29.8	1.3	0.89	0.05	0.36	0.00	0.00	0.000	1.25	0.05	0.095	0.0041	7.7	0.33
	Plain	29.0	1.6	38.8	2.1	1.00	0.08	0.52	0.02	0.00	0.000	1.52	0.11	0.153	0.0084	14.3	0.79

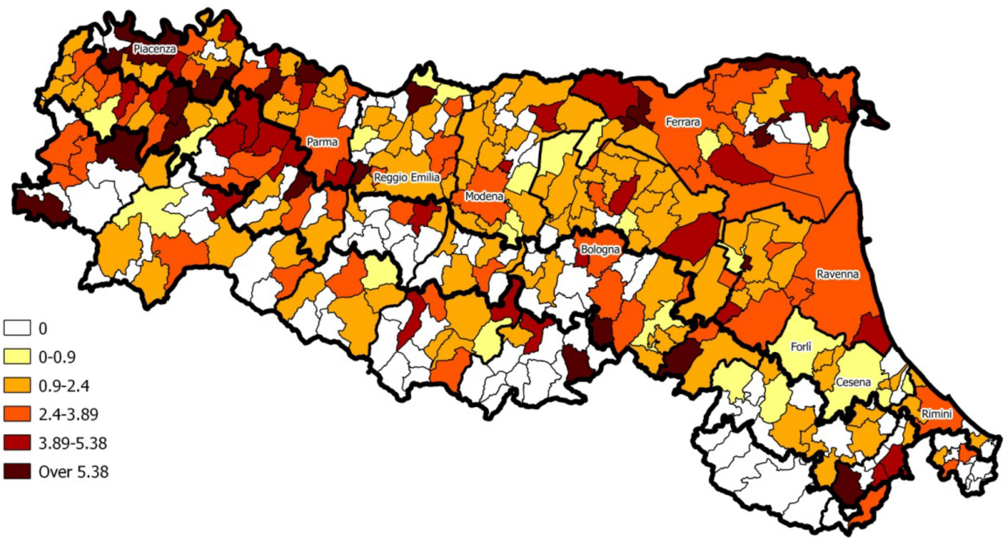


Figure 21. Frequency index.

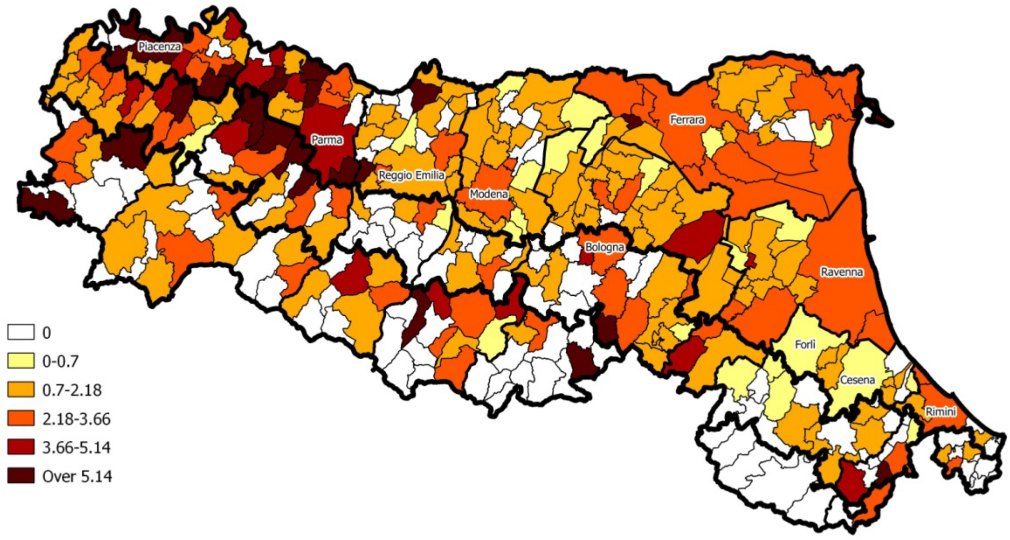


Figure 22. Incidence index.

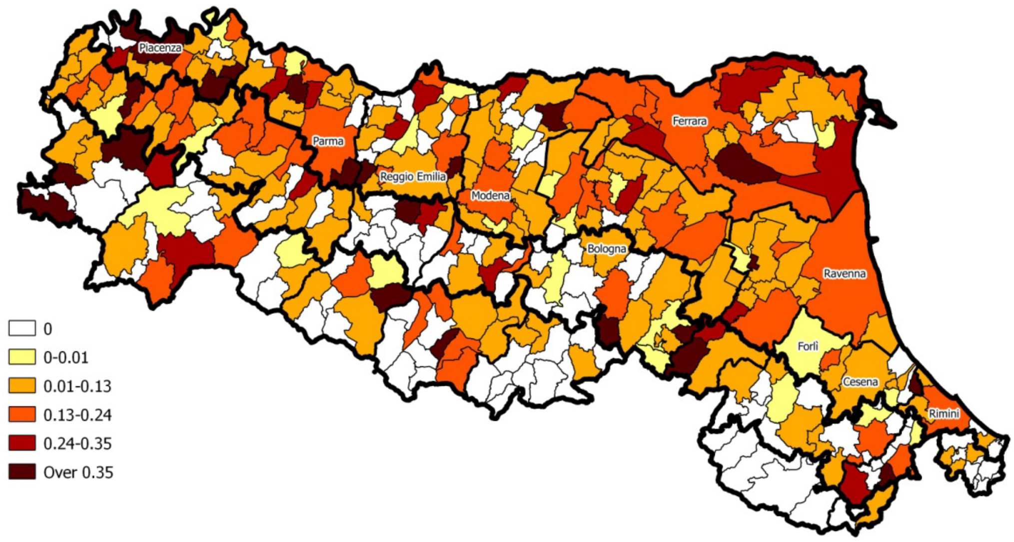


Figure 23. Severity index.

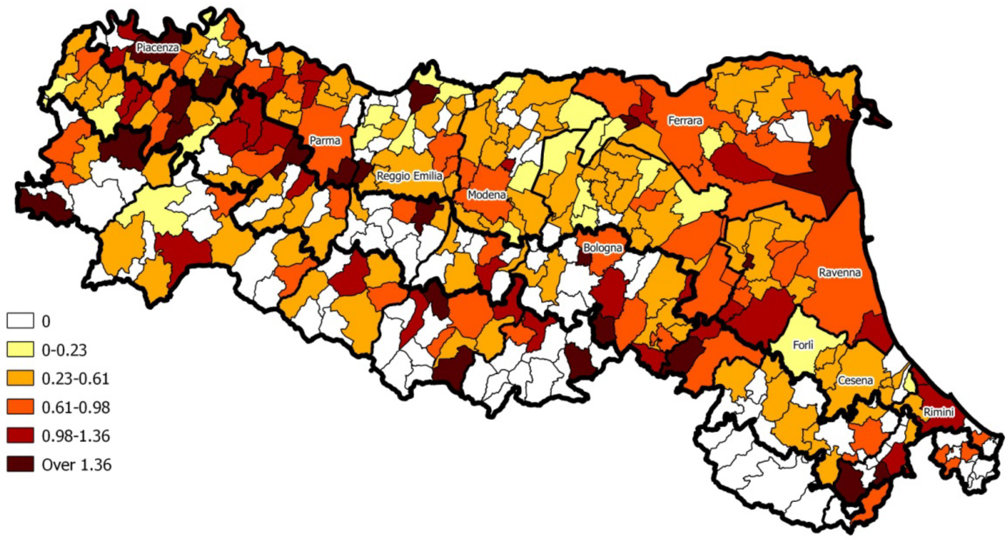


Figure 24.Accidents-tractors ratio.

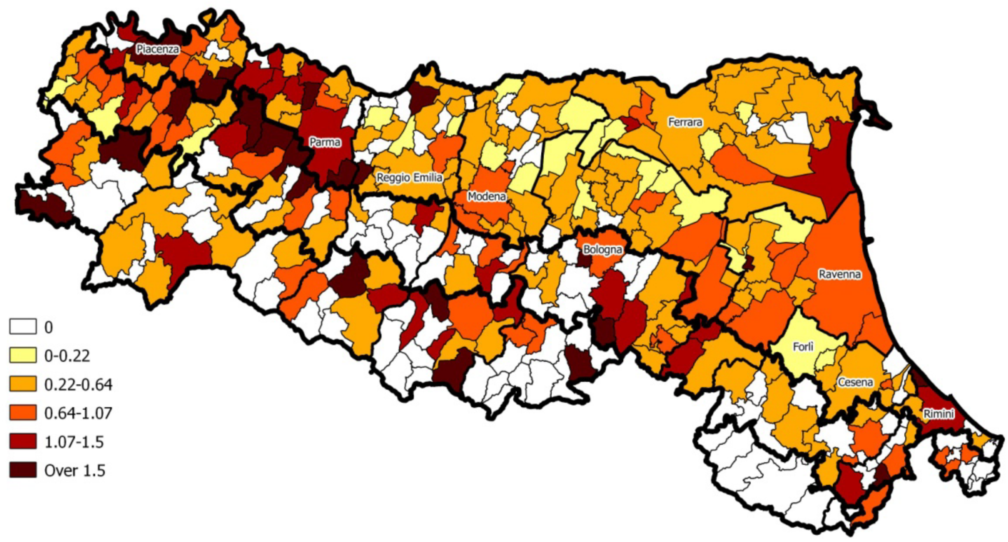


Figure 25. Work intensity index.

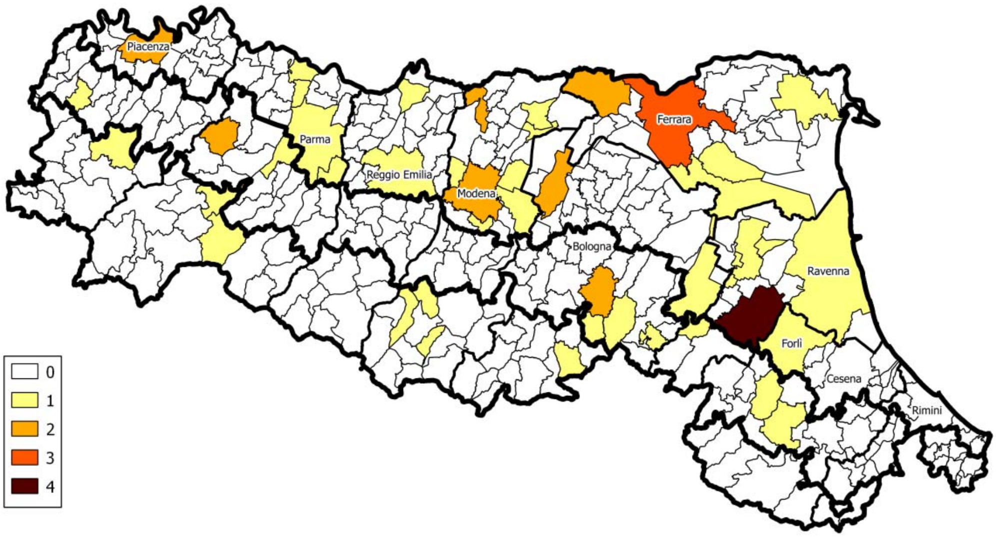


Figure 26. Rollovers.

3.3. TERRITORIALS MAPS OF HOMOGENEITY

In order to obtain a better knowledge of the data related to the territory it seemed appropriate to create a map that consider the agricultural homogeneities creating a territorial partition of the region. Territorial units, municipalities, have been grouped on the basis of the overall level of similarity of variables suitable in describing the problem in this study: the agricultural activity related to the use of tractors.

Indicators were then selected evaluating the most relevant aspects: the level of mechanization, the farm activities and engagement.

Indicators of agricultural mechanization:

- Number of tractors per hectar of UAA
- Number of tractors with power over 60 kW on the total number of tractors.
- Number of registered tractors since 1994, compared to the total number of tractor
- Number of tractors per farm

Environmental indicators:

- Ratio between mountain area and municipal area
- Ratio between UAA and municipal area
- Ratio between forestry area and UAA
- Ratio between arable land and UAA
- Average UAA per farm
- Ratio between number of livestock farms and the total number of farms

Engagement indicators:

- Number of workers per hectar of UAA
- Number of workers per farm
- Number of averaged working days per holder
- Ratio between Continuous Manpower and workers
- Ratio between Occasional Manpower and workers
- Ratio between Italian manpowers and workers
- Ratio between not italian Manpower and workers
- Ratio between holders over 60 and holders.

Since it is important to visualize a multi-dimensional problem, multivariate statistical techniques are suitable to get the appropriate grouping. It is therefore necessary to simultaneously evaluate indices with different values, even by orders of magnitude, thus it was carried out a preliminary standardization by dividing the values of each indicator per the relative standard deviation.

The variables obtained are definitely suitable to describe the problem, but there is no guarantee that they are orthogonal to each other, so it is possible that more variables consider the same leading principle that governs the behavior of the system, resulting in a redundancy of information that can lead to errors of judgment. The problem can be simplified by using the established technique of principal components analysis in which the set of variables is transformed into a new set of mutually orthogonal variables.

Each principal component is the linear combination of the original variables to obtain an orthogonal basis for the space of the considered data.

The first principal component in fact consists of an axis in space. The projections of each observation on that axis represent a new variable whose variance is the maximum one among all the possible choices of that axis. The second axis is perpendicular to the previous and projecting the observations on it a new variable is obtained whose variance is the maximum possible depending on the choice of the axis and so on. In table 14 it is possible to see the different weight of the indicators chosen in the calculation of the principal components, the first of which is more closely linked to environmental indicators, the second at the level of agricultural mechanization and the third to the engagement situation.

The whole set of new variables is equal in number to the original set, but commonly only the variables of the new set are used. The sum of which reaches 80% of the total variance of the original data. In this case the first 6 variables of the new set have been considered, as visible in the Pareto chart of Figure 27.

The result of this first procedure was then a matrix of 348 rows, one for each municipality, and 6 columns. But to obtain a more precise result were excluded the municipalities for which the distances of at least one of the 6 variables from the relative average were in excess of three times the standard deviation. 14 municipalities were thus considered outliers and omitted from the grouping procedure.

The data were then divided into mutually exclusive clusters by the k-mean clustering, a partitioning method in which, unlike the hierarchical methods, is not created a tree structure, but only one level of clusters. This method is generally considered more suitable to group a large number of data, as in the case of our interest. Each cluster in the partition is defined by the objects that compose it and its centroid, the point at which the sum of distances between all objects in the cluster is minimized.

The grouping into 8 clusters is shown in Figure 28. It is notable how the clusters are related to the altimetry of the territory. Carefully observing the maps of previous paragraphs some groupings are familiar. It is also visible a sort of division between east and west of the region.

In particular, the cluster 1 covers 19 municipalities mainly in the hilly area characterized by a certain obsolescence of the tractors, the cluster 2, 51 municipalities, including mainly plain areas of Piacenza and Parma, the most active and mechanized in the region; cluster 3, 46 municipalities in mountain areas of Piacenza, Parma and Bologna often family-runned and poorly mechanized; cluster 4, 49 municipalities, mainly including the remaining municipalities in the mountains of the region.

The cluster 5, 29 municipalities, is located mainly in the eastern part of the Rimini area, characterized by intensive arable land; cluster 6, 55 municipalities, is composed of municipalities located mostly in the central plains and hills of the region; cluster 7, 25 municipalities, in the flat area of Ferrara and the romagna area as well as 8, 60 municipalities, in which are collected most of the municipalities of the eastern plain.

In Table 15 are presented accidents indicators for each cluster and, as expected, these are consistent with the data presented in Table 13. The flat area of Piacenza in fact still looks like the one with highest frequency of accidents related to the use of tractors.

Table 14. Coefficients for the transition from the old to the new system of reference.

