

DESIGN FOR SAFETY IN AGRICULTURAL MACHINERY

M. Fagnoli, V. Laurendi and M. Tronci

Keywords: design for safety, occupational safety, machine directive, risk assessment, agricultural tractors

1. Introduction

The field of machine safety has recently received new issues by the introduction of the directive 2006/42/CE in EU Countries, which has just come into force. The impact of this novelty is quite significant for companies, both users and producers, because of the new Essential Health and Safety Requirements (EHSR) required by the directive, as well as by the extension of its scope. In such a context, the research work presented in this paper is focused on the field of machines for agriculture, and in particular tractors, which partially fall under the scope of the new directive, in spite of the presence of a proper directive (the so called "Tractor Directive" 2003/37/EC). The study concerned the analysis of the relationship between these two directives in order to bring to light the aspects which must be investigated by using the new Machine Directive approach. Starting from this, a procedure for Risk Assessment was developed with the aim of supporting tractors' designers and producers in being in compliance with the new regulations. The proposed approach was developed throughout its application to an agricultural and forestry narrow-track tractor.

2. Safety in Agricultural Machinery

Even though there is a growing awareness of the importance of safety in the agriculture sector, difficulties related with the implementation of safety measures are numerous, in particular for small and medium sized companies, which are usually not able to bear additional costs for supporting experts' help. This is particularly true at an operative level, i.e. concerning the management of basic working activities. Lack of information concerning safety instructions of different working tasks and the use of PPEs (Personal Protection Equipments), difficulty in keeping the company in compliance with up-to-date laws and regulations, as well as hindrances in carrying out the regular maintenance of equipment and safety devices (which are often very old and obsolete), are quite common in the sector [Schenker and Orenstein 2002], as also underlined by the latest reports of EU-OHSA (European Agency for Safety and Health at Work). In order to point out the main aspects of the situation, as the basis for the implementation of the research approach, the study was focused on the analysis of: accidents which occurred recently in the sector, laws and regulations in the field of safety, and the latest addresses aimed at improving the safety of agricultural machinery.

2.1 Accidents Statistics

In recent years the occurrence of occupational accidents in the sector of agriculture has reached a significant relevance in Italy both considering its absolute value, and taking into account accidents which have occurred in agricultural activities compared to sectors of other activities. As a matter of fact, in accordance with data published by INAIL (Italian Workers' Compensation Authority), the

number of accidents in the period 2005-2007 has reached the average number of more than 62.000 workers injured per year, and 120 fatalities per year. Official statistics also show that the agriculture sector is the one where the least improvement in terms of accidents reduction has been obtained recently: in Table 1 the comparison of accidents which occurred per 1000 employees (frequency index) in agriculture and industry sectors is shown. Analyzing these data from the “material agent” point of view, it emerged that the most dangerous sub-sector in agriculture (e.g. considering the number of permanent injuries and fatalities which occurred) is that related to the machines, and in particular the use of tractors, which turned out to be the most dangerous activity. In order to obtain a more complete overview of this phenomenon, other sources were also investigated.

Table 1. Accidents which occurred in agriculture in 2007-2008 in Italy

| Injuries | | | | |
|-----------------------------------|-------------|-------------|-------------|-------------|
| Sector | 2005 | 2006 | 2007 | 2008 |
| Agriculture | 70,2 | 64,2 | 61,9 | 59,5 |
| difference with previous year (%) | 0,3 | -8,5 | -3,6 | -3,9 |
| Industry | 60,8 | 59,7 | 57,1 | 52,8 |
| difference with previous year (%) | -6,5 | -1,8 | -4,4 | -7,5 |
| Fatalities | | | | |
| Sector | 2005 | 2006 | 2007 | 2008 |
| Agriculture | 0,149 | 0,126 | 0,114 | 0,135 |
| difference with previous year (%) | -15,8 | -15,4 | -9,5 | +18,4 |
| Industry | 0,089 | 0,098 | 0,087 | 0,08 |
| difference with previous year (%) | -9,2 | +10,1 | -11,2 | -8 |

Statistics provided by the information system of ISPESL (National Institute for Occupational Safety and Prevention), according to which in 2008 accidents related to the use of tractors were 169 (of these, 153 accidents were due to the turnover of tractors and 114 people died). Data provided by ASAPS (Association for Traffic Safety, connected with Italian Traffic Policy Department) on accidents which occurred on the road involving tractors: only in the period May-August 2009 the number of accidents was 134, with 94 fatalities, 67 of which concerning tractor drivers and 4 tractor passengers (in comparison, accidents which occurred on the Italian highway in the same period, i.e. involving cars and trucks, caused 67 deaths). The main reasons of such a situation can be found in the following aspects. The number of old tractors still used is very large: of 1,6 million tractors used in Italy, at least a third is older than 20 years old. This aspect is very significant because of technical and safety reasons:

- Technical obsolescence of tractors, i.e. the age limit over which the machine starts losing its technical efficiency and functionality is estimated in 15 years.
- The development of standards and regulations for tractors safety requirements in recent years guarantees a much higher level of safety for new machines, compared with the old ones.

