Retrofitting Agricultural Tractors with Aftermarket Weather Cabins: Safety Issues for Manufacturers and Users

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Abstract

Despite the effort of governments in promoting stricter safety requirements to reduce the number of accidents among farmers, agriculture still represents a very hazardous sector worldwide. In particular, the increasing importance of safety in the agriculture activities has been characterizing this sector both from the equipment manufacturers' and from users' point of view, since the use of tractors is recognized as the main cause of fatalities. In fact, tractor overturn associated with the absence or the improper use of the rollover protective structure (ROPS) represents the prevalent cause of this phenomenon. In this study we focused our attention on the use of aftermarket weather cabins and their interferential relationship with the tractor's protective structure. Actually, although the use of weather cabins temporarily installed on tractors for specific needs is very common among farmers, there is a lack of a normative framework that can provide safety requirements for both users and cabin manufacturers. In detail, taking the cue from the issues emerged in a specific working group led by the National Institute for Insurance against Accidents at Work in Italy, the manuscript analyzes the hazardous situations that might arise when using weather cabins, discussing the safety measures aimed at guaranteeing a correct safety assessment.

Keywords
Occupational Health and Safety (OHS); Machinery Safety; Work Equipment; Safety Assessment; Agricultural Tractors; Weather cabins.

1. Introduction

Agriculture is considered a hazardous sector worldwide (Caffaro et al. 2017a; Fargnoli et al. 2019a, Ivascu and Cioca 2019) and in such a context the use of tractors is deemed to be the source of the majority of fatal and severe accidents occurred (Caffaro et al. 2017b; Kogler et al. 2016). In particular, tractor overturn associated with the absence of the rollover protective structure (ROPS) and seatbelt has been recognized as the prevalent cause of this phenomenon (Schwab et al. 2018, Tinc et al. 2018; Mann and Jespen 2017). Nowadays, the presence of these safety components (i.e. ROPS and seatbelt) is mandatory in most countries both for new tractors and for the older ones, which should be retrofitted accordingly (Cecchini et al. 2018; Fargnoli and Lombardi 2020). Nevertheless, the number of unprotected tractors is still very large due to multiple reasons, ranging from the financial efforts needed for retrofitting (Jenkins et al. 2012; Myers and Purschwitz 2012), to the negative attitude of farmers about the need of updating older tractors in accordance with mandatory safety requirements (Sorensen 2006; Caffaro et al. 2018a). In addition, it has to be highlighted that a large number of aged tractors are used by non-professional farmers, i.e. people performing agricultural activities for hobby or part-time job (Fargnoli et al. 2018; Caffaro et al. 2018b), as well as by foreigner operators (Vigoroso et al. 2019). In these cases, the operator skills might vary greatly, as well as the related knowledge of safety practices and obligations. In order to support and motivate farmers owing aged tractors in dealing with safety updates several measures have been implemented worldwide (Yoder and Murphy 2012; Franklin et al. 2006; Tinc et al. 2015). For instance, in the USA the Cost-effective ROPS (CROPS) program aims at supporting farmers in retrofitting aged tractors with protective structures (Myers 2010; Hard et al. 2016). Similarly, in Australia, the ROPS rebate program has been issued to promote the safe update of tractors (Day et al. 2004; Jones et al. 2013).

In Italy, the guidelines issued by the National Institute for Insurance against Accidents at Work (Inail) provide information on ROPS retrofitting for the most diffused tractors. This open-source database is constantly updated and currently constructive and installation characteristics of different types of ROPS for the most diffused tractors in Italy are available (Inail 2014). This type of initiatives is certainly contributing to the reduction of the problem of safety instructions about ROPS retrofitting especially among nonprofessional farmers. However, there is still a lack of information on the use of aftermarket cabins, which are installed on ROPS-equipped tractors (i.e. the so-called weather or meteorological cabins) especially during winter season and/or in occasion of specific activities such as the application of pesticides to reduce the operator's exposure (Fargnoli et al. 2019b). As a matter of fact, while safety features of cabins including a ROPS have been investigated by several studies (e.g. (Kumar et al. 2015; Kabir et al. 2014)), safety problems related to the installation of a cabin (or cab) on a ROPS-equipped tractor are scarcely addressed although such a practice is quite common among farmers (Pessina 2018). In addition, to the Authors knowledge, no international technical standards have been issued so far in order to provide safety criteria for ensuring that in case of a rollover a retrofitted cab does not harm the tractor's operator, nor reduces the effectiveness of the ROPS. Hence, the goal of this study consists in investigating safety criticalities related to the use of this type of cabs. In particular, starting from the issues emerged in a specific working group led by INAIL, hazardous situations are elicited providing a discussion of the specific safety criteria which both cabs' manufacturers and users should pay attention to in risk assessment activities. More in detail, remainder of the paper is articulated as follows. In Section 2, the background of the study is introduced, while Section 3 discusses hazardous situations related to weather cabins. Then, Section 4 illustrates the safety criteria for the development and assessment of cabins, and Section 5 discusses the results concluding the article.