	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7	PC 8	PC 9	PC 10	PC 11	PC 12	PC 13	PC 14	PC 15	PC 16	PC 17	PC 18
Tractors/UAA	0.021	0.355	-0.205	-0.406	-0.158	0.152	-0.046	0.512	0.019	-0.139	0.067	-0.107	0.007	-0.072	0.294	0.031	0.476	0.000
Tractors with P>= 60kW/ Tractors	-0.086	-0.414	0.023	0.078	-0.244	0.121	-0.209	0.024	-0.417	-0.517	-0.091	-0.367	-0.255	0.158	0.001	0.148	0.037	0.000
Tractors>= 1994/ Tractors	0.080	-0.044	0.256	0.274	-0.641	0.367	-0.232	0.092	0.363	0.245	0.120	-0.001	-0.028	-0.140	-0.076	0.099	-0.018	0.000
Tractors/ Farms	-0.261	-0.232	-0.121	-0.344	0.180	0.079	-0.156	0.480	0.100	0.178	0.010	0.074	-0.084	0.034	-0.276	0.354	-0.441	0.000
Mountain municipal area / Municipal area	0.334	-0.102	0.287	0.015	0.075	0.024	-0.107	0.070	-0.188	0.057	0.076	0.477	0.039	0.380	0.476	0.359	-0.011	0.000
UAA/ Municipal area (ha)	-0.357	-0.056	-0.171	0.013	0.030	0.108	0.032	-0.308	0.167	0.278	-0.198	-0.386	0.321	0.183	0.359	0.404	0.095	0.000
Forestry area/ UAA	0.296	-0.069	0.312	-0.037	0.193	-0.189	-0.019	0.121	-0.044	0.055	0.551	-0.542	0.314	-0.094	-0.042	0.090	-0.046	0.000
Arable land/ UAA	-0.243	-0.161	-0.375	0.191	-0.157	0.122	0.078	0.048	-0.144	-0.250	0.425	0.314	0.552	-0.078	0.043	-0.070	-0.101	0.000
UAA/ Farms	-0.213	-0.405	0.070	0.027	0.089	-0.016	-0.094	0.240	0.149	0.235	0.075	-0.077	-0.078	0.286	0.320	-0.655	0.055	0.000
Livestock farms/ farms	0.256	-0.285	0.154	-0.276	-0.021	0.041	-0.165	0.028	0.036	-0.124	-0.541	0.033	0.493	-0.361	0.082	-0.158	-0.090	0.000
Workers/ UAA	-0.021	0.467	0.111	-0.168	-0.273	0.062	0.058	-0.006	-0.073	-0.137	-0.066	-0.174	0.134	0.373	0.124	-0.222	-0.616	0.000
Workers/ Farms	-0.291	0.168	0.362	0.017	0.041	-0.005	-0.222	0.078	-0.144	0.024	-0.120	0.103	0.360	0.379	-0.486	-0.038	0.376	0.000
Holder workingdays/ Conductors	-0.113	-0.156	0.168	-0.626	-0.075	0.098	-0.045	-0.497	0.282	-0.214	0.331	0.144	-0.093	0.063	-0.045	-0.030	0.088	0.000
Continuous manpower/ Workers	-0.116	-0.177	0.081	-0.195	-0.514	-0.575	0.372	0.077	-0.180	0.224	-0.041	0.057	0.015	-0.020	-0.012	0.083	0.060	-0.269
Occasional manpower/ Workers	-0.337	0.162	0.286	0.125	0.185	0.006	-0.169	0.021	0.031	-0.174	0.032	0.045	-0.066	-0.286	0.218	0.028	-0.081	-0.724
Italian manpower/ Workers	-0.296	0.054	0.269	0.177	0.000	-0.414	0.032	0.161	0.380	-0.386	-0.046	0.060	-0.013	-0.104	0.177	0.139	-0.040	0.496
Not Italian manpower/ Workers	-0.324	0.109	0.241	-0.125	-0.011	0.139	-0.096	-0.111	-0.540	0.317	0.089	0.045	-0.095	-0.406	0.169	-0.066	-0.056	0.396
Holders over 60/Holders	0.064	0.123	-0.331	-0.015	-0.120	-0.472	-0.768	-0.159	-0.015	0.100	0.070	0.020	-0.002	0.003	0.044	-0.029	-0.042	0.000

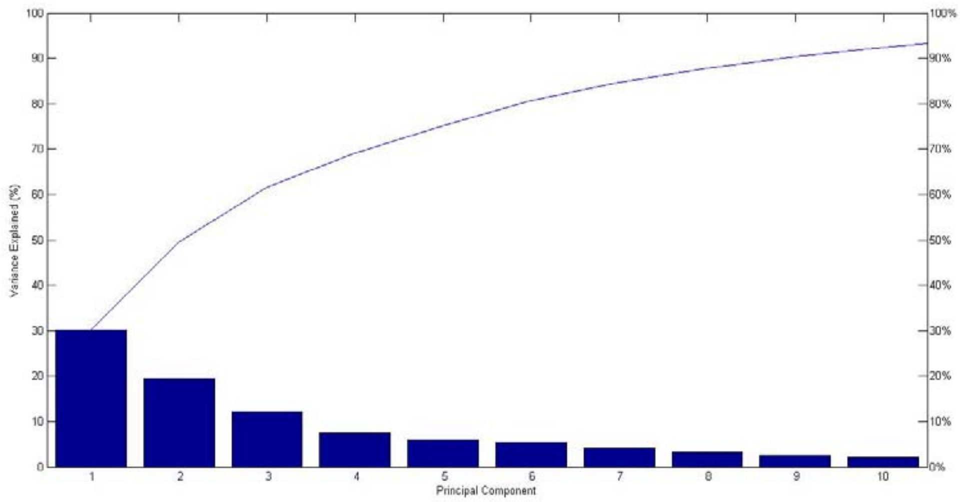


Figure 27. Pareto diagram relating to variances percentages. Only the first 10 indicators of the 18 are shown.

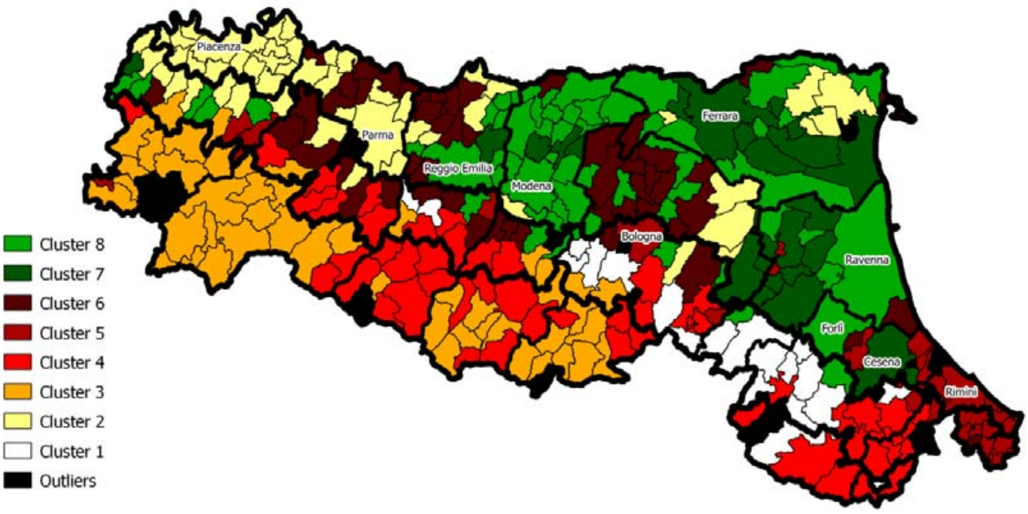


Figure 28. Clusters.

Table 15. Accidents index per cluster

	INCIDENCE		FREQUENCY		TEMPORAL SEVERITY		PERMANENT SEVERITY		MORTAL SEVERITY		TOTAL SEVERITY		ACCIDENTS/ TRACTORS		WORK INTENSITY	
	AGRIC	**TRACT**	**AGRIC**	**TRACT**	**AGRIC**	**TRACT**	**AGRIC**	**TRACT**	**AGRIC**	**TRACT**	**AGRIC**	**TRACT**	**AGRIC**	**TRACT**	**AGRIC**	**TRACT**
Cluster 1	27.45	1.00	38.43	1.41	0.96	0.04	0.39	0.01	0.68	0.00	2.03	0.05	0.14	0.01	12.83	0.47
Cluster 2	40.59	3.62	39.57	3.53	0.99	0.11	0.54	0.05	0.66	0.13	2.19	0.30	0.08	0.01	10.43	0.93
Cluster 3	24.81	1.29	30.49	1.58	0.84	0.06	0.55	0.05	0.00	0.00	1.39	0.11	0.08	0.00	7.85	0.41
Cluster 4	40.95	1.52	41.66	1.55	1.13	0.05	0.60	0.03	0.73	0.18	2.45	0.26	0.12	0.00	15.22	0.57
Cluster 5	29.30	1.06	42.18	1.53	0.98	0.05	0.55	0.02	0.24	0.00	1.77	0.07	0.14	0.01	12.18	0.44
Cluster 6	29.06	1.94	36.21	2.42	0.85	0.06	0.50	0.06	0.15	0.00	1.50	0.12	0.07	0.00	7.29	0.49
Cluster 7	29.60	1.52	44.18	2.27	0.94	0.06	0.46	0.05	0.67	0.07	2.07	0.19	0.13	0.01	11.05	0.57
Cluster 8	26.65	1.34	38.93	1.95	0.89	0.06	0.57	0.04	1.00	0.06	2.46	0.16	0.10	0.00	8.39	0.42

3.4. PREDICTION MODEL

It seemed interesting to investigate which of the data collected are the most significant for the accidents situation assessment. For this purpose the municipal data were considered, because related to the territorial extent, rather than the indicators used previously, in order to introduce the smallest number of steps to reduce possible deviations. It was then used a particular methodology for the selection of variables to be included in a multiple linear regression model, the Stepwise Regression. Adopting this method it is possible to calculate the values of the expected number of accidents on the basis of the parameters shown in the second column of Table 16.

This method is based on subsequent steps and at each step introduce the most significant variable, from the statistical point of view, namely the one with minor p-value. The process ends when all the terms have been entered.

The p-value is the probability of obtaining a correlation equal to that which would occur if the values were random distributed. If p is lower than a certain limit value the correlation is significant. In this case the limit value has been set equal to 0.05, the most commonly used.

In Stepwise regression function, available in the programming environment of Matlab, the dependent variable that identifies the number of accidents for each municipality, represented by a vector y, is calculated as a function of the independent variables whose values, for each municipality, form the columns of a X matrix. The result is a vector b of coefficients relating to the columns of X.

Some input variables in a multiple regression does not have a significant effect in the explanation of the answer. Only the significant terms of the model have been maintained, they are shown in Table 16 and it is interesting to note what they are.

In the table the coefficients related to the selected variables related to the prediction of accidents are shown in four separate cases: accidents caused by tractors in the municipalities of the province of Bologna, accidents caused by tractors in the municipalities of the region, accidents in agriculture in the municipalities of the province of Bologna and finally common accidents in agriculture in the region.

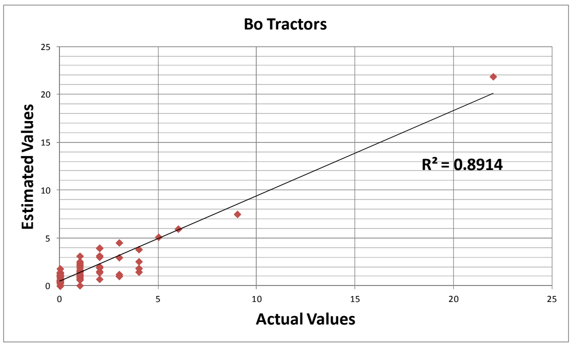
To assess the suitability of the formula obtained, the value of R^2, the square of the correlation coefficient, was used. It represents a ratio between the variability of the data and the correctness of the statistical model.

Figure 29 shows the values calculated on the basis of the data distribution. It was then obtained a prediction model related to municipalities in the region where the level of reliability is satisfactory, as shown in Figure 29 (e) and 29 (f). Nevertheless generalizing this result to other Italian areas can lead to a level of uncertainty that has to be evaluated. Thus in order to verify if this methodology is reliable in these cases, the models obtained for the municipalities in the province of Bologna were considered, because this is the province that includes the largest number of municipalities in Emilia Romagna. The results are shown in Figure 29 (a) and in figure 29 (b). These results are even better than the regional ones. Then applying the model obtained for the Bologna province to the entire region the results in Figure 29 (c) and 29 (d) were obtained. Good results are still observed with regard to the agriculture, but a reduction of the reliability level in accidents related to tractors is noticeable.

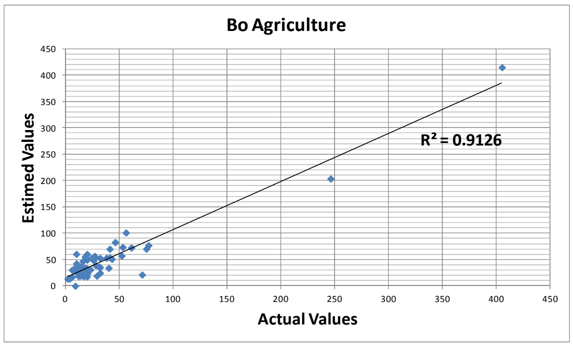
This is easily explained by considering the number of data used for these calculations, the largest number of these data in the more general case of accidents in agriculture allowed a greater level of accuracy.

Table 16. Independent variables and their coefficients calculated with the Stepwise method.

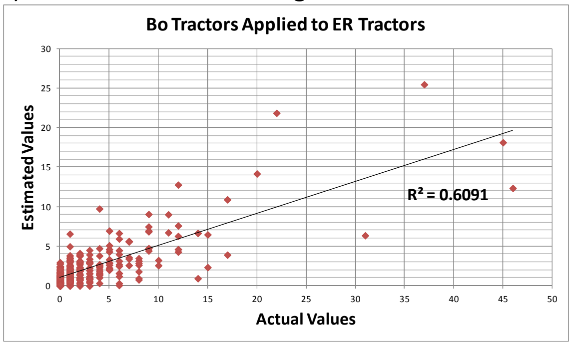
		Bo Tractors	**ER Tractors**	**Bo Agricult**	**ER Agricult**
A	Altimetric area	-0.0800	0.0355	-0.2979	0.6600
B	Farms number	-0.0039	-0.0005	-0.0646	**2.2798**
C	UAA	-0.0003	-0.0001	**-0.0217**	-0.0006
D	Working days (including not direcly employed)	0.0000	0.0000	**0.0006**	**0.0020**
E	Arable land (ha)	-0.0002	-0.0001	-0.0042	-0.0007
F	Permanent grassland (ha)	0.0001	-0.0008	-0.0032	0.0033
G	Forestry (ha)	0.0003	0.0001	0.0046	-0.0030
H	Livestock Farms	-0.0013	**0.0403**	-0.2751	**0.2082**
I	Working days (excluding not direcly employed)	0.0000	0.0000	-0.0058	0.0048
J	Working days of manpower not directly employed	0.0003	-0.0002	0.0058	-0.0048
K	Farm holders	-0.0045	-0.0002	-0.0887	**-1.9821**
L	Working days of the holders	0.0000	0.0000	0.0003	**-0.0018**
M	Number of family members and relatives working in the farm (excluding the holder)	-0.0022	-0.0002	-0.0288	-0.0301
N	Working days of family members and relatives working in the farm (excluding the holder)	0.0000	0.0000	0.0006	0.0000
O	Number of continuous manpower	0.0072	0.0052	-0.0477	0.0364
P	Working days of continuous manpower	0.0001	0.0000	0.0000	0.0003
Q	Number of italian continuous manpower	0.0093	0.0016	-0.0777	-0.0505
R	Working days of Italian continuous manpower	0.0001	0.0000	0.0001	-0.0001
S	Number of EU continuous manpower	0.0109	0.0119	-0.0235	0.4239
T	Working days of EU continuous manpower	0.0002	**0.0007**	0.0004	0.0043
U	Number of extraEU continuous manpower	0.0155	0.0155	0.0295	0.1835
V	Working days of extraEU continuous manpower	0.0001	0.0000	-0.0025	**-0.0026**
W	Number of occasional manpower	-0.0011	**0.0055**	-0.0393	0.0121
X	Working days of occasional manpower	0.0000	0.0000	-0.0005	**-0.0018**
Y	Number of italian occasional manpower	**-0.0115**	**-0.0126**	-0.1040	-0.0086
Z	Working days of Italian occasional manpower	**0.0220**	0.0004	0.0272	0.0471
AA	Number of extra EU occasional manpower	-0.0011	-0.0004	-0.1168	**0.1170**
AB	Tractors with Power <60 KW	-0.0020	-0.0094	0.0843	0.0152
AC	Tractors with Power >=60 KW	**0.0193**	**-0.0255**	0.0853	0.0070
AD	Tractors <1994	-0.0027	**-0.0353**	**-0.0979**	0.0104
AE	Tractors >=1994	-0.0027	**-0.0234**	**0.5508**	0.0271
AF	Total Tractors	-0.0023	**0.0443**	0.0898	0.0074
AG	Mountain Area 05 (Km2)	0.0028	**-0.0448**	**-0.8069**	-0.0378
AH	Municipal area (Km2)	0.0040	**0.0431**	**1.1406**	0.0294
AI	Farm Manager without diploma	-0.0085	-0.0038	-0.1027	**-0.2699**
AJ	Farm Manager with diploma or degree	-0.0015	0.0055	-0.1041	-0.0718
AK	holders < 60 years old	-0.0054	-0.0002	-0.2129	-0.0883
AL	Holders >= 60 years old	-0.0085	**-0.0372**	-0.1127	**-0.4053**
AM	Altimetric area	-0.0800	0.0355	-0.2979	0.6600



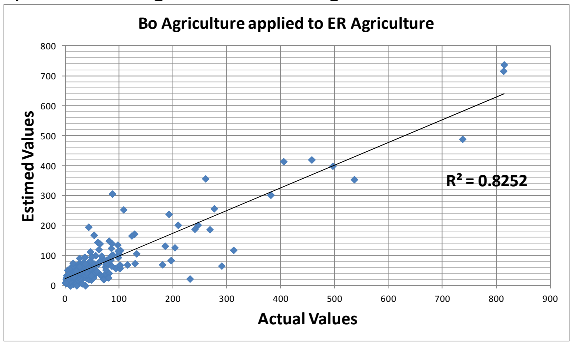
a) Tractors Bologna Model.