At the same time, also the type of tractor users influences the frequent occurrence of accidents:

- Most companies involved in agricultural and forestry activities are small or very small enterprises: investments aimed at improving safety level of activities in accordance with current regulations and laws often represent a big issue for them.
- The lack of knowledge and expertise in both risk assessment and safety management is significant due to the large number of elderly operators or foreigners, who have rarely received professional training for the activities they are asked to perform.

2.2 Laws and standards evolution

Another aspect which influences the phenomenon illustrated above is related to the management of regulations and laws about tractors. Actually, they are under the scope of the so-called “Tractor Directive”, the OECD codes, the occupational safety laws and the Machine Directive. Moreover, all of

them have been updated recently, or they are going to replace older versions by the end of 2009, as summarized in Table 2.

Table 2. Regulations concerning tractors and recent updates

| Law | Schedule | Requisites |
|---|---|---|
| Tractor Directive (Directive 2003/37/EC) | July 1 st , 2009 | EC type-approval for all new vehicles belonging to categories T1, T2 and T3 is requested, ("EC type-approval" is the procedure whereby a type of vehicle is certified as having satisfied relevant technical requirements of the Tractor Directive). |
| New Machine Directive (Directive 2006/42/EC) | The provisions of the new Directive become applicable on 29th December 2009 | Agricultural and forestry tractors fall in the scope of the directive for the risks not covered by Directive 2003/37/EC; machinery mounted on these vehicles fall in the scope of the directive with no exceptions. |
| Occupational Health and Safety | Issued in April 2008 and updated in August 2009 | National Law concerning occupational health and safety requirements (D.Lgs. 81/2008) takes into account also maintenance of working equipment; recently updated by Directive 2009/104/EC concerning the minimum safety and health requirements for the use of work equipment by workers at work |
| OECD Standard Code 6 | Updated in February 2009 | Testing of front-mounted protective structures on narrow-track wheeled agricultural and forestry tractors |
| <p><u>Notes:</u></p> <p>"Tractor" is defined as any motorised, wheeled or tracked agricultural or forestry tractor having at least two axles, the main function of which lies in its tractive power and which has been especially designed to pull, push, carry and actuate certain interchangeable equipment designed to perform agricultural or forestry work, or to tow agricultural or forestry trailers (Art. 2, (j) - Directive 2003/37/EC).</p> <p>Categories T1, T2 and T3 are defined in Annex II of Directive 2003/37/EC.</p> | | |

Without going into details of these laws and regulations, we have to underline that the new machine directive indeed represents a significant novelty for tractors' manufacturers. In fact, until the process of updating the Tractors Directive is completed taking into account all risks related to tractors, the Machine Directive must be considered valid, and thus manufacturers are asked to:

- Assess the conformity of the tractor with the Essential Health and Safety Requirements of Annex I of the Machinery Directive that deal with the risks concerned.
- Affix the CE-mark to the tractor and establish an EC Declaration of conformity with these requirements.

Finally, it has to be noted that an additional aspect, which might generate confusion, is the fact that in Italy laws and regulations concerning the safety of tractors are managed by four different public bodies (Ministry of Industry, Ministry of Transportation, Ministry of Agriculture and ISPEL, which belongs to Ministry of Health). The coordination of activities is sometimes difficult because of the number of different departments involved in issuing national regulations.

2.3 Safety Approaches

As seen from the analysis carried out in collaboration with ISPEL, the number of companies operating in agricultural and forestry sector not complying with law requisites is still large. One of the most important reasons of the lack of safety is the difficulty in implementing safety requirements in accordance with compulsory regulations in the field, especially in small and medium sized enterprises (SMEs). This is due to the specific typology of working activities, which characterize this sector, quite different from the manufacturing ones. The main aspects that make the management of safety issues in agricultural activities difficult are the following:

- The large variety of activities usually carried out by companies operating in this sector;
- The frequent exchange of tasks among workers within the same company or the frequent exchange of workers for the same activity (e.g. seasonal workers).