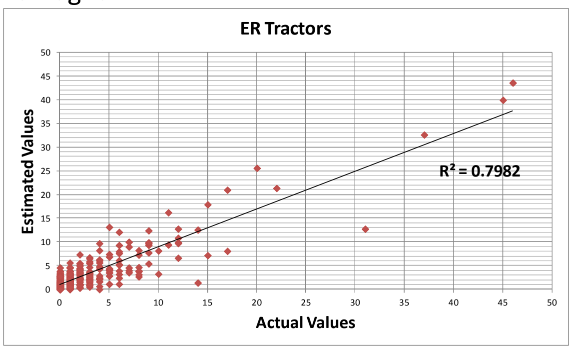
b) Agriculture Bologna Model.



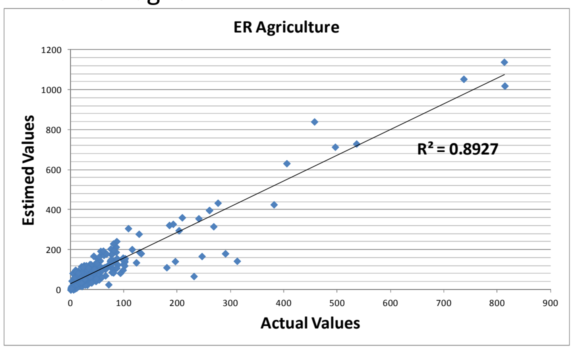
c) Tractors Bologna Model applied to Emilia Romagna.



d) Agriculture Bologna Model applied to Emilia Romagna.



e) Tractor Emilia Romagna Model.



f) Agriculture Emilia Romagna Model.

Figure 29. Comparison of actual and calculated number of accidents.

4. ROLLOVER DETECTION IN OPERATING CONDITIONS

The analysis of tractor rollover in working conditions is very complex. Indeed, if theoretically, in laboratory tests, it is possible to use a very simplified model, on the contrary, in the case of an operating tractor, considering a variety of factors is necessary. The stability of the tractor in fact in these cases is influenced not only by the geometric parameters such as the position of center of gravity, the stability triangle and the possible connection to implements, but also by the dynamic characteristics such as forward speed or steering, related to operators' tractor use, then by his ability, reaction time, experience and perception of risk.

Moreover, environmental factors also become essential, so as considering not only the slope of the land, but also, directly or indirectly, other terrain features such as the roughness and texture. Environment can also affect driving performance of the operator determining elements of stress due to disturbing weather conditions, excessive heat or cold that can be added to other stressors such as noise and vibration of the vehicle.

For these reasons the study of stability in real conditions is of ever greater importance in recent research increasingly addressed to the analysis of real cases rather than theoretical laboratory evaluations. Devices have been developed to inform the operator about tractor stability and warn him in case of overturn risk (Mitchell et al., 1972; Spencer and Owen, 1981) or to alert medical assistance in case of accident (Sarghini and D'Urso, 2010). Frequently, devices evaluating tractor stability conditions take into account mathematical models based on the forces acting on the tractor that can cause the upset. Both the constructive aspects of the tractor, such as weight or the position of the centre of gravity, and those related to its movement such as speed, turning radius and slope are taken into account. Murphy et al. (1985) developed a mathematical model to measure the relative stability of a tractor considering weight and centrifugal force vectors and the effects of ground roughness.

Active systems have been evaluated to stop the tractor in case of rollover risk by cutting fuel supply or ignition system (Murphy et al., 1985). Nichol et al., (2005) developed a low cost device based on sensors and a display to inform the tractor operator of possible instability and to assist him in avoiding dangerous situations. Etzler et al. (2008) proposed a methodology for establishing a risk threshold to inform the tractor operator and assist him in performing corrective manoeuvres for mitigating risks according to risk level.

Some of these prototypes deserve special attention because they represent the evolutionary steps of the research in this field.

Sperncer and Owen (1981) designed a device indicating a maximum slope at which a tractor could descent without sliding by using a simple and robust pendulum accelerometer. They proved that the accuracy of the instrument was sufficient for practical use even if the prediction tend to underestimate the slope with drive wheels rotating.

Freeland (1990) elaborated an interesting method to test tractor pitch and roll angle measurements obtained by two inexpensive inclinometers. The sensors detected the distribution of a dielectric liquid and inert gas pressed between two etched copper-plated discs. Capacitance variations caused by the gravity-induced repositioning of the mixture, indicated an angular displacement. A single circuit for computer interfacing of the sensor was developed then roll and pitch angle performance data were collected at different speeds. The Inclinometers resulted slightly influenced by vehicle acceleration and deceleration.

Greene and Trent (2002) elaborated a system, as a predictive rollover sensor, composed by a single axis accelerometer, used as an inclinometer, an inexpensive solid state rate gyro and a microcontroller.

Liu et al. (1999) have developed a site-specific driving safety management and stability mapping system utilizing a measuring system of tractor stability, Differential Global Positioning System, Geographic Information System and Video Mapping System. The vehicle stability mapping is based on the vehicle stability index and GPS information.

The measuring system of tractor stability is composed of four sensors, which measure both position and speeds of a tractor, and a data acquisition system which record and analyze the information from the sensors (Liu,1998).

An interesting application of the method complemented by a risk index algorithm developed by Ayers and Liu was obtained by Koc et al. (2012). They built and programmed autonomous model tractors using the Lego Mindstorms kits. In addition to the simulated tractor pulling activities, they developed an experiment to integrate smart phones with the Lego Mindstorms kits to demonstrate instabilities taking place during tractor operation and to predict potential rollover situations. The mathematical model used in the mobile application uses the tractor dimensions entered by the user and the data from the accelerometer and gyroscope sensors of the smart phone. Next, the application calculated a stability index value, displayed the change of stability index on the screen and sent automated emergency messages in case of a rollover.

Nichol et al., (2005) developed a new device using low−cost sensors and microcomputers with a simplified mathematical model of an agricultural tractor to inform the operator of potential tractor instability. It was also capable of interfacing with newer on−board tractor systems via a CAN bus to make it more attractive to tractor manufacturers who may want to incorporate this device into new models.

A simplified quasi static mathematical model and an inexpensive MEMSIC dual−axis thermal accelerometer (MXD2020U, MEMSIC, Inc., North Andover, Mass.) was used. This accelerometer was very small and capable of sensing static and dynamic accelerations.

A microprocessor (AT Mega 163−10SI, Atmel Corp., San Jose, Cal.) was used to measure the signal from the accelerometer and process the information. Although the PIC microprocessor family from Microchip Technology, Inc., has a comparable processor that would have been equally capable of accomplishing the tasks, and at a comparable price, the Atmel microprocessor had many features that were more desirable.

A 128−kbit EEPROM chip was also included in the device for storing a small burst of data during testing. The microprocessor communicates to the EEPROM chip. After a tractor overturn test, the stored data would be communicated to a PC. The information would be downloaded over the CAN bus into the PC and stored in a text file for later evaluation. The display device presents a short−time history of roll angle encountered over the last 15 seconds to give the operator a chance to react and later inspect what level of potential instability was encountered, Figure 30. This task was accomplished with a matrix of tricolor LEDs

This device could not prevent the tractor operator from encountering a potential rollover situation, but it could educate the operator as to how potentially unstable a situation is, and it could allow the operator to vary one of the three critical parameters under his control, i.e., speed, turning radius, and current side−hill operating angle.

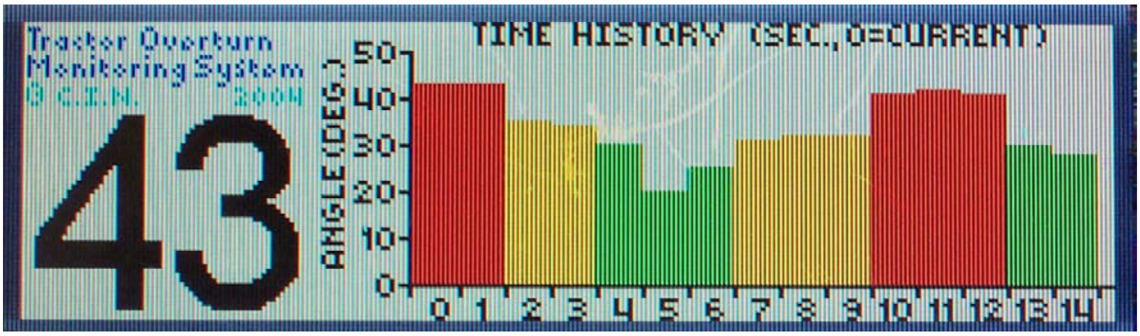


Figure 30. Monitoring device (Nichol et al., 2005).

Sarghini and D’Urso (2010) developed a combined rapid alert device integrating a GPS-GSM chip with a MEMS (Micro Electro-Mechanical Systems) tilt sensor, including miniaturized accelerometers and inclinometers in order to detect rollovers and collisions in real time.

They sustained that previous application of GPS technology in tractor rollover problems was mainly focused in increasing off-road vehicle stability mapping integrating GPS/GIS and video technology (Liu et al., 1999). They were instead interested in developing a fast hardware platform, able to transmit essential information about the accident in short time, avoiding possible black out due to platform failure as a consequence of the accident itself.

They add that several handheld device or smartphones today incorporates tilting sensors and a GPS chipset. Nonetheless their GPS fix is often poor, and tilt sensors do not provide the necessary reliability, time resolution and vibration filtering.

Two platform were developed: a high computational power platform based on a 100 MIPS processor interfaced with a MEMS integrated tilting sensor, and a low cost platform with self assembled sensors a reduced computational power. But they described in detail the first one.

The purposes of the hardware platform were the following:

1)to determine the dynamics of rollover;

2)localize geographically the location of the accident through a GPS tracking system;

3)communicate data to central control base the accident by phone SMS message to immediately activate the medical care rescue.

The device was constituted by the elements described below.

1) A microcontroller board, the motherboard is a FOX LS832, based on Axis 100 MIPS processor, 32 MB RAM, 8 MB Flash, Ethernet interface, two USB Host ports, three UART interface for Secure Digital cards and three RS232 interfaces. This card uses Linux operating system, thus allowing rapid application development.

2) A three-axis tilt sensor for the detection of three-dimensional positioning of the vehicle; they used U.S. Digital X3M Multi-Axis Absolute MEMS Inclinometer (US Digital, 2009), which is a digital three-axis high precision MEMS tilt sensor. The sensor X3M is an absolute inclinometer using MEMS technology (micro-electro mechanical systems), and allows the detection angles on 360 ° of extension. The X3M sensor is a very flexible device, allowing the user to connect via the serial interface RS232, across six programmable outputs or through both. The X3M sensor can also be configured to operate as a precision tilt switch to 1 or 2 axes.

The sensor calculated the angle of tilt sensing acceleration from MEMS accelerometers embedded in a monolithic integrated circuit, since the acceleration of gravity, centrifugal forces, and speed changes are all forms of linear acceleration. Configurations and parameters are stored in non-volatile memory, and the sensor is interfaced to the microcontroller board via a serial port. The sensor can use only two axis simultaneously, roll and pitch axes.

3) A GPS/GSM board for the localization of the vehicle and the transmission of alarm messages; a Telit GM862-GPS chip connected to the microcontroller via a serial port embedded in a specially purpose designed carrier board. The GM862 module has a quad-band dialer GSM / GPRS modem functionality with an integrated 20-channel GPS receiver based on the high-sensitivity SiRFstarIII ™ single-chip. The GPS receiver features low power consumption has a resolution of the position with precision of less than 2.5m, SàBAS (WAAS and EGNOS) as well as high sensitivity for indoor fixes.

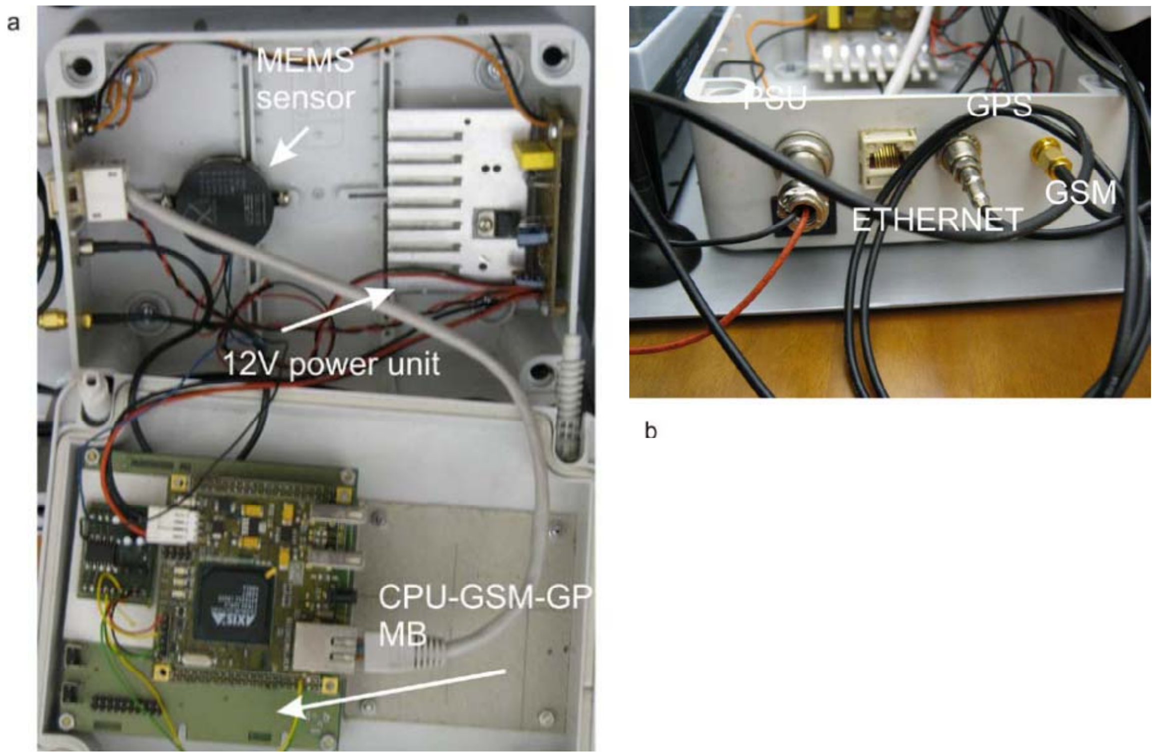


Figure 31. Assembled prototype (Sarghini and D'Urso, 2010).

However, only very few commercial warning systems have been developed nowadays and additional research needs to be carried out to assess their performance on tractors operating in farms.

A commercial device in fact has to cope with the problem of an adequate balance between reliability and simplicity. Are indeed necessary both cheap and not bulky components as well as sufficiently precise, moreover a suitable calculation algorithm is essential.

It is therefore necessary a commercial driver assistance device that allows a continuous monitoring and a continuous visualization of risk levels, taking into account the continuous interactions between the tractor operator and the environment.

4.1. MULTISENSOR DEVICE TESTED

The research was focused on field tests carried out on a group of tractors operating in the experimental farm of the University of Bologna. The tractors were monitored by a commercial warning device during two whole vegetative seasons (years 2012, 2013). Preliminary tests were performed to assess the device performance.

The commercial driver assistance system evaluated in this research project is composed of a Master unit, a display and WED sensors (Wireless End Device), Figure 32. Installation on the tractor has to be performed by the manufacturer technical staff in order to set up the device and calibrate the system.

The main unit contains various sensors for the detection of the dynamic parameters, summarized in Table 17, and the microprocessor that processes the data on the basis of an algorithm that allows the calculation of a risk index instant by instant. The main unit is installed horizontally on the cab of the tractor in order to avoid obstacles to the transmission of data and in a central position so that tilt sensor and gyroscope operate symmetrically. For tractors without cab the main unit is positioned on the tractor platform, behind the seat, in the center.

The color display, installed on a single bracket, provides the driver, intuitively, information on the level of risk. The calculated risk, expressed by percentage value, is displayed by a video signal consisting of green circles or, if the risk index reaches or exceeds 70%, yellow circles. An audio signal is added for cases considered of greatest danger, if the risk index reaches or exceeds 95%, and the video signal turns to red color.

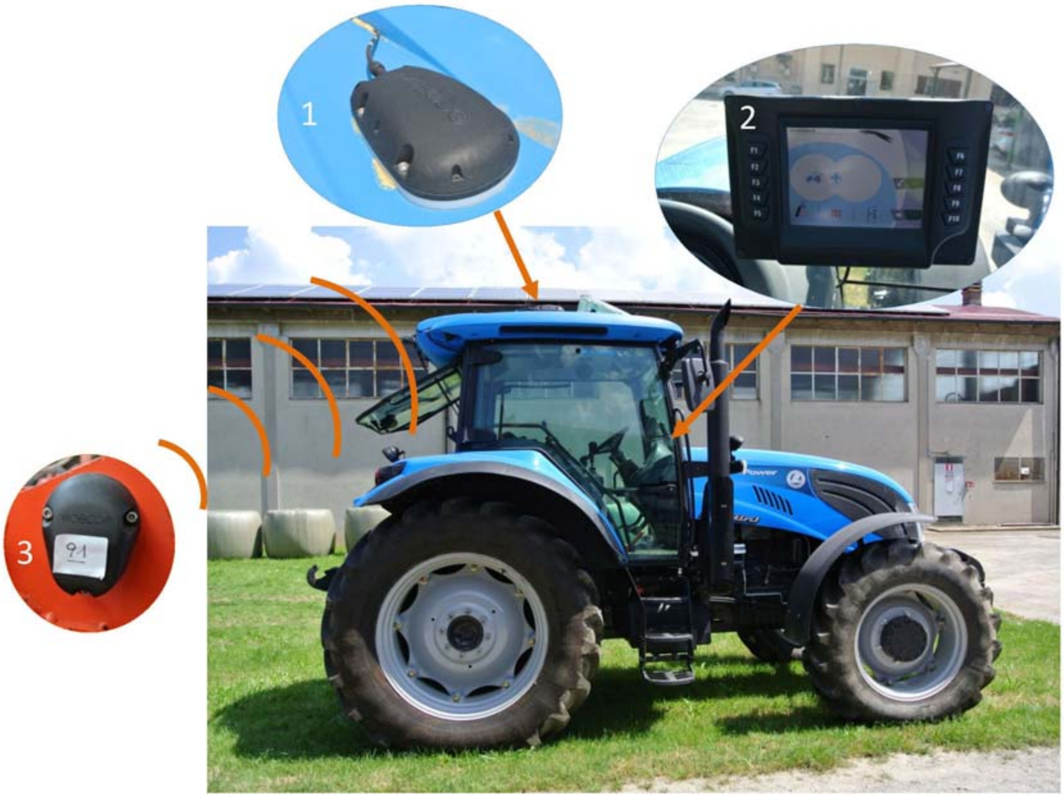


Figure 32. Tractor fitted with multisensor device, main unit (1), warning display (2), implement transceiver (3).

Furthermore, through the use of symbols, the cause of the risk condition is shown and which dynamic parameter, under the operator control, modifying is suggested. The system is completed by WED transceivers installed on the implements that enable the automatic recognition of implements connected to the tractor thus allowing the identification of the type of operation performed.

Table 17. Parameters recorded by sensors.

Parameter	**Units**
Speed	km h^{-1}
Elevation	m
Pitch angle	degrees
Roll angle	degrees
Steering	Degrees/seconds
Coordinates	Degrees Minutes Seconds

4.1.1. COMPONENTS

All sensors used are very small and low cost components.

Dual axis accelerometer, MXD2020 G/H/M/N, MEMSIC (Andover, Massachussets, USA).

The MEMSIC device is fabricated on a monolithic CMOS IC process and can measure both dynamic acceleration, e.g. vibration, and static acceleration, e.g. gravity. In this application it is used as a tilt sensor and uses force of gravity as an input to determine the inclination angle.

Tri-axial accelerometer, AIS328DQ, STMicroelectronics (Geneva, Switzerland).

This is a “nano”, low power, digital output accelerometer used to validate the signals from the bi-axial accelerometer and to confirm tractor overturn.

Gyroscope, ENC-03R, Murata (Kyoto, Japan) to measure tractor steering angle rate.

It is an angular rate sensor that uses the phenomenon of Coriolis force, wich is generated when a rotational angular rate is applied to the vibrator.

GPS, SLE-1613, KNCTEK (Seoul, Korea) for tractor geographical localization.

GSM/GPSR, GC864-QUAD V2 Compact, Telit (London, UK) For data transmission

Transceiver, CC2500, Texax Instruments (Dallas, Texas, USA) Installed on the implements to recognize them.

4.1.2. ALGORITHM

Several studies have realized mathematical models for predicting tractor rollovers, but these models are typically very complex and unwieldy when the problem of real-time stability is considered, especially with low-cost devices and with limited computing power.

For cases like the one considered in the present study, simplified models have been realized; in fact the quasi-static calculation algorithm used by the system belongs to this category and consider a few geometric parameters of the tractor (overall weight distribution, center of gravity and track wheelbase) and dynamic parameters detected by the sensors (speed, roll and pitch angles, steering rate). An overview scheme of the procedure of calculation of the risk index is summarized in Table 18.

The tractor geometry data are inserted through a preliminary calibration operation performed by a trained technical staff of the manufacturer during the system installation.

Tractor mass on the four wheels was measured by means of four scales, Figure 33.

The same weighing operation was carried out both on the horizontal plain and on a slope in the range 8-15 degrees.

The tractor Wheel base, track with and the distance between front axle and center of gravity of the ballast were also measured.

The coordinates of the center of gravity of the tractor were then calculated by trigonometric formulas.

The same procedure is performed to calculate the coordinates of the center of gravity of the implement connected to the tractor. The weighting operation was repeated for the tractor-implement system. The implement disconnected from the tractor was also weighed.

Thereby the program calculated the stability geometric triangle. The static rollover angle was considered in the preliminary phase.

A series of factors aggravating the risk index are introduced on the basis of what is the prevalent working condition: roll angle, pitch angle or steering angle rate.

The calculated result is the instantaneous risk index.

As indicated in Table 18, an additional control step is also provided to account for the proximity of areas that are reported to the system as dangerous. This control affects the calculation of the risk. Finally, a rollover check is done with the purpose, if the event has occurred, to send alarm to preset phone numbers

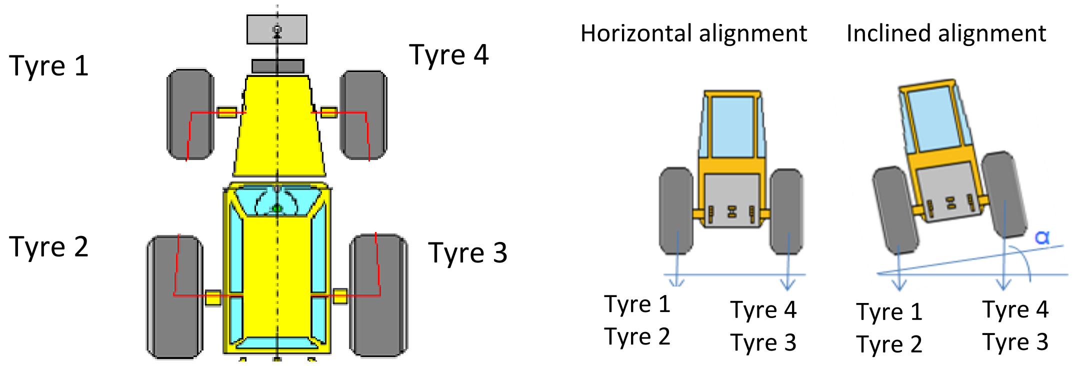


Figure 33. Instructions for calibration.

Table 18. List of software's main steps.

SENSORS READING	Pitch angle: accelerometer Roll angle: accelerometer Forward speed: GPS Steering angle rate: gyroscope Transceiver for implemet detection
TRACTOR DATA LOADING	Tractor: weight, track width, wheel base Rearward Implement: weight Front implement: weight
ROLLOVER ANGLE CALCULATION	Calculation of the rollover angle by the stability triangle.
STATIC RISK CALCULATION	Calculation of the rollover risk on the basis of the tractor dynamic parameters and rollover angle, calculated in the previous step.
WORKING CONDITIONS	Verify the PREVALENT working condition (roll, pitch)
DYNAMIC PENALTIES	Evaluation of the penalties on the basis of the working condition Increase in the percentage of risk Penalties are related to the PREVALENT working condition and increase the risk on the basis of e.g. Forward speed, steering angle rate
DANGEROUS AREAS CONTROL	The risk level increase if the tractor is approaching to a dangerous area. 100% if it exceed the boundaries
ROLLOVER CONTROL	Further check to verify, regardless the level of risk, if the tractor is overturned to send SOS alarm.
DISPLAY UPDATE	Value setting for display visualization
AGGIORNAMENTO WED	Sending data to WEB server

In order to obtain more detailed information about the calculation logic of the algorithm a comparison was done between the risk index values and the measures of the parameters recorded by the sensors.

As indicated in the list of passages provided by the manufacturer, it was found a threshold value of the angle of inclination below which the risk index was null and above the system performed a further verification if the forward speed of the vehicle was greater than a threshold value. If the speed was below this value a calculation of the risk index was carried out based on the only parameter of the roll angle, but if the threshold value was exceeded, the calculation of the risk was carried out based on of both roll angle and speed.

For pitch angle it was observed that there was also a threshold value of the pitch angle below which the risk index was zero, while above this there was a calculation that considered only the pitch angle. In this second procedure did not appear the value of the forward speed.

Relate to the steering data, also in this case there was an steering angle rate threshold and a forward speed threshold. Only if the values of these two variables were higher than the thresholds, risk index due to steering angle rate was different from zero.

It must be specified that the evaluation presented was based only on recorded data and is therefore necessarily incomplete because it is not possible to cover all the possible cases. Nevertheless, the comments were never confuted by the analyzed data. Moreover It has been seen as the recorded value of the risk index corresponds to the higher of the three ones obtained with the models described above.

4.2. INTEGRATED INFORMATION SYSTEM

The commercial system evaluated provides the opportunity to use an integrated information system through a constant connection via Internet to tractors, implements and cultivation areas.

In fact a dedicated website is available. It works as an operating center and database. In this site it is possible to visualize maps of the working area where the tractors are located. It is also possible to divide a farm in 10 areas in order to highlight them on the map on the basis of any criterion such as the type of cultivation. They can be created by drawing closed polygons directly on the website.

There is also the possibility of delimiting, by 10 other virtual enclosures, hazardous areas for the presence of landslides, ponds or inaccessible areas. The tractor approaching to these areas cause an increase of the risk index which reaches the maximum value if the boundaries are exceeded.

This function was not used in this research study, however, 10 areas have been highlighted corresponding to the main production units of the experimental farm of the University of Bologna where the tests were carried out.

The farm is mainly cultivated with cereal and fodder crops. Fields are located partly in Cadriano, a flat area with altitude in a range of 19 to 40 m above sea level, and partly in Ozzano, a hilly area with altitude up to 370 m above sea level. In Figures 34 and 35 are visible the main productive units.

In these images tractors are also visible which are easily localized by GPS and, due to the automatic recognition device, it is possible to know which operation they are doing. Then a continuous traceability of the tractor is available which allows, in the event of rollover, tractor localization when automatic calls are done to preselected numbers as first aid and forest guard.

It is also possible to identify if tractors are working or moving in the fields or on the road, and the values of the risk index. All the data in fact are available for downloading as excel files, which can be processed. Data can also be filtered through queries to limit the analysis to the only information of interest.

Due to the continuous data overflow it is possible to get information on schedules, equipment, position of vehicles, routes, dynamic parameters and possible dangerous situations and corresponding causes that have determined them.

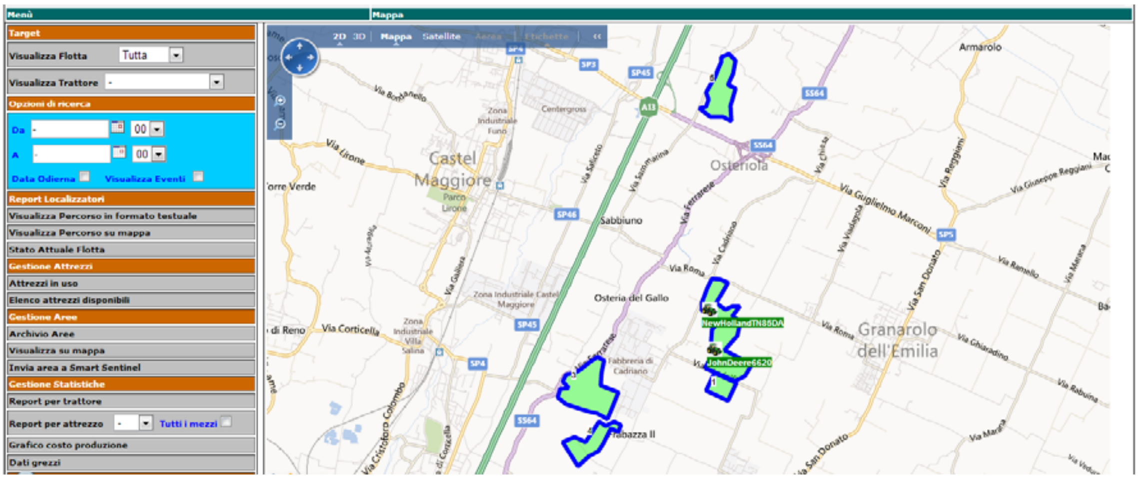


Figure 34. Website overview of main production units in Cadriano.

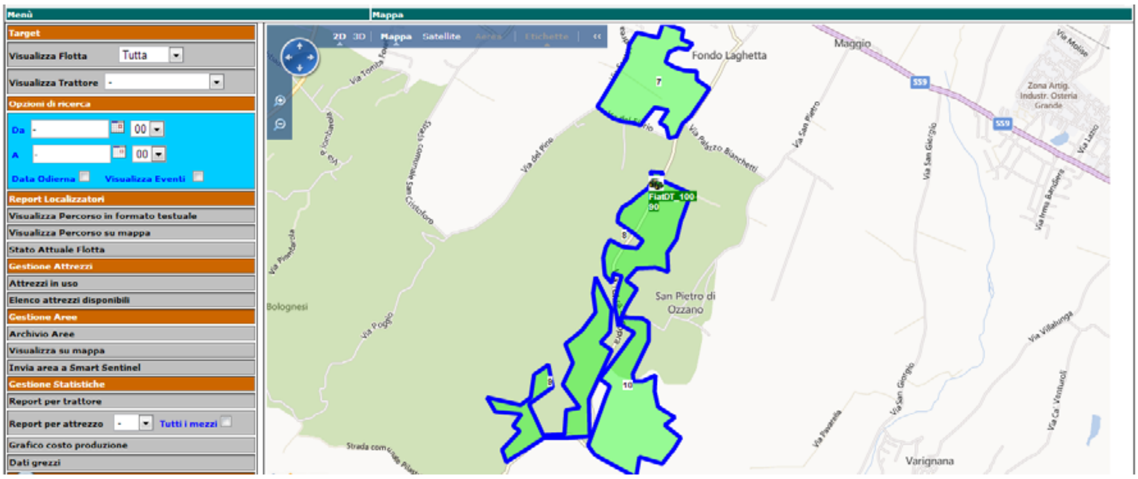


Figure 35. Website of main production units in Ozzano.

4.3. TESTS

It was carried out a first tests period during the 2012 growing season, but the results were partly inconsistent. Reports were then submitted to the manufacturer who has modified and optimized the devices that were then used in the 2013 test period. Instruments and methodology of this second series of tests were those developed during the first one.

4.3.1. PRELIMINARY TESTS

Evaluating the performances of the improved system was thus essential to understand the level of reliability of the single components and of the whole system during the tests. Then preliminary tests in static and dynamic conditions were carried out.

In static tests a multisensor provided tractor was placed on a slope to assess pitch angle, roll angle and the combination of both. The values on the display were compared to those obtained by a commercial digital level, and the differences were in the range of ± 1 degree. The values on the display of the system were also compared to those downloaded from the website and the perfect coincidence of the data was verified.

Moreover the threshold of the slope, above which the alarm was supposed to appear, has been deliberately exceeded and the system responded as expected.

In Figures 36 and 37 is shown a test where pitch angle, roll angle and the risk threshold were verified simultaneously. It is also visible the shots recorded by a camera integrated into the main unit of the system.

Figure 36. Tractor on the test slope during the static tests.

Figure 37. Display device during the static test.

Figure 38. Track for dynamic tests.

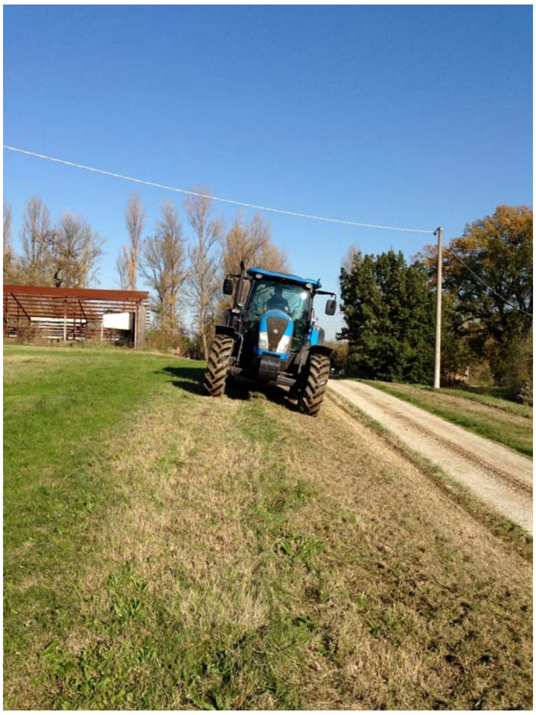


Figure 39. Tractor during the roll angle dynamic tests.

Figure 40. Tractor during the response time tests.

For tests in dynamic conditions a 20 meters long track was chosen. At the side of the track ranging poles were placed at regular intervals, one each 5 meters, to highlight the way. The track had a transverse slope that allowed the tractor to follow it maintaining a roll angle of 9-12 degrees. The tractor ran through an initial ramp that allowed to reach the constant speed and inclination then kept on track.

The values of speed and roll angle on the display were compared to those obtained from a commercial digital level, digital protractor, and a Racelogic V -box with high performance GPS. The speed was maintained at about 2.8 km/h referring to the v -box, the values measured with the multisensor were on 2.3 km/h, the slope instead was kept at 11 degrees while the display showed values about 9 degrees. The test was repeated three times to verify the results.

The same test was carried out at 10 km/h speed and the results were similar, but the steady value of the roll angle was reached when the tractor had covered already half of the trak.