- The great variety of work environments, which is not easy to foresee in advance, when risk assessment is carried out (e.g. different grounds, different atmospheric conditions, etc.).
- Workers' stress caused by seasonal jobs (in some situations workers have to work continuously for a period of time which is longer than an usual shift, and this might cause stress, fatigue, tiredness, etc.).

In such a situation, even a correct application of safety requirements by company's managers might result in being less effective: spreading information concerning risk prevention and providing right procedures, which should be followed with the aim of reducing the occurrence of accidents, is certainly more difficult than in traditional industry sectors.

At the same time, we have to note that in scientific literature there are a few studies concerning specific issues in the field of risk assessment of tractors. Most research works regard:

- Particular solutions related to technical aspects, such as ROPS (Roll Over Protection Structure)/FOPS (Falling Object Protection Structure) implementation, vibration control, robotics, etc., e.g. in [Mangado et. al. 2007, Mayers et. al. 2009].
- The use of pesticides and other substances for agriculture, mainly from the point of view of environmental impact.
- Professional diseases, from a medical point of view.

In the ambit of machine safety and occupational safety, many Design Tools have been proposed, characterized by different ways of use, complexity, effectiveness and efficiency, and mostly oriented to solve only specific problems. Nevertheless, the evolution of market requirements in the last years has deeply transformed the designer way of thinking and operating, obliging designers to consider a great number of parameters and constraints. The lack of an overall approach aimed at supporting companies in correctly assessing risks and able to provide prevention and protection measures is felt. The goal of the present research work is to provide a solution to such a problem, throughout the development of a risk assessment procedure of a general nature, which can be applied in different work situations, overcoming the complexity of regulations in the sector.

3. Research approach

The issue of the new Machine Directive represents an important improvement for Hazard Analysis (HA) activities: manufacturers have to design the machine systematically assessing all risks which can occur during activities which are performed throughout the whole machine's life cycle and sufficiently minimizing them. In Annex I a clearer concept of risk assessment is proposed, introducing the procedure for risk assessment and risk reduction, which is stated in section 5.1.3 of the standard ISO 12100-1:2003 (considering also the indications of a general nature proposed by the standard ISO14121-1:2007 and the guide ISO/IEC Guide 73:2002). In particular, the approach proposed for risk management by these standards can be summarized as shown in Figure 1. As a matter of fact, even the introduction of the mandatory requirement of taking into account any reasonably foreseeable misuse of the machine is a significant novelty, especially for machines, such as agriculture equipments, whose use conditions are very changeable. For this reason a checklist for verifying the conformity of the tractor with safety laws' requirements was developed, considering the above mentioned laws, as well as other specific directives (e.g. Directive 86/297/ECC concerning the power take-offs of wheeled tractors and their protection) and standards (e.g. EN 982:1996 + A1:2008, concerning safety requirements for fluid power systems and their components) which manufacturers must be in compliance with. An excerpt of such a conformity checklist is shown in Figure 2. It has to be underlined that if there is no specific directive concerning the hazard treatment, standards' requirements were proposed, even if they are not mandatory. In order to perform a correct risk assessment activity, both in the case of the design of a new machine, and the control of the conformity of the machine to Essential Health and Safety Requirements (EHSRs), traditional methods of HA [Pighini et al. 2001, Wang and Ruxton 1997, Clifton 2005] have to be taken into account, introducing them within the procedure stated by standards ISO 12100-1:2003 (concerning general principles for design for machine safety). With this aim in mind, the following tools were considered:

- Preliminary Hazard Analysis (PHA) [Clifton, 2005].

- Fish Bone Diagram (Cause-Effect Diagram) [Clifton, 2005].
- ISSA (International Social Security Association) Technique for the assessment of accident risk [ISSA, 2000].

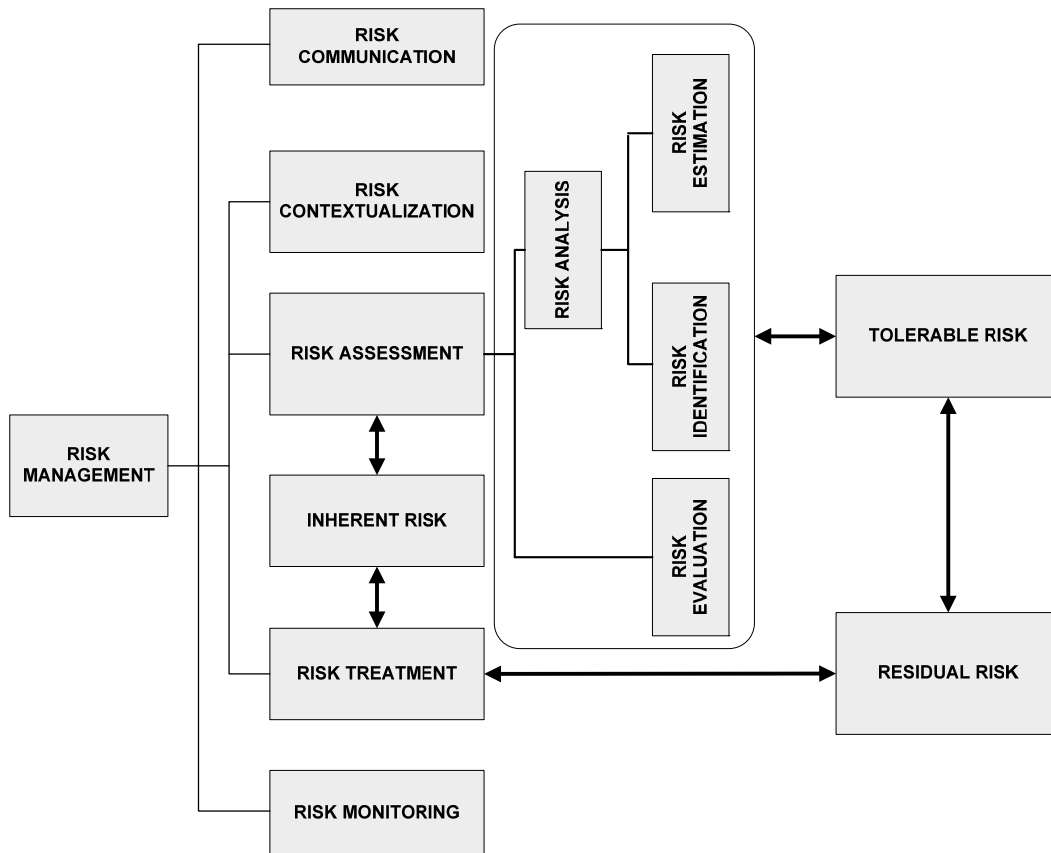


Figure 1. Risk management flow (adapted from ISO/IEC Guide 73:2002)

| Tractor's Use Limits | Hazards | Law Requisites | Safety Measures |
|---|---|---|--|
| Tractor connection with operative machine | Snag, Shock, Abrasion | Directive 86/297/EC | Safeguard of the connection system, User information, etc. |
| | Hydraulic circuit | EN 982:1996* | Design of circuit, Excess-pressure valve, User information, etc. |
| Tractor working on ground (reasonable foreseeable misuse) | Roll-over because the ROPS was removed/put down in order to work under trees) | Directive 2006/42/EC (annex I, 1.1.2, C) OECD Code 7 | Safebelt, ROPS redesign, cabin |

Figure 2. Safety Law Conformity Checklist (excerpt)

In other words, starting from the general framework proposed by the standard 12100-1:2003, the research work was focused on tailoring each phase of the risk assessment process for their application in the field of tractors (the overall procedure is schematized in Figure 3), providing:

- Accurate instructions on the coordinated use of Hazard Analysis and Risk Assessment tools.
- Specific tools for risk analysis and assessment (i.e. the SLC Checklist), as well as a database containing the most common solutions for risk reduction in the use of tractors.