In order to check the pitch angle an internal road of the university farm in the hills of Ozzano was chosen with a 8 degrees slope. The tractor has covered it three times at a speed of about 10 km/h. The results showed a level of reliability similar to the static tests, acceptable for a low-cost commercial device.

In Ozzano a further test was conducted. The tractor moved on a circular track with a diameter of 10 meters at constant speed of about 5 km/h. The track was marked on a grassy area with a slope of about 7degrees. It was evident that the tilt sensor of the device could not follow the changes in the roll and pitch angles due to the continuous change in the conditions of stability of the tractor.

So in dynamic but not very variable tests the system has provided acceptable results, while in more variable tests the deficiencies of the system were not acceptable.

4.3.2. FIELD TESTS

The aim of the tests was to monitor a fleet of tractors operating in a farm, during a growing season, with different levels of risk related to different land slopes and different working conditions. For this reason five tractors operating at the experimental farm of the University of Bologna have been equipped with multisensor.

The monitored machinery includes modern four-wheel drive tractors fitted with ROPS cab and engine power in the 60 to 100 kW range.

Table 19 shows the images of tractors, their engine power, the main operations they usually do and the altitude they mainly work at. In fact, two tractors work only in the hilly area of Ozzano, one only in the flat area in Cadriano, while of the other two, one operates mainly in the plain and the other equally in plain and hill.

The five tested tractors were driven by operators employed in the experimental farm and experienced in tractor driving. Tests were arranged to keep the operators in their usual working area, with the two exceptions already mentioned, that enable to compare their risk perception in an unusual working area.

In addition to the signal detected by the sensor, a data collection form was provided to the operators involved in the tests, to be filled in after completing the normal activity to report the operations performed, the working time and the number of events considered potentially dangerous. The compiled forms allowed to verify the information provided by the multisensor.

TRATTRICE:						
DATA	ATTREZZO	OPERATORE	ORE DI LAVORO	ZONA	HAI AVVERTITO SENSAZIONE DI PERICOLO? (NO/MODERATAMENTE/MOLTO) SE SI' PERCHE'? (Es: perdita di controllo del mezzo, elevata pendenza, velocità eccessiva, sterzata brusca...)	SI E'ACCESO IL SEGNALE DI PERICOLO? (SI'/NO) SE SI' COSA INDICAVA E PERCHE'?

Figure 41. Data collection form.

Fourteen of the most used implements were equipped with transceivers, the list is available in Table 20 and 21.

Each multisensor is able to recognize no more than 6 connections thus the pairings that seemed more useful to describe the activity in the field were chosen, but they do not consider all the possible combinations.

Both tractors and implements have been identified by a code number in order to have concise and unambiguous indication, these codes are shown in table 19, 20 and 21.

The growing season considered for data collection included the period from May 1, 2013 to December 31, 2013, with the exception of tractor 3 for which it was possible to begin collecting data only since July 29 2013 because this tractor was not supplied to the farm before that date.

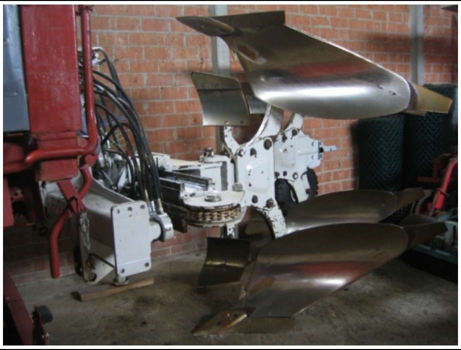
Table 19. Tractors monitored during the test period, code number, power, working area and main field operations.

	**1** **Power:** 107 kW **Working area:** Hill **Main field operations:** Harrowing, Baling, Liquid manure spreading
	**2** **Power:** 74 kW **Working area:** Hill **Main field operations:** Baling, Liquid manure spreading, Mowing
	**3** **Power:** 200 kW **Working area:** Hill and Plain **Main field operations:** Plowing
	**4** **Power:** 103 kW **Working area:** Plain (mainly) and Hill **Main field operations:** Harrowing, Subsoiling, Baling
	**5** **Power:** 63 kW **Working area:** Plain **Main field operations:** Mowing, Hay Making

Table 20. Implements transceiver provided and code numbers.

	
86 Rotary mower	87 Tedder
	
88 Liquid manure spreader	89 Round baler
	
90 Rotary harrow	91 Rotary harrow II
	
92 Harrow	93 Subsoiler

Table 21. Implements transceiver provided and code numbers.

	
94 Mower conditioner	95 Plough
	
96 Grubber	97 Round baler II
	
110 Liquid sprayer	111 Flail mower

4.4. RESULTS

The research intends to provide a statistical overview of the main dynamic parameters of tractors on a farm during an entire growing season.

The forward speed values were analyzed by the relative frequency, but the data for the other dynamic parameters are presented in form of Boxplot, figures 49, 50 and 51, because these are indicative of the dispersion of the data and point out the extreme cases, the most interesting by safety point of view.

The Boxplot are based on percentiles, the values below which falls a given percentage of observations within a group of observations.

The quartiles, that divide a population in four parts of equal number, are particularly evident.

The lower base of the box plots represents the Lower quartile, or 25th percentile, the upper base represents the upper quartile, or 75th percentile, while the intermediate segment, parallel to the bases, represents the median, the 50th percentile.

The distance between Lower and Upper quartile is called the interquartile range.

At the bases there are the lower and upper whiskers, segments perpendicular to the bases proportional to the interquartile range, the proportion generally used is 1.5 the interquartile range and it is the one chosen for these calculations. But if the minimum or maximum value of the entire population is located at a distance less than a whisker this is interrupted at this value. The values at a distance from the rectangle basis greater than whiskers are outliers and are the most anomalous data.

Then the risk index values were analyzed by relative frequencies and the events characterized by alarm signals were evaluated through diagrams of the values of the main dynamic parameters.

4.4.1. FORWARD SPEED

The relative frequencies of tractor speed during the whole period are shown in figures 42 to 48. The data have been divided on the basis of the implement connected to the tractor to distinguish different speeds during the different operations. The values obtained in the two different altimetric areas were also separated.

Zero values were filtered to exclude cases of tractor in idle.

In many of the following diagrams speeds due to tractor in transfer or in working conditions are recognizable, in fact peaks are often visible at high speeds in the case of road transfer.

Liquid manure spreader is characterized by very distributed values of working speed up to 9 km/h in the hills and on the plain, with minor peaks for higher speeds.

Round baler was used only in hills at quite variable speed. The case of the rotary harrow, on the contrary, has speeds concentrated at around 3 km/h both in the hills and in the plains. Even in the case of the grubber speeds are concentrated at low values. Rotary mower shows a peak of speed very defined at 7 km/h.

The harrow, unlike rotary harrow is used with a wide range of speeds up to about 10 km/h in both plain and in hills and has peaks at speeds typical of road transfer due to the fact that the tractor is used equally in the two parts of the farm and frequently moves on the road.

The plough, on the contrary, in spite of being connected to the same tractor does not present speed of frequent use over the 7 km/h.

The subsoiler was used only in plain at distributed speed up to 6km/h in one case and with a peak around 5 km/h in another.

The case of the flail mower has a peak at 3 km/h and a frequent use of up to 5 km/h.

The tedder is used at distinct speeds below 11 km/h.

Finally the mower conditioner speed is enough distributed up to 9 km/h.

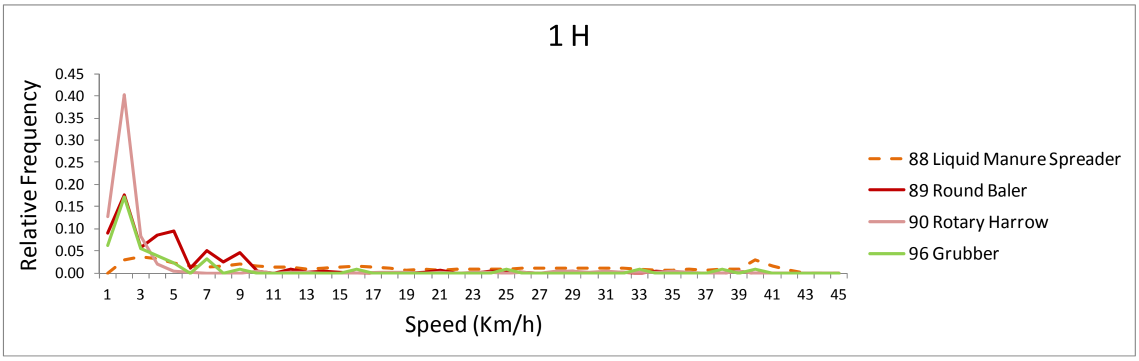


Figure 42. Tractor 1 forward speed in hill area, frequency distribution.

Figure 43. Tractor 2 forward speed in hill area, frequency distribution.

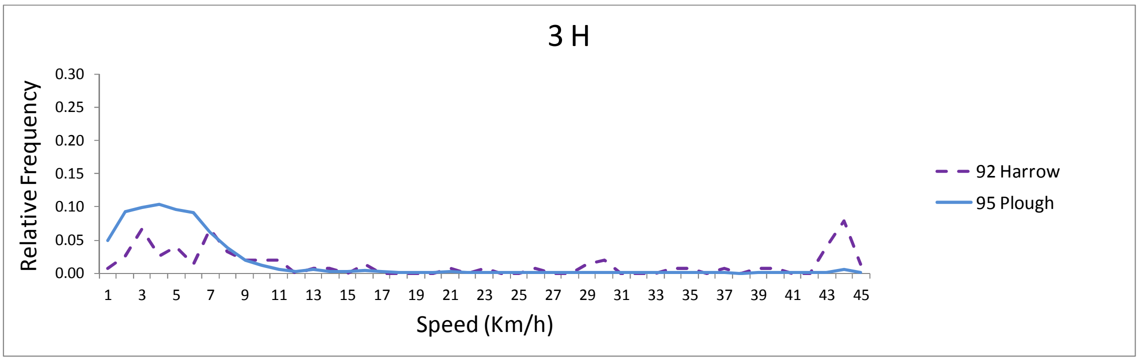


Figure 44. Tractor 3 forward speed in hill area, frequency distribution.

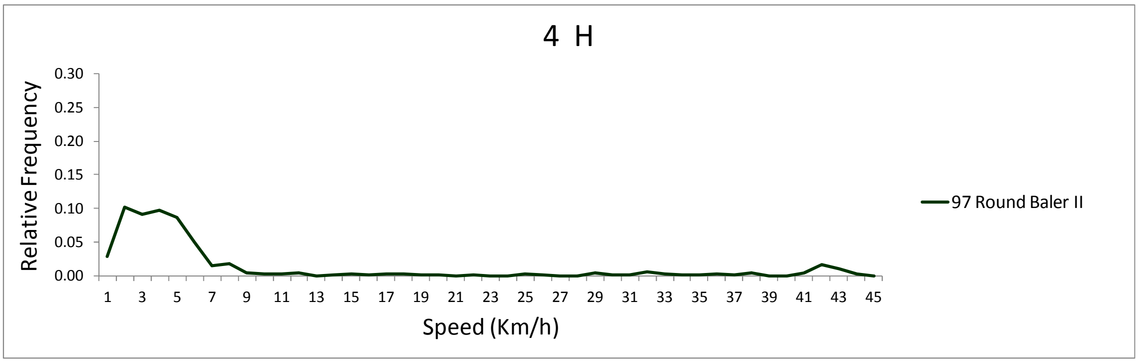


Figure 45. Tractor 4 forward speed in hill area, frequency distribution.

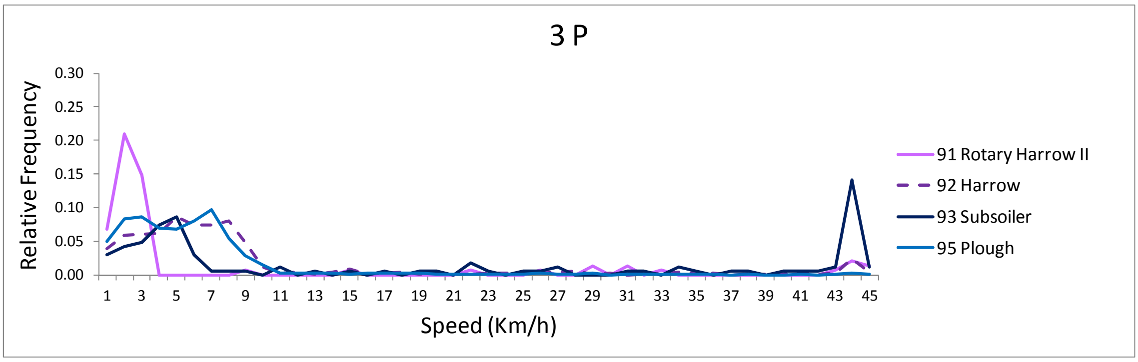


Figure 46. Tractor 3 forward speed in plain area, frequency distribution.

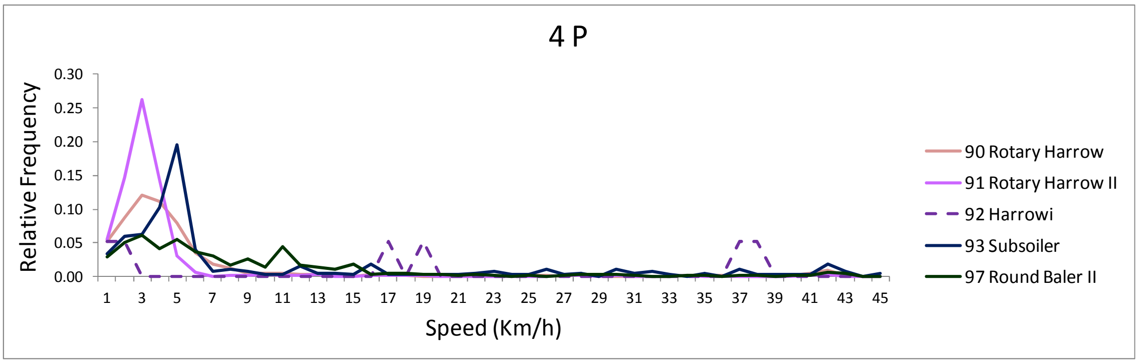


Figure 47. Tractor 4 forward speed in plain area, frequency distribution.

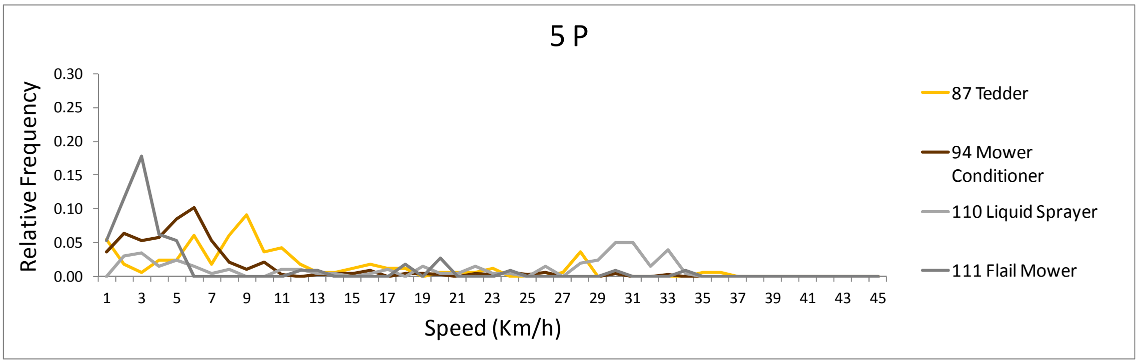


Figure 48. Tractor 5 forward speed in plain area, frequency distribution.

4.4.2. ROLL ANGLE

Figure 49 shows the distributions of roll angles. It is one of the parameters of greatest interest since most of tractors rollover are lateral. The values measured during the entire test period are shown. Each graph refers to a tractor and the implement connected to it with the exception of the graph 49 (e) in which data of tractors 3 and 4 were grouped in order to minimize the group of diagrams. The diagrams on the left refer to the hilly area, the ones on the right to the plain. Thus the scale values are different, suitable for the altimetric area. It is notable as the round baler 89, the one that is connected to the tractors that work exclusively in hills, has very distributed data and reaches very high values. The rotary harrow 90 instead reaches very high values, but the data distribution is more concentrated. Another implement that reaches very high values is the plough. Even in the plains, although the values are lower, as might be expected, it is the machine with the more extreme values, even higher than rotary harrows 90 and 91 connected to the tractor 4. It is also notable the rather broad distribution of the values of the flail mower 111.

4.4.3. PITCH ANGLE

The same type of representation of the data used for the roll angle was resumed for the pitch angle.

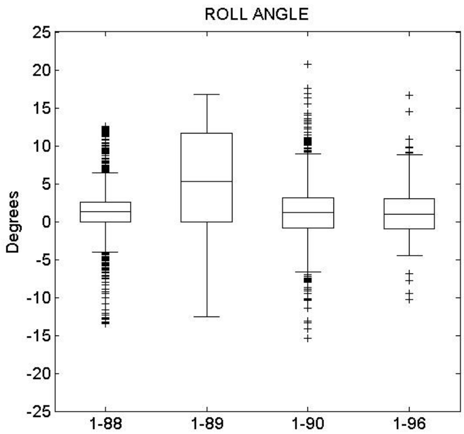
For the hilly area Rotary mower is to be pointed out for the very distributed data and the very high extremes. The rotary harrow has sporadic data at high values, the plough also has distributed values, and outliers at very high values.

Even in this case, the plow has very high values compared to the other implements both on the hill and on the plain, in fact, with the harrow, is the case with higher values. The rotary harrow instead, significant in the hills, has no relevant values in plan.

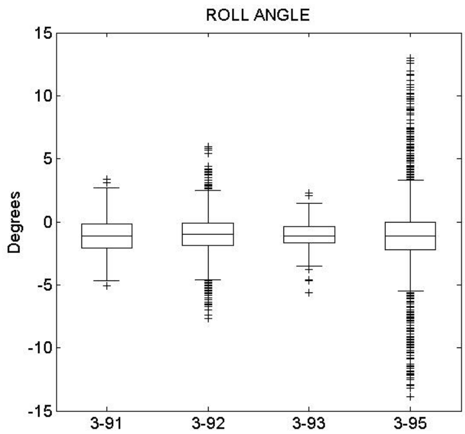
4.4.4. STEERING ANGLE RATE

For the steering angle rate data, presented in Figure 51, the scale remains the same for both altimetric areas since there are not significant differences. The values are highly concentrated around zero and the data outside of this value are sporadic.

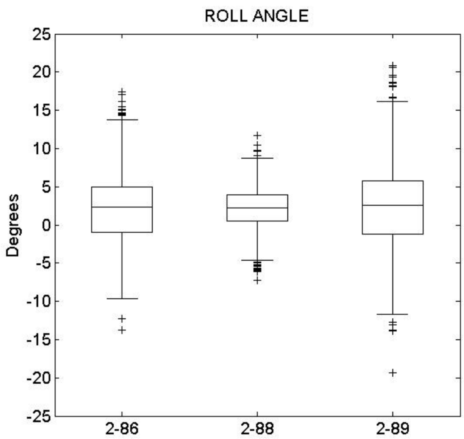
The higher values in hill area are achieved by the liquid manure spreader 88, rotary mower 86 and round baler II 97, and in plain mainly by round baler II 97.



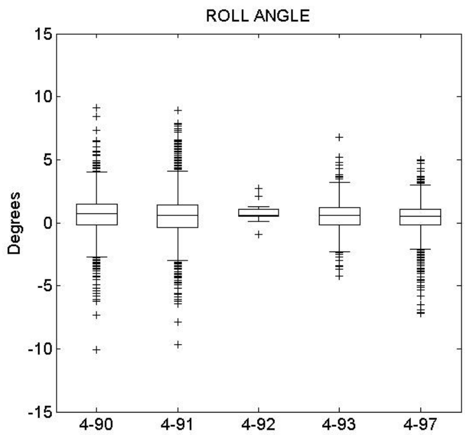
a) Tractor 1 in hill, 88-Liquid manure spreader, 89-Round baler, 90-Rotary harrow, 96-Grubber.



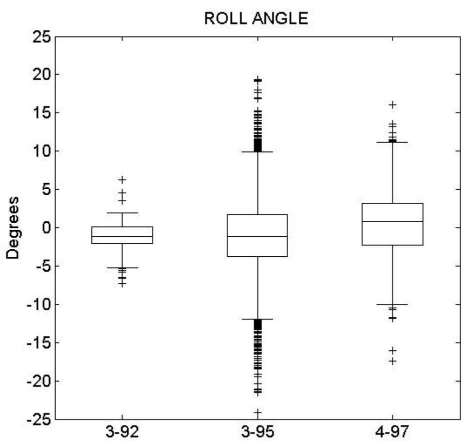
b) Tractor 3 in plain, 91-Rotary harrow II, 92-Harrow, 93-Subsoiler, 95-Plough.



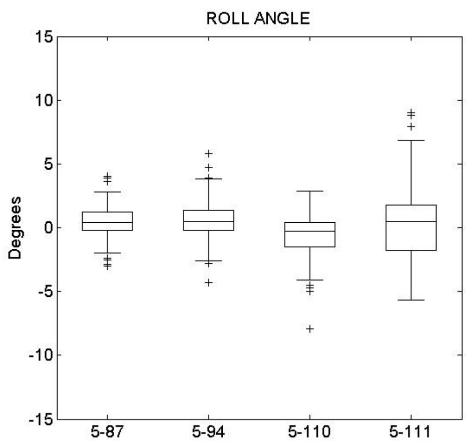
c) Tractor 2 in hill, 86-Rotary mower, 88-Liquid manure spreader, 89-Round baler.



d) Tractor 4 in plain, 90-Rotary harrow, 91-Rotary harrow II, 92-Harrow, 93-Subsoiler, 97-Round bal.II

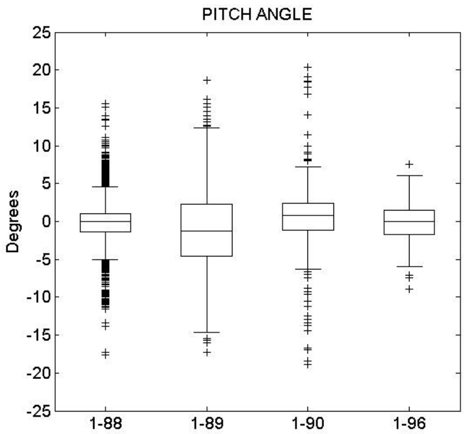


e) Tractor 3 and 4 in hill, 92-Harrow, 95-Plough, 97-Round baler II.

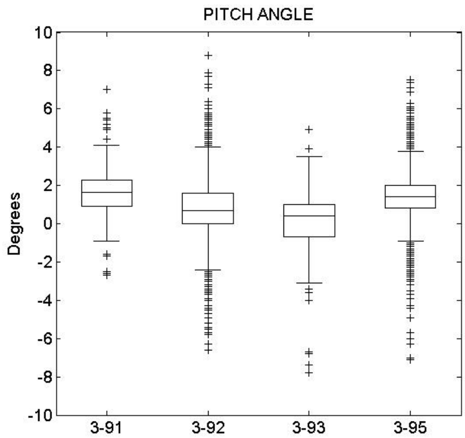


f) Tractor 5 in plain, 87-Tedder, 94-Mower conditioner, 110-Liquid sprayer, 111-Flail mower.

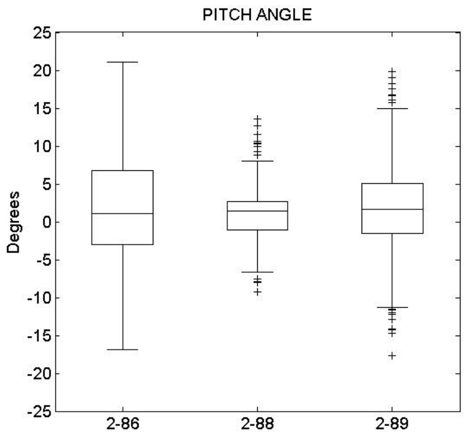
Figure 49. Roll angle boxplots.



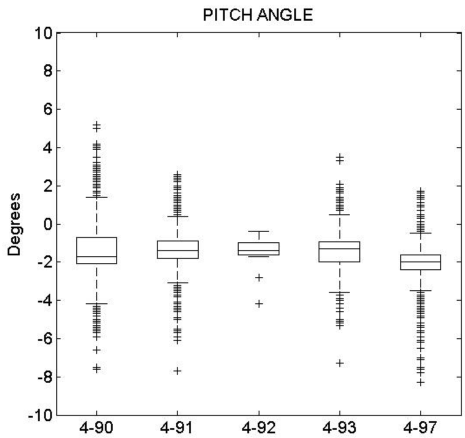
a) Tractor 1 in hill, 88-Liquid manure spreader, 89-Round baler, 90-Rotary harrow, 96-Grubber.



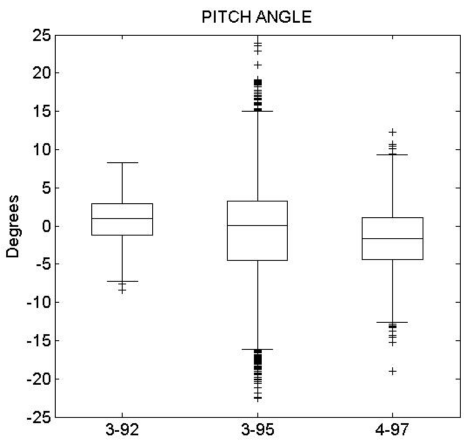
b) Tractor 3 in plain, 91-Rotary harrow II, 92-Harrow, 93-Subsoiler, 95-Plough.



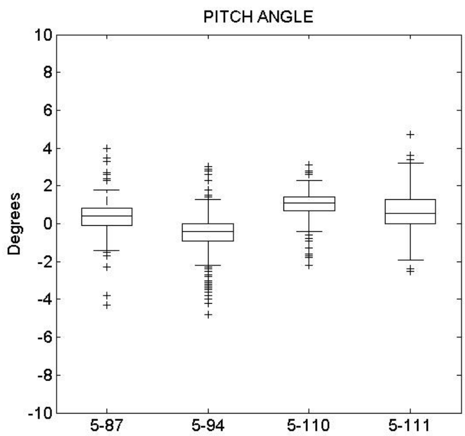
c) Tractor 2 in hill, 86-Rotary mower, 88-Liquid manure spreader, 89-Round baler.



d) Tractor 4 in plain, 90-Rotary harrow, 91-Rotary harrow II, 92-Harrow, 93-Subsoiler, 97-Round bal.II

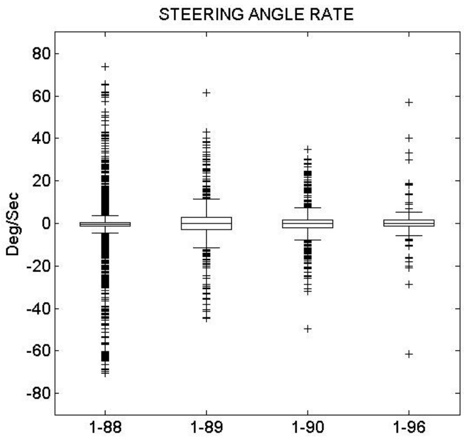


e) Tractor 3 and 4 in hill, 92-Harrow, 95-Plough, 97-Round baler II.

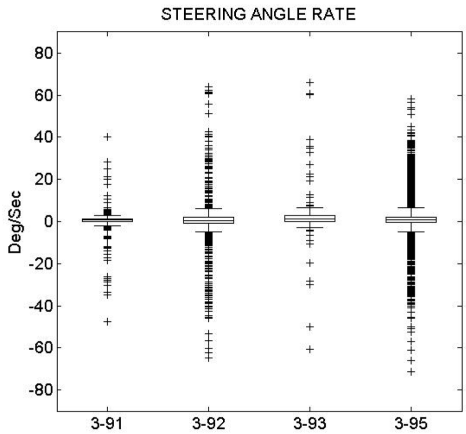


f) Tractor 5 in plain, 87-Tedder, 94-Mower conditioner, 110-Liquid sprayer, 111-Flail mower.

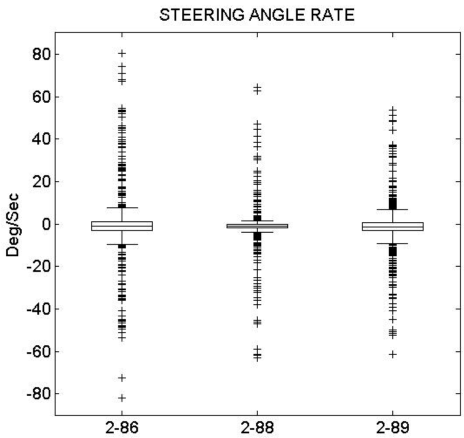
Figure 50. Pitch angle boxplots.



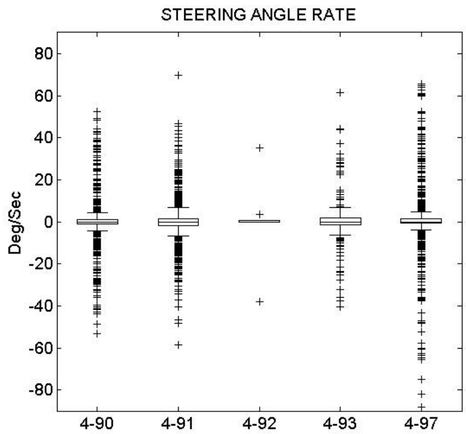
a) Tractor 1 in hill, 88-Liquid manure spreader, 89-Round baler, 90-Rotary harrow, 96-Grubber.



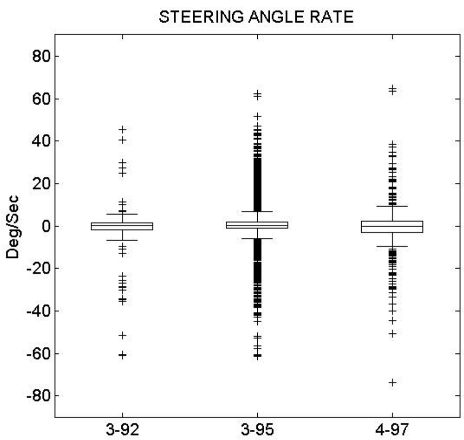
b) Tractor 3 in plain, 91-Rotary harrow II, 92-Harrow, 93-Subsoiler, 95-Plough.



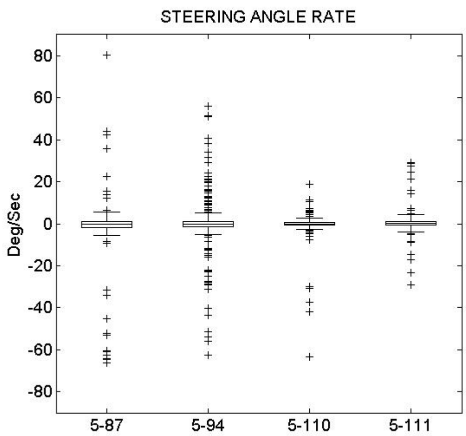
c) Tractor 2 in hill, 86-Rotary mower, 88-Liquid manure spreader, 89-Round baler.



d) Tractor 4 in plain, 90-Rotary harrow, 91-Rotary harrow II, 92-Harrow, 93-Subsoiler, 97-Round bal.II



e) Tractor 3 and 4 in hill, 92-Harrow, 95-Plough, 97-Round baler II.



f) Tractor 5 in plain, 87-Tedder, 94-Mower conditioner, 110-Liquid sprayer, 111-Flail mower.

Figure 51. Steering angle rate boxplots.

4.4.5. RISK LEVEL

The relative frequencies of the values of the risk index grouped into classes were considered. In the graphs of Figure 52 to 58 has been excluded the class 0 to 10, considered not significant.

In this analysis high frequencies at high risk index values may not correspond to a large number of warning signals if the implement has been used infrequently. It is instead a question concerning the overall hazard reached with respect to the frequency of use of the machine.

The high hill frequencies at high values of the risk index are characteristics of the round baler, in fact it showed rather high values of roll angle.

In the plain area the scale is smaller and peaks are visible at high values of the risk index for the subsoiler 93 and 87 tedder. It is also evident how the plow, while reaching rather high values of pitch and roll angle, in the hills above 15 degrees, has no high frequencies at high values of risk index.

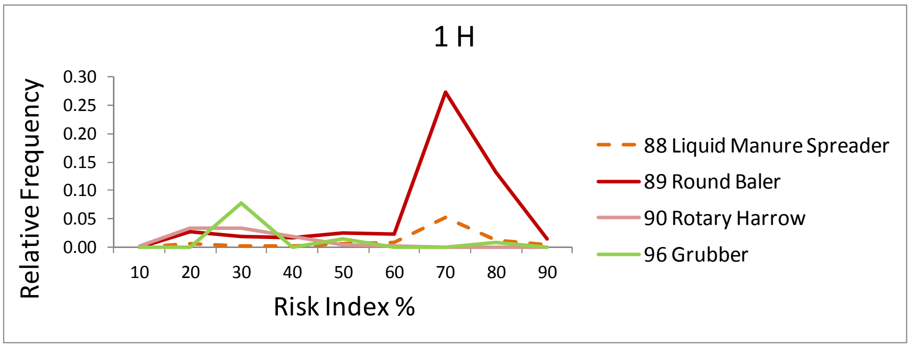


Figure 52. Tractor 1 in hill area. Risk index classes, frequency distribution.

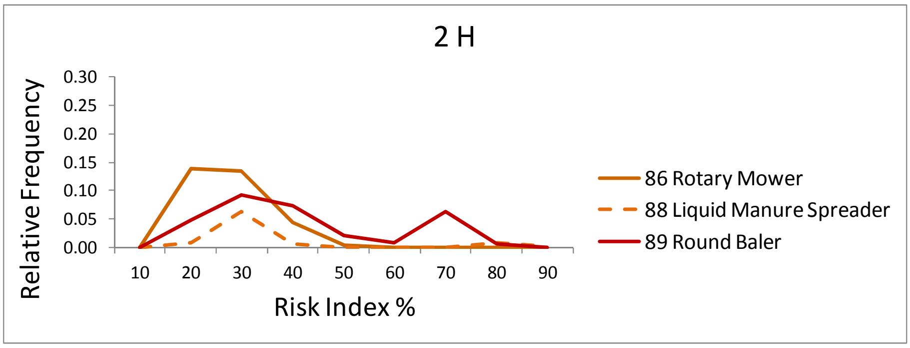


Figure 53. Tractor 2 in hill area. Risk index classes, frequency distribution.