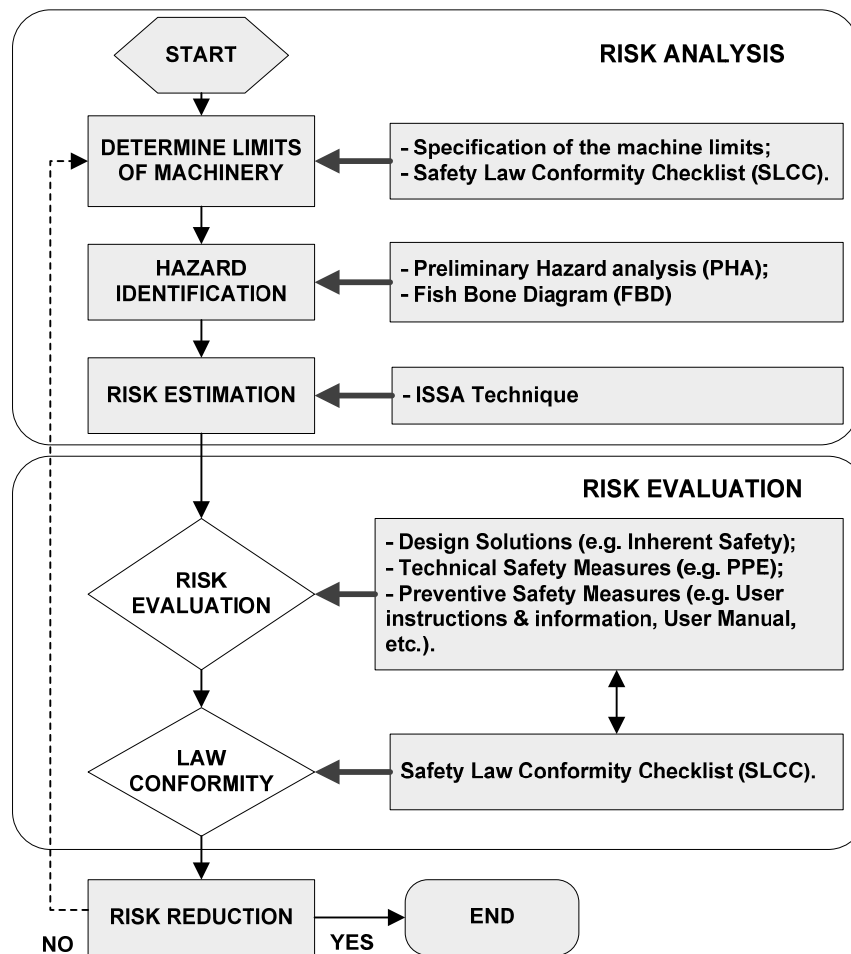


Figure 3. Risk Assessment procedure

4. Case study

In order to validate the effectiveness of the procedure developed, it was applied to the risk assessment of a tractor, which is today on the market. The tractor's type examined in the study is a narrow-track wheeled tractor, belonging to the T2 category of Directive 2003/37/EC and it is used both in agricultural and forestry activities, especially in the case of work in orchards, vineyards, greenhouses where the operative space is limited [Molari and Rondelli 2004]. In Figure 4 a scheme of this type of tractor is shown.

4.1 Determine limits of the tractor

In this phase of risk assessment, the limits of the tractor were analyzed: space limits, time limits and use limits were investigated. In particular, the following aspects were taken into account:

- Access to the seat (clearance zone);
- Connection with equipment throughout the Cardan joint;
- Use in the field (both regular operations, and reasonable foreseeable misuse);
- Use of the tractor as a power supply unit (e.g. supplying power for irrigation).

This analysis was carried out also considering law requisites using the SLC Checklist: in this case, apart from the above mentioned directives, the 86/298/EC and 87/402/EC directives were considered, as well as the OECD 6 and OECD 7 Codes.

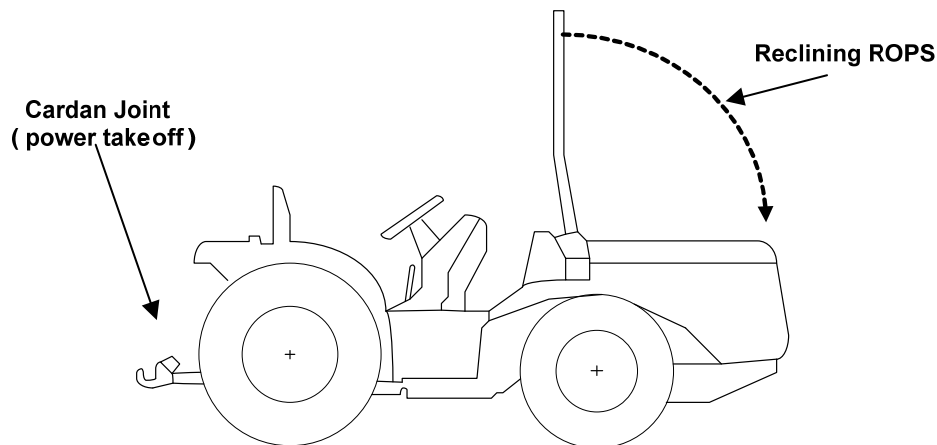


Figure 4. Scheme of a narrow-track tractor

In Figure 5 an example of minimum dimensions of the user seat are shown (OECD Code 6 - Testing of front-mounted protective structures on narrow-track wheeled agricultural and forestry tractors).

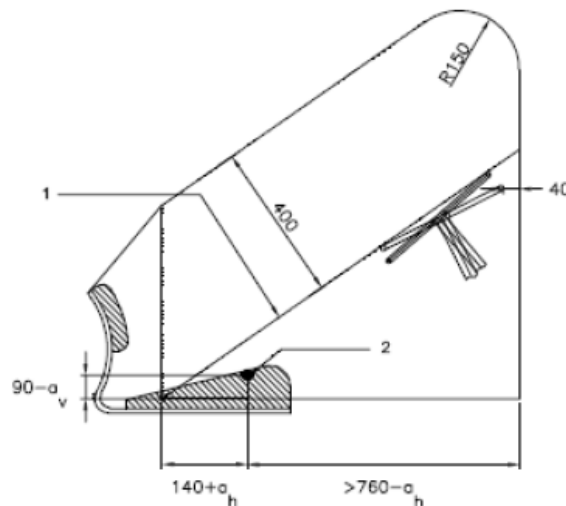


Figure 5. Minimum dimensions of user seat (source: OECD Code 6)

4.2 Hazard identification

The following step concerned the application of the Preliminary Hazard Analysis, in combination with the Fish Bone Diagram, in order to investigate main hazards and their causes. Considering a rating scale from 1 (less significant) to 5 (most significant) both for Probability and Severity of risks, the analysis was carried out considering data from the information service of ISPESL regarding the last three year period. The results obtained brought to light that the most relevant risks are:

- Turn-over/roll-over of the tractor.
- Power take-off (PTO) entanglement.
- Use of the tractor while driver is not on board.

These three main risks were further analyzed by using the Cause-Effect Diagram, in order to point out most common causes and their relationships: in Figure 6 an excerpt concerning the roll-over/turn-over risk is shown.

4.3 Risk estimation

The estimation of risks was quite difficult because of the different types of work in which the tractor can be involved, such as work in orchards, vineyards, nurseries, greenhouses, etc., as far as agricultural activities are concerned [Yadav and Tewari 1998]. Then forestry work must also be taken into account.

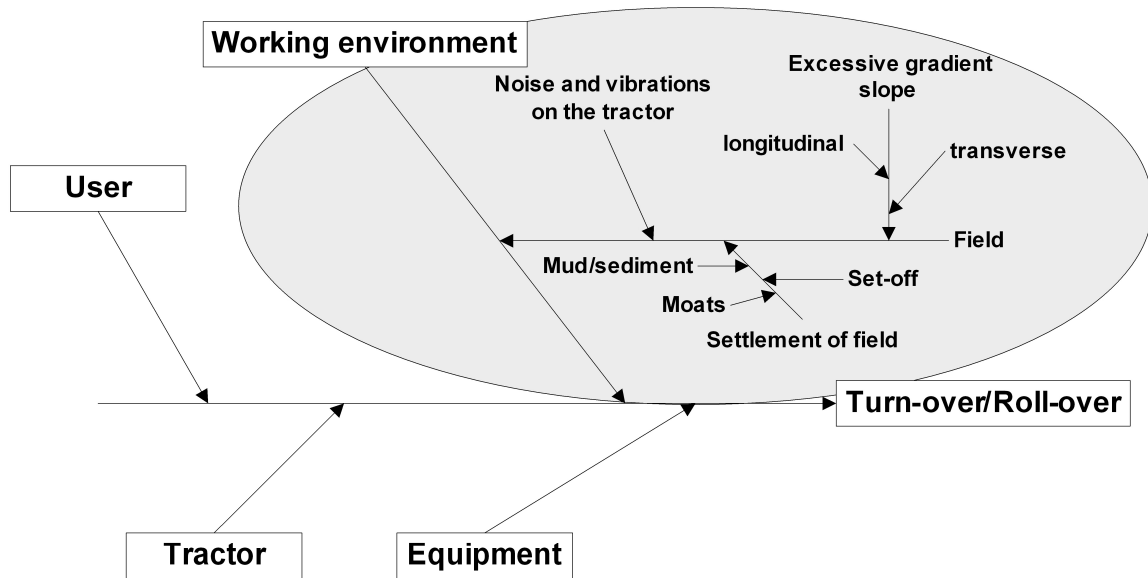


Figure 6. Excerpt of the Cause-Effect Diagram concerning the roll-over/turn-over risk