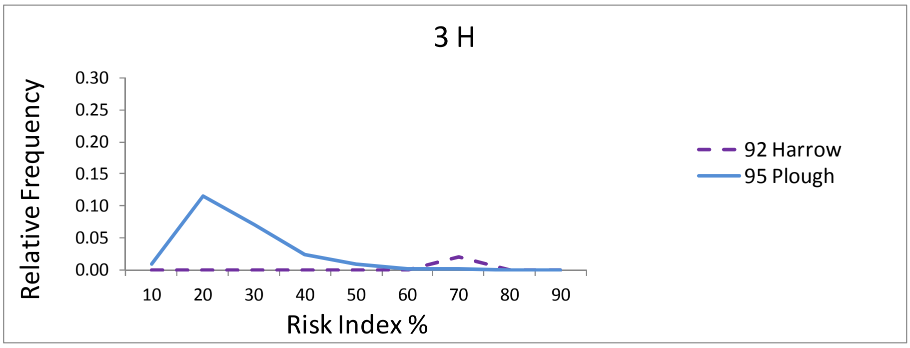


Figure 54. Tractor 3 in hill area. Risk index classes, frequency distribution.

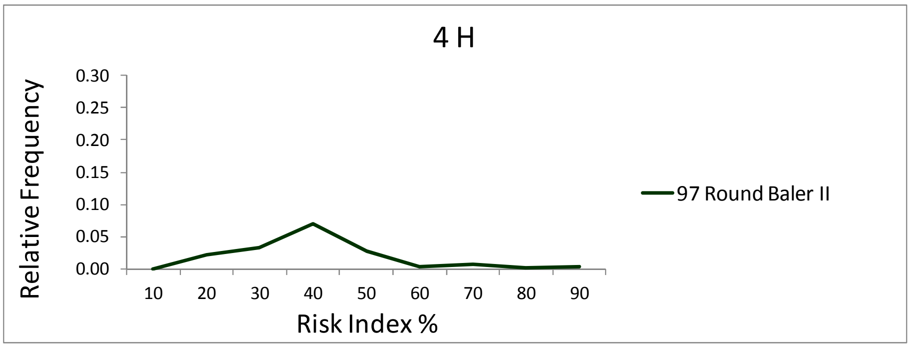


Figure 55. Tractor 4 in hill area. Risk index classes, frequency distribution.

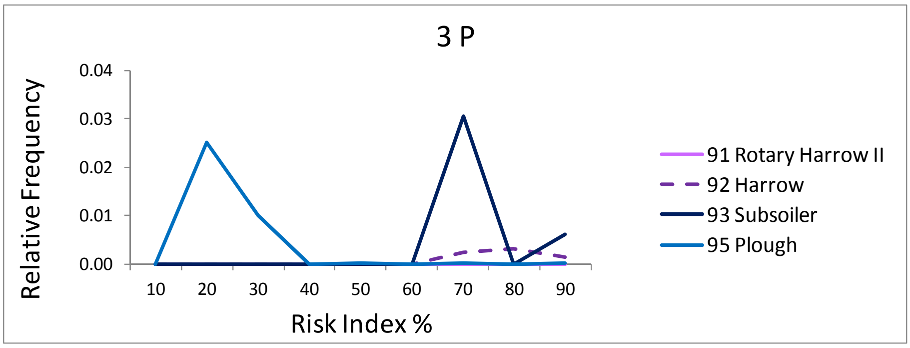


Figure 56. Tractor 3 in plain area. Risk index classes, frequency distribution.

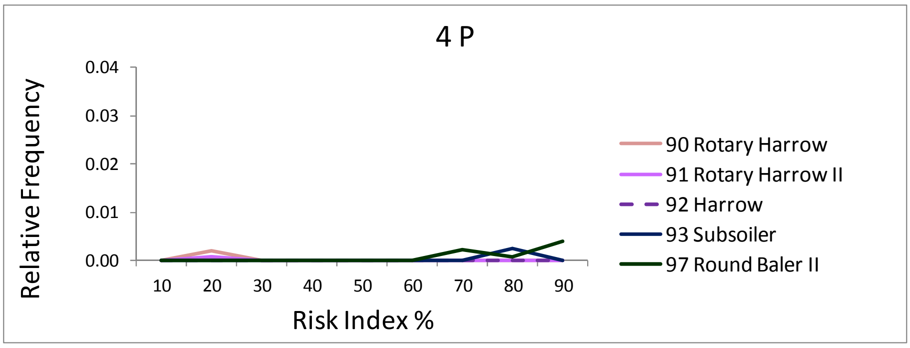


Figure 57. Tractor 4 in plain area. Risk index classes, frequency distribution.

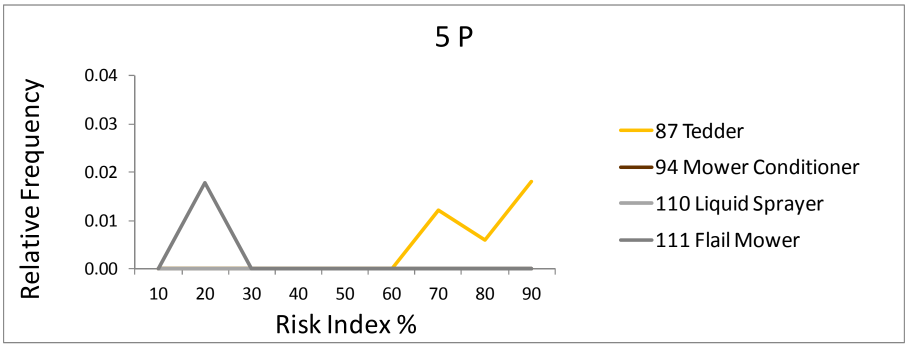


Figure 58. Tractor 5 in plain area. Risk index classes, frequency distribution.

4.4.6. ALARM SIGNALS

In Figures 59 to 72 there are diagrams of the values of the dynamic parameters in cases reported as dangerous by the system.

The horizontal axis shows the values of the roll angle, while on the vertical axis are the values of pitch angle in absolute values due to the nearly symmetrical position of the center of gravity of the tractor.

Two different groups of data are reported, the cases in which it is possible to recognize the type of operation and those in which this is not possible, defined as "undetermined", due to a implement-tractor coupling different from the planned ones or with the tractor not connected to any implement. Thus it’s possible to perform a greater number of comparisons.

The alarm cases symbols are completely colored when the value of the angular velocity of steering in absolute value is very high, exceeding 60 degrees/second, and internally empty when the values are lower, generally below 30 degrees/second. There is in fact a significant gap between these two different sets of data. In this way it is possible to identify immediately the cause that led to the alarm signal. Considering as an example the diagram in Figure 61 relative to the plow in the hills, one of those with a greater range of data, three different groups of data are visible. It is easy to identify the cause of the signal between roll angle, pitch angle and steering angle rate.

The diagrams of figures 59 to 65 refer to cases in which the risk index values were between 70% and 95 % corresponding to a red signal on the display of the sentinel system.

Among the signals due to roll angle the ones related to the roundbaler 89 are evident, figure 59, connected to the tractor 1 and 2 in a hilly area, this is consistent with the very high values of the roll angle in figure 49 (a) and 49 (c). When it is connected to tractor 1 the stability angle threshold is lower than in tractor 2 case. This is due to geometrical characteristics of the tractors. Tractor 2 is thus more stable.

The plough presents many high values in the figure 49 (e), but no signals of danger, while the tractor 3, the one that is connected to the plough, when it is disconnected presents danger signals even below 20 degrees of roll angle. It can be inferred that the plough is considered a stabilizer of tractor – implement system. In plain, plough presents the most extreme values for that altimetric area, but warning signals do not appear, as well as for rotary harrows that, despite reaching higher values than other machines, figure 49(b), presents values lower than the plough.

Signals for the rotary harrow may be expected due to roll angles values greater than liquid manure spreader, figure 49 (c), but their absence suggests, as in the case of the plough, that it is considered as a stabilizer for the implement – tractor system.

Round baler II presents signals due to roll angle higher than 15 degrees in the hills, in plain instead it does not reach these values, in fact there are not signals of danger.

The only signals due to excessive pitch angle of the tractor - implement system are in the case of the plough uphill, but there are not undeterminated cases, this may imply that the plough is seen as an aggravating factor. Indeed, the plow reaches high values, Figure 50 (e). The rotary mower, that instead has a maximum just over 20 degrees in the hills, has no warning signals and so the harrow.

The alarms due to steering angle rate have the same characteristic for all tractors and all implements: the steering angle rate higher, in absolute value, than 60 degrees/sec combined with forward speed exceeding 25 km/h. It can be assumed, therefore, that in these circumstances the tractor is in transfer phase rather than in working phase.

The high risk levels in figure 56 and 58 for subsoiler and tedder are due to steering angle rate.

The signals in which the risk index reaches 95%, and then the red circle appears on the display, coupled to the acoustic signal, are shown in figures 66 to 72.

It is evident that they are due almost exclusively to the angular velocity of the steering angle rate with the exception of tractor 1 that presents many cases due to roll angle especially "undeterminate " and some cases with round baler. It is also visible a case for the tractor 2 due to roll angle.

Even for these values it is noticeable as forward speed is always higher than 25 km/h combined with the steering angle rate higher, in these cases, than 64 degrees/second.

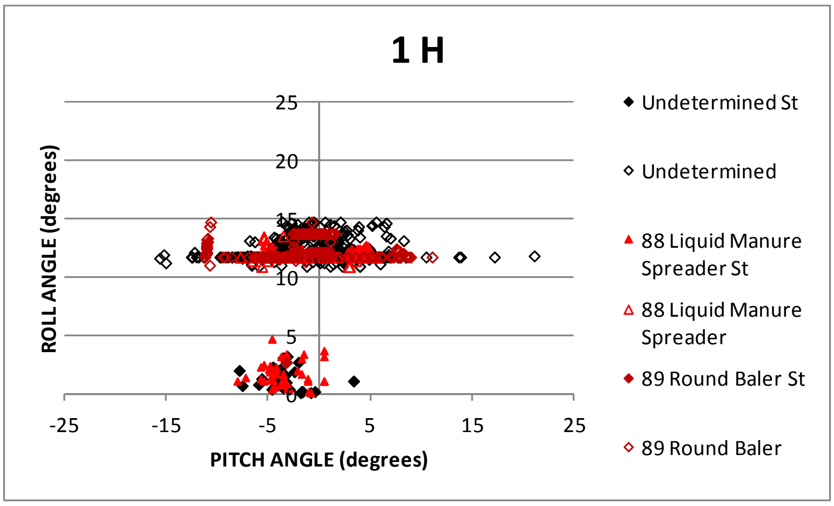


Figure 59. Values of main parameters for yellow warning cases. Tractor 1 in hill area.

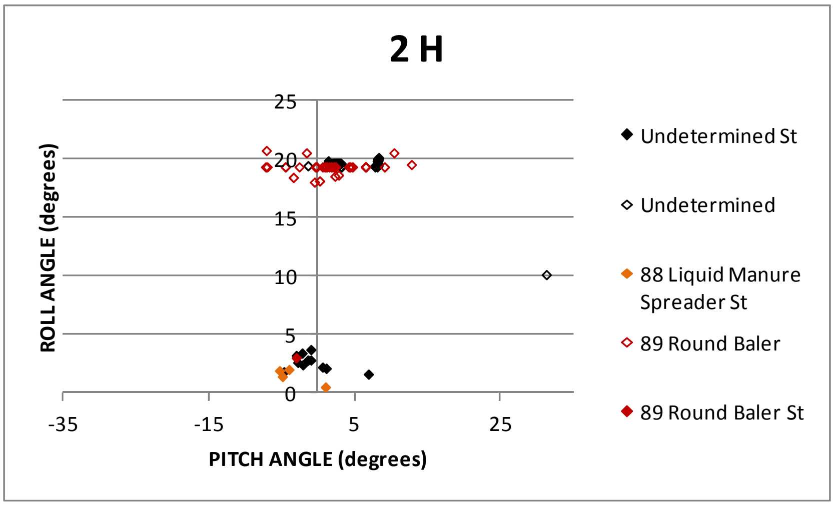


Figure 60. Values of main parameters for yellow warning cases. Tractor 2 in hill area.

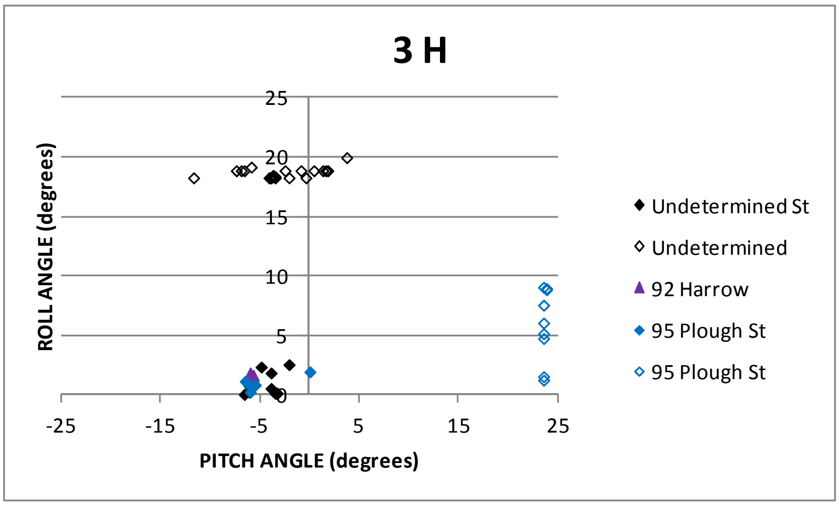


Figure 61. Values of main parameters for yellow warning cases. Tractor 3 in hill area.

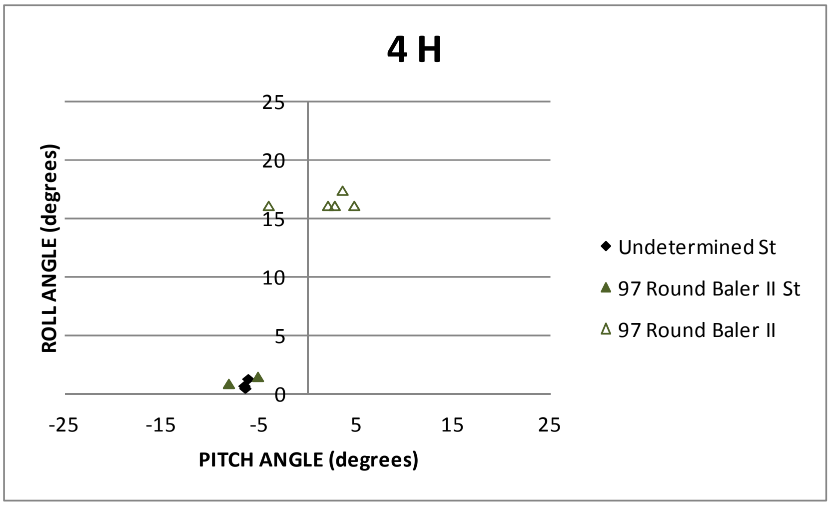


Figure 62. Values of main parameters for yellow warning cases. Tractor 4 in hill area.

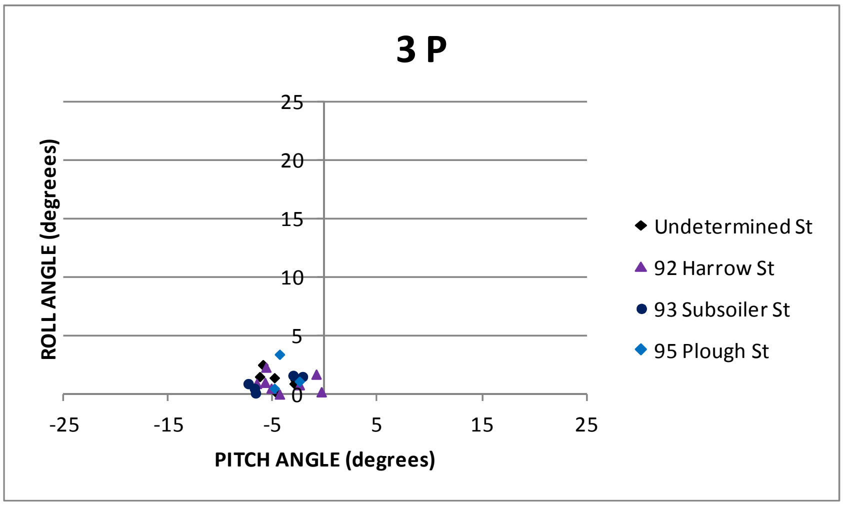


Figure 63. Values of main parameters for yellow warning cases. Tractor 3 in plain area.