The analysis was carried out using the ISSA Technique, investigating the following risks: turn-over/roll-over of the tractor, and the power take-off and its attachments. The ISSA Technique allowed us to consider different working situations depending on:

- Working environments (excessive slope, plain field with mud, plain field with grass).
- Settings of the tractor (different positions of ROPS, presence of FOPS, different seat-belts).
- Operator skills (experienced, non experienced, trained).
- Equipment of the tractor (presence of operative machine connected, different types of the Cardan joint system).

More in details, the goal of the method is to calculate the risk of accident (R_a), which is the result of the formula shown in the equation (1), where R_G is the global risk, W represents the skills of operator in managing the risk:

$$R_A = R_G - W \times \frac{Mat}{30} \quad (1)$$

R_G is related to material (Mat) and environment (Env) risks, which are evaluated taking into account respectively the magnitude of the event (Ev), the frequency of exposition to machine's risks (F), the probability of occurrence of risks related to "materials" (P_o), and the probability of avoiding or reducing injuries (Pa) as for Mat ; instead Env is calculated by summarizing the influence of: the working place location (Q_w), the working environment Q_E , and the possible stress due to the workplace Q_S . Equations concerning these parameters are shown in the following formulas:

$$R_G = Mat \times Env \quad Mat = Ev \times F \times P_o \times P_a \quad Env = Q_w + Q_E + Q_M \quad (2)$$

Finally, the operator skills are estimated taking into account the parameters shown in equation (3):

$$W = Q + \varphi + O \quad (3)$$

where Q represents the qualification degree of the operator, φ concerns physiological aspects, and O takes into consideration the organization of working activities. The combination of the working situations used in the analysis is summarized in Table 3: for each combination of these aspects the level of risk of accident R_G was estimated.

Table 3. Working situation analyzed

| Risk | User | Settings | Equipment | Environment |
|-----------------------|---------------------------------------|--|-----------------------------------|---|
| Turn-over/Roll-over | Experienced, Non experienced, trained | Correct use of ROPS, ROPS and FOPS, misuse of ROPS | operative equipment, no equipment | Excessive slope, plain field with mud, plain field with grass |
| Power take-off system | Experienced, Non experienced | Cardan joint with no protection, safeguard | operative equipment, no eq. | Plain field with mud, plain field with grass |

4.4 Risk evaluation

On the basis of the results obtained in the previous stage, the risk evaluation was carried out with the aim of providing safety measures for the reduction of risk level to tolerable values. For these reasons, the compliance with laws and standards was taken into account. In particular, three different types of safety measures were developed in accordance with the procedure shown in Figure 3.

4.4.1 Protection Measures

Regarding the three risks analyzed, technical safety measures for the user protection concern mainly the use of Personal Protection Equipment (such as gloves, helmet, mask, etc.).

4.4.2 Preventive Measures

Preventive measures can be carried out providing a proper instruction to the tractor user, as well as developing accurate instructions concerning the tractor use in different situations. Additional information can be provided using signals and pictographs on the machine. Maintenance operations also have to be taken into account, focusing the attention on the seat-belt status, on the relief valve of the hydraulic circuit, on the cabin windows (if present), and on the ROPS connection system.

4.4.3 Inherent solutions

Most significant safety measures can be implemented at the design level, because inherent solutions avoid or reduce the misuse of the machine, as well as when operators neglect instructions. Regarding the risk of roll-over/turn-over the use of a proper ROPS is fundamental: in this case, the new EHSRs require stricter measures than the ones from the tractor directive and OECD Codes, extending the use of ROPS to a larger number of tractors. The position of ROPS (front or rear side, behind the driver) and the possibility of declining it was analyzed. Different technical solutions also should be implemented in order to modify the clearance space for the tractor driver (e.g. shifting down the seat and modifying the space and the angle of the driving wheel). Some design solutions were pointed out for the joint system too: embedding a safeguard/protection case for the Cardan joint resulted in being the safest solution. Another relevant aspect concerned the use of the tractor while the operator is not on board: such a misuse is quite frequent in special agricultural work (e.g. in vineyards or when the tractor is carrying operative equipment which needs to be regulated while working). Such a situation caused 11 fatalities in 2009 and numerous accidents. Today most tractors do not have a safety device for avoiding such a risk because it is not required by regulations, but the new Machine Directive oblige manufacturers to take into account such a situation.

5. Discussion of Results and Conclusion

The impact of the new machine directive is quite relevant in the field of agricultural and forestry machinery: manufacturers and users are obliged to take into account numerous risks which have been disregarded so far. The procedure developed for the risk assessment resulted in being rather effective for the analysis of these types of machines, allowing us to investigate in details the occurrence of most the significant risks. Moreover, the checklist for assessing the conformity of the tractor with safety laws and standards (e.g. the SLC Checklist) resulted in being a very useful tool, which can be used both by manufacturers in design activities, and by users in the development of the company's documents concerning risk assessment. The study is the first output of a collaboration between the

Ministry of Agriculture, ISPESL, and the University of Rome “La Sapienza”, and is aimed at providing a general framework concerning safety requirements of agricultural tractors for both users and manufacturers. At the same time, the procedure is addressed to public officers, who are in charge of carrying out the risk assessment during official inspections and controls. All these aspects are summarized in Table 4.

Table 4. Possible beneficiaries of the developed procedure

| Beneficiaries | Activities |
|----------------------|--|
| Manufacturers | Updating new tractors before putting them on the market |
| Suppliers | Providing correct safety information to purchasers, in particular in case of second-hand tractors and/or modified tractors |
| Users | Providing correct risk assessment records, in particular in case of already existing tractors |
| Public Officers | Performing risk assessment during control and market surveillance activities |

The theoretical basis of the research work carried out belongs to well known topics of the machine safety field. Nevertheless, these issues are not very widespread in the ambit of agricultural machinery, probably because of the extreme fragmentation of stakeholders involved in the sector. Tools developed in the present research work are aimed at making it easier to understand the interwoven requisites of regulations and standards, and how they should be correctly applied. Above all, they proved to be of great help in putting these requisites in practice. Needless to say, further developments are needed because of the complexity of the problem. Preliminary results are of a general nature, and can be improved using additional tools of Hazard Analysis, such as the FMEA method, with the aim of examining the problem more closely. Another aspect, which will be the object of a future improvement of the procedure, concerns the use of tools for taking into account the human factor, since the occurrence of most risks related to the use of the tractor assumed a high level of probability because of the incorrect behaviour of users.

References

- Clifton, A.E.II, “Hazard Analysis Techniques for System Safety”, John Wiley & Sons, 2005.
- ISSA (International Social Security Association), “Assess your accident risk yourself! Risk evaluation at workplace”, Brochure of the International Section Machine and System Safety, Mannheim, 2000.
- Mangado, J., et. al., “Design Calculations on Roll-over Protective Structures for Agricultural Tractors”, *Journal of Biosystems Engineering*, Vol. 96 (2), 2007, pp. 181–191.
- Molari, G., Rondelli, V., “On the Definition of Narrow-track Wheeled Agricultural Tractors”, *Journal of Biosystems Engineering*, Vol. 88 (1), 2004, pp. 75–80.
- Myers, M. L., Cole, H.P., Westneat, C., “Injury severity related to overturn characteristics of tractors”, *Journal of Safety Research*, Vol. 40, 2009, pp. 165–170.
- ISO 12100-1:2003, “Safety of machinery -- Basic concepts, general principles for design -- Part 1: Basic terminology, methodology”, 2003.
- Pighini, U., Fagnoli, M., Geraci, D., “A Design Procedure for the Safety of Mechanical Systems” - 13th International Conference on Engineering Design, Proceedings of ICED 01, Glasgow, 2001, vol. 28, pp. 11-18.
- Schenker, M.B., Orenstein, M.R. “Use of protective equipment among California farmers”, *American Journal of Industrial Medicine*, Volume 42 Issue 5, 2002, Pages 455 – 464.
- Wang, J., Ruxton, T., “A review of Safety analysis methods applied to the design process”, *Journal of Engineering Design*, Vol.8, No.2, 1997.
- Yadav, R., Tewari, V.K., “Tractor operator workplace design—a review”, *Journal of Terramechanics*, Vol. 35, 1998, pp. 41–53.

Ing. Mario Fagnoli, PhD
 Technical Director
 Ministry of Agriculture, Department of Rural Development, SVIRIS I
 via XX Settembre 20, I-00187, Rome, Italy
 Telephone : +39 06 4665 5052
 Telefax: +39 06 4881 707
 Email: m.fagnoli@politicheagricole.gov.it