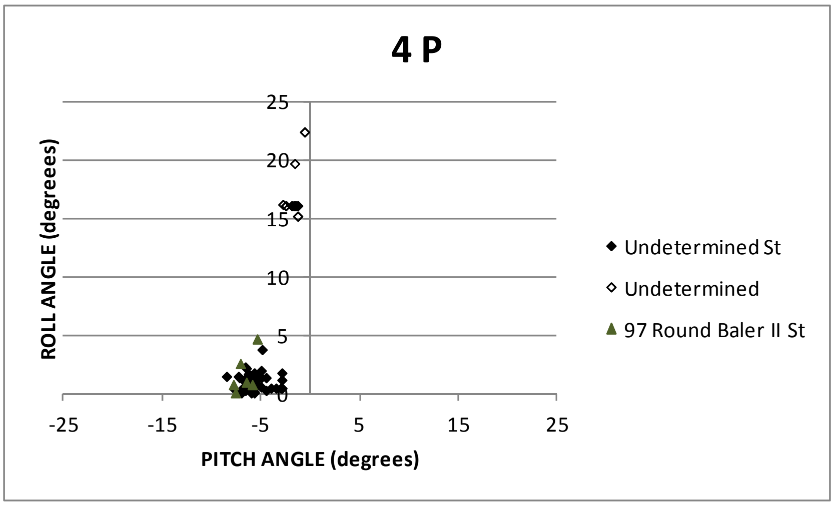


Figure 64. Values of main parameters for yellow warning cases. Tractor 4 in plain area.

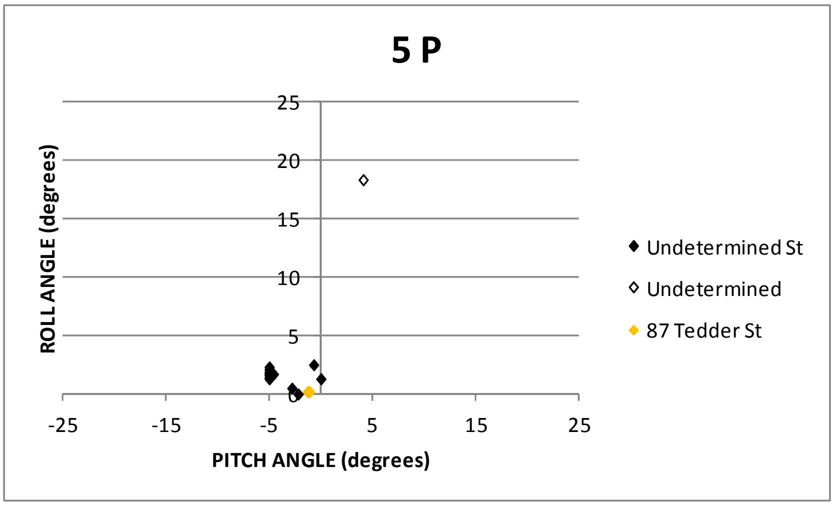


Figure 65. Values of main parameters for yellow warning cases. Tractor 5 in plain area.

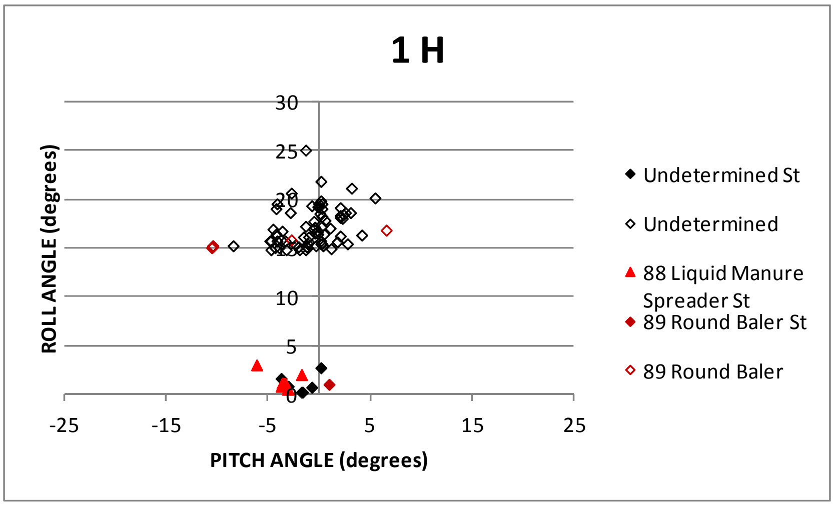


Figure 66. Values of main parameters for red warning cases. Tractor 1 in hill area.

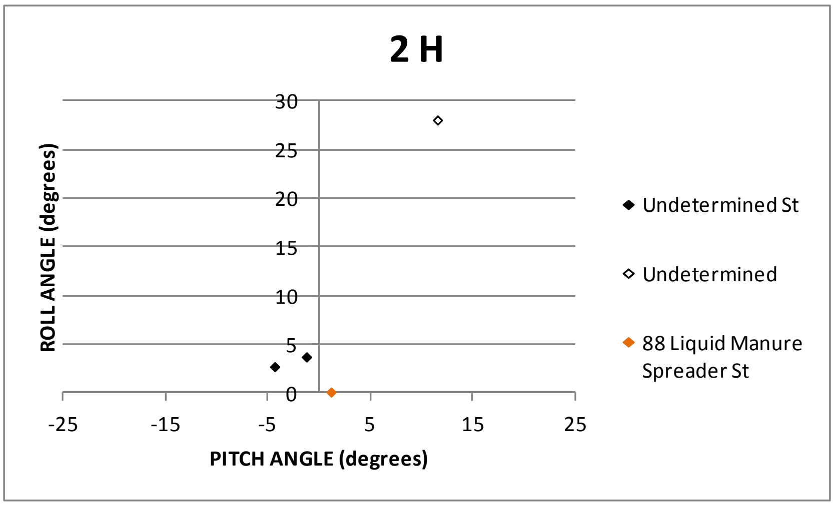


Figure 67. Values of main parameters for red warning cases. Tractor 2 in hill area.

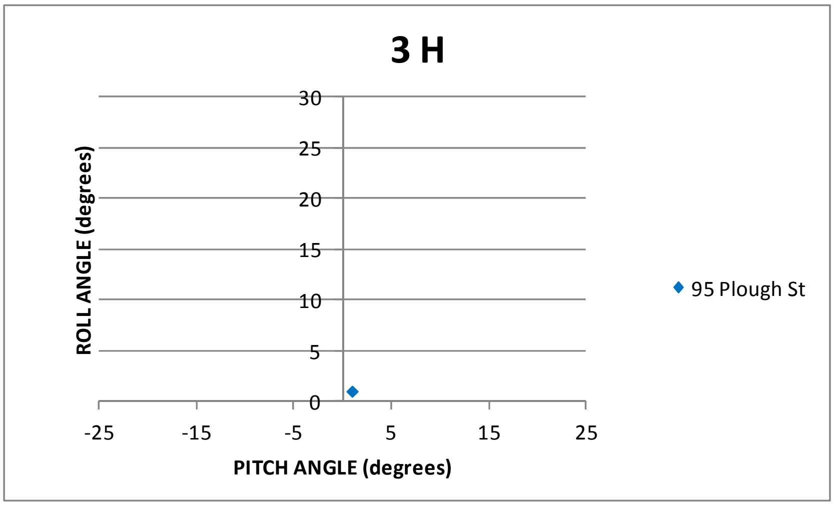


Figure 68. Values of main parameters for red warning cases. Tractor 3 in hill area.

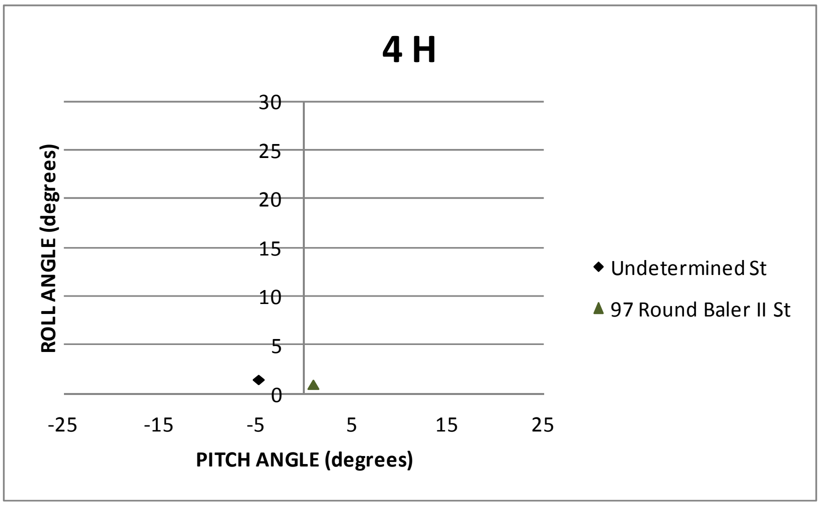


Figure 69. Values of main parameters for red warning cases. Tractor 4 in hill area.

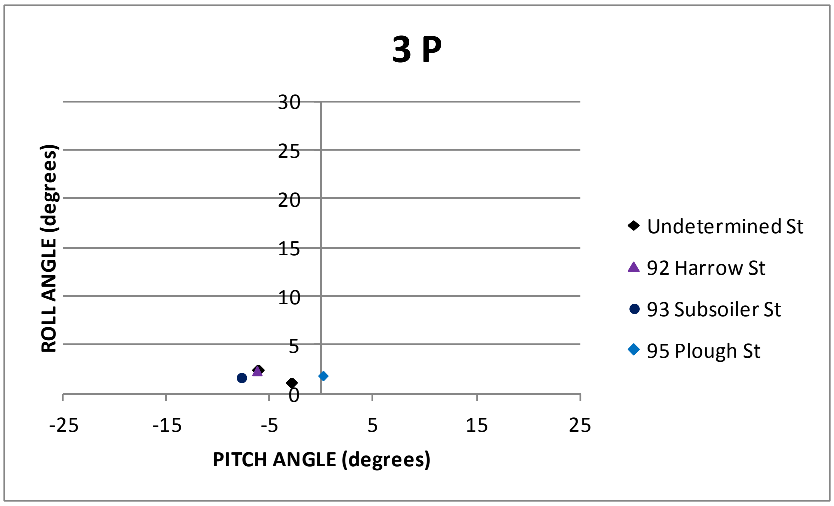


Figure 70. Values of main parameters for red warning cases. Tractor 3 in plain area.

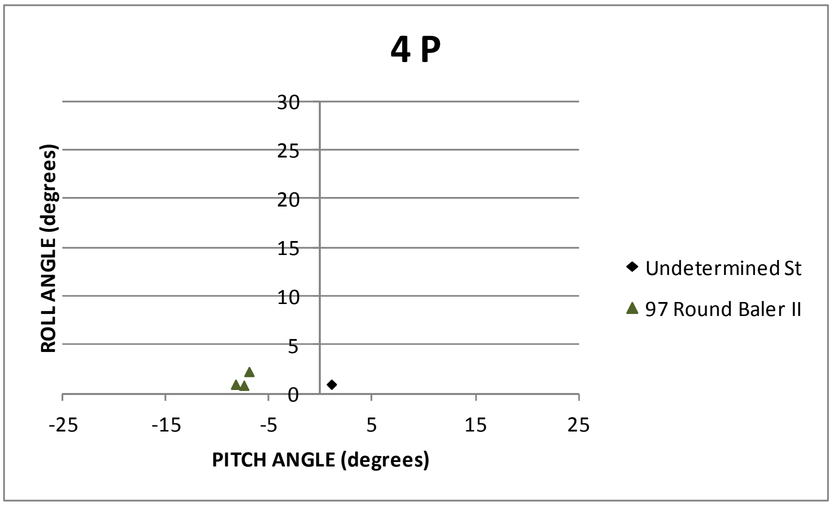


Figure 71. Values of main parameters for red warning cases. Tractor 4 in plain area.

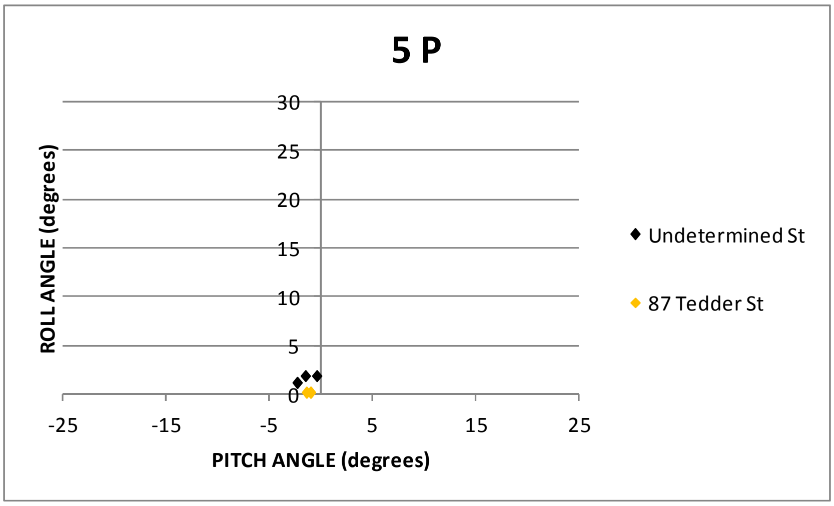


Figure 72. Values of main parameters for red warning cases. Tractor 5 in plain area.

5. CONCLUSIONS

The research studies on risk evaluation related to the use of tractors are becoming less focused on the use of controlled tests in field or in laboratory and more oriented towards the evaluation of the actual working conditions. The development of instruments for driver assistance and data acquisition is therefore increasing important, these applications were prototypes, but now they are becoming commercial devices thus making the evaluation of their performance and data recorded very important. This was the main goal of this research activity.

In order to assess the tractor rollover risks, investigating the current state of the art in tractor related accident was necessary. Therefore an evaluation of the data on work accidents in the archives available for consultation was carried out and it was noticed that the traditional work insurance sources of INAIL are now complemented by other institutions as observatories and this approach increased the available data, but caused also new problems arising from data crossing.

The assessment of the reliability of data related to the problem considered, showed that the numerical values from the different sources may have differences of one order of magnitude for the same information. It is, however, essential combining data from these so different sources. Therefore, to obtain a realistic result, it is necessary to introduce a correction factor that takes into account the problems due to the different systems of data collection of the organizations involved in the activity.

After becoming familiar with the level of reliability of the data a territorial assessment of the tractor related accidents situation was performed for the Emilia Romagna region. In was thus possible connecting the accidents rates to the characteristics of the land, farming, mechanization and employment. Areas have been distinguished in more or less active and more or less modern in the agricultural sector.

Also territorial maps were obtained that evaluated the territorial homogeneity using cluster analysis. In these maps the factors that could be relevant for the specific problem studied, accidents related to tractors, were taken into account, unlike other studies that were aimed at a more general study of accidents in agriculture.

In addition the evolution of the traction system of tractors was studied. It resulted that the four wheel market is growing to the detriment of wheeled tractors and especially of track laying tractors, particularly common in the mountains.

Finally using stepwise regression a predictive model to predict agricultural tractor accidents was developed, based on the characteristics of the territory. The model gave better results in the prediction of accidents in agriculture rather than in the more specific case of accidents related to tractors. This was due to the higher number of accidents in the generic case of agricultural activity which allowed greater accuracy. The number of tractor accidents suitable for the calculation was in fact quite small as it concerned the time period of three years. This suggests that the method is reliable if a greater number of data are availabe, as demonstrated by the good results obtained for the more general case.

In order to assess the level of rollover risk during the field work, a group of tractors operating at the experimental farm of the University of Bologna was monitored during two vegetative seasons using a commercial integrated information system that enables the recognition of tractors and implements through a dedicated website, and it includes a multisensor main unit to detect and record the values of the main dynamic parameters such as forward speed, roll and pitch angles and steering angle rate. It is equipped with a microprocessor that performs the calculation of a rollover risk index on the basis of these parameters and geometric characteristics of the tractor.

Preliminary tests were performed in order to assess the performance of the system in controlled operations.

All these data were downloaded and analyzed to obtain a database for the evaluation of the performance of the system and the data related to the work.

Among the monitored operations the results identified as the most dangerous activities were the ones involving the use of liquid manure spreader and round baler, often caused by high values of roll angle during the operation. In particular, there were high levels of risk index for the round baler when connected to two different tractors both working in hilly areas with steep slopes. In detail the rollover risks were more frequent with one tractor because of the geometric characteristics of the tractor.

Other operations such as those with plough and rotary harrow demonstrated that these implements probably were considered as stabilizers, so there were no warning signals despite the high values of roll angle achieved.

For implements as subsoiler and tedder high levels of risk were achieved associated to the high steering angle rate in tractor transfer phases. in fact, unfortunately, the algorithm of calculation of the risk index seems to consider the values of the steering angle rate as a potential dangerous factor only where the forward speed of the tractor is high.

The system performance could be considered as a compromise between security evaluation, and farm management, and this is potentially a good result as a combination of the two objectives.

However the assessment of the stability of the tractor was the main goal and the field results proved that the monitoring system was hardly suited to predict extraordinary cases, such as the most closely related to the possibility of the accidents. Indeed it is based on a quasi static evaluation of the stability conditions. On the contrary it showed to be suitable to correct dangerous working methods based on constant and ordinary conditions. Therefore it could represent a good tool to educate the unskilled tractor drivers.

Preliminary tests and the subsequent test period showed that the low cost tilt sensor, used in the main unit, provided results not suitable for activating self deployable ROPS, because it had no high performance in sudden changes. This could be due to the sensors or to the internal architecture of the main unit designed for a different purpose.

Finally the comparison between the warning signals displayed to the tractor driver and his personal perception of risk demonstrated that the device probably to overestimates the risk. It has to be pointed out that the operators involved in the tests were skilled employees. Probably the risk perception of casual workers, beginners or anyway inexperienced operators could be less predictive with respect to the actual rollover risk.

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