2. Background

The use of aftermarket cabins aimed at protecting the operator from weather conditions as well as from other hazards (such as dust or pesticides) is rather diffused. For example, in Italy it was estimated that 150,000 tractors are retrofitted with this type of cabs (Pessina 2018), which corresponds to almost 19% of currently used tractors. The main problem when using of an aftermarket cab is related to the loss of stability of the tractor, which is the cause of most serious accidents in this sector (Kogler et al. 2016; Irwin and Poots 2018; Caffaro et al. 2018b). This is confirmed by accident statistics on occupational injuries occurred in agricultural activities (Rondelli et al. 2018). Hence, the starting point for investigating safety issues related to the use of aftermarket cabs consists in defining the normative framework for guaranteeing the safety of the operator in case of crushing due to a rollover. In other words, this means analyzing mandatory safety requirements concerning ROPS' testing and installation (Biestrato and Mazzetto 2018; Myers and Purschwitz 2012). With reference to the Italian context, the obligation of the installation of ROPS on agricultural and forestry tractors entered into force on January 1st, 1974 for new tractors; then, in 1981 such an obligation was extended to all tractors, i.e. including those put on the market before 1974. Accordingly, for tractors put on the market from 1974, the European directives 74/150/EEC and 2003/37/EC apply (Monarca et al. 2013; Cavallo et al. 2014). These directives were repealed with effect from 1 January 2016 by the Regulation (UE) 167/2013 (EU 2013), which updated the legislative framework for tractor safety in the European Union. This normative act confirmed as reference for ROPS' testing the rules provided by the Organization for Economic Co-operation and Development (OECD) standard codes for the official testing of agricultural and forestry tractors (OECD 2020). In summary, such frame of reference and the related acts indicate that rollover protection structures (safety cabs or structures) have to ensure an unobstructed space inside them (i.e. a safety zone called "clearance zone" or "deflection limit volume", depending on the tractor type) large enough to protect the operator in case of rollover.
This requirement is valid for both the ROPSs installed by the tractor manufacturer (i.e. before the tractor is put on the market) and those ROPSs put on the market separately and intended for such vehicles. To verify the compliance with such a requirement, the use of OECD standard codes as delegated acts is foreseen. In particular, in Table 1 the standard codes that should be used for each type of ROPS are reported (OECD 2020). As far as cabs without ROPS properties are concerned, safety prescriptions for tractor manufactures (or original equipment manufacturers (OEMs)) concern only: 1) the ventilation and filtration system; and 2) the burning rate of cab material (as for the Annex I of Regulation 167/2013).

Table 1. The current OECD Codes for tractor's ROPS testing (OECD 2020).

Code no.	Subject
Code 3	Dynamic testing of roll-over protective structure for standard tractors
Code 4	Static testing of roll-over protective structure for standard tractors
Code 6	Testing of front-mounted protective structures on narrow-track tractors
Code 7	Testing of rear-mounted protective structures on narrow-track tractors
Code 8	Testing of protective structures on tracklaying tractors

However, taking into account the above criteria, when a tractor is put on the marked with its-own ROPS and in addition its specific cab for weather protection the manufacturer guarantees the safe behavior of the whole vehicle in case of rollover: i.e., in this case the cab is considered as an original spare part of the tractor. The situation is different for cabs put on the market separately, i.e. from a company different from the manufacturer (or the OEM). In fact, if the cab includes ROPS' features (safety cab) a normative reference indicating safety requirements for the protection of the operator in case of rollover is provided by the national guidelines issued by INAIL addressing tractor retrofitting with ROPS (INAIL, 2011). In addition, these guidelines, which have legal value in the ambit of occupational health and safety, rely on the technical provisions of OECD standard codes. It has to be noted that in this case, the tractor's users have to demonstrate the unavailability of the original cab on the market and at the manufacturer. Conversely, in the case of aftermarket "weather" (or "meteorological") cabs without ROPS' features, there are no norms, nor technical standards addressing the problem of rollover. Based on the above considerations, two main situations can occur when retrofitting a tractor with a weather cab:

1) The cab is provided by the tractor manufacturer or by an original equipment manufacturer (OEM) for a specific type/model of tractor: the manufacturer guarantees that the cab is not dangerous for the operator in case of rollover, i.e. no parts of the cab infringe the deflection limit volume or the clearance zone.
2) The cab is put on the market by a different company from the manufacturer: this aftermarket product usually can be installed on different types of tractors and it is guaranteed for protecting the operator from meteorological hazards as well as from other hazards as for example pesticides and dust.

More in detail, in the latter case, the scenario is twofold: S.1. The cab is provided with a ROPS, i.e. the ROPS is embedded in the cab: in this case the system (safety cab) should be tested in accordance with the proper testing code by OECD, and thus resulting effective in case of rollover; S.2. The cab does not include a ROPS (meteorological cab): this type of product is likely to harm the operator in case of rollover since no safety declarations in this regard are provided by the cab manufacturer due to the absence of a specific technical standard or regulation.
Hence, as schematized in Figure 1, while both in the case of cabs provided by the manufacturer (or an OEM) and when the cab includes the ROPS there is a normative reference for ensuring safety requirements of the cab, for meteorological cabs no safety requirements to protect the operator in case of rollover are foreseen hitherto.

3. Analysis of hazardous situations

As mentioned above, a safe condition in the event of a rollover is ensured when the cab does not invade the clearance zone (Figure 2) protected by the ROPS. Hence, two main issues derive from such a requirement: 1) the cab shall not affect the reliability of ROPS; 2) the cab shall not infringe the clearance zone.
In order to define a context analysis, the possible practical combinations of meteorological cabs and tractors were taken into account. Theoretically, we can find six different combinations depending on the type of ROPS installed:

C.1. four-post ROPS: the cab encloses the ROPS;
C.2. four-post ROPS: the cab is inside the ROPS;
C.3. two-post ROPS mounted to the rear axle: the cab encloses the ROPS;
C.4. two-post ROPS mounted to the rear axle: the cab does not enclose the ROPS;
C.5. two-post ROPS mounted to the front axle: the cab encloses the ROPS;
C.6. two-post ROPS mounted to the front axle: the cab does not enclose the ROPS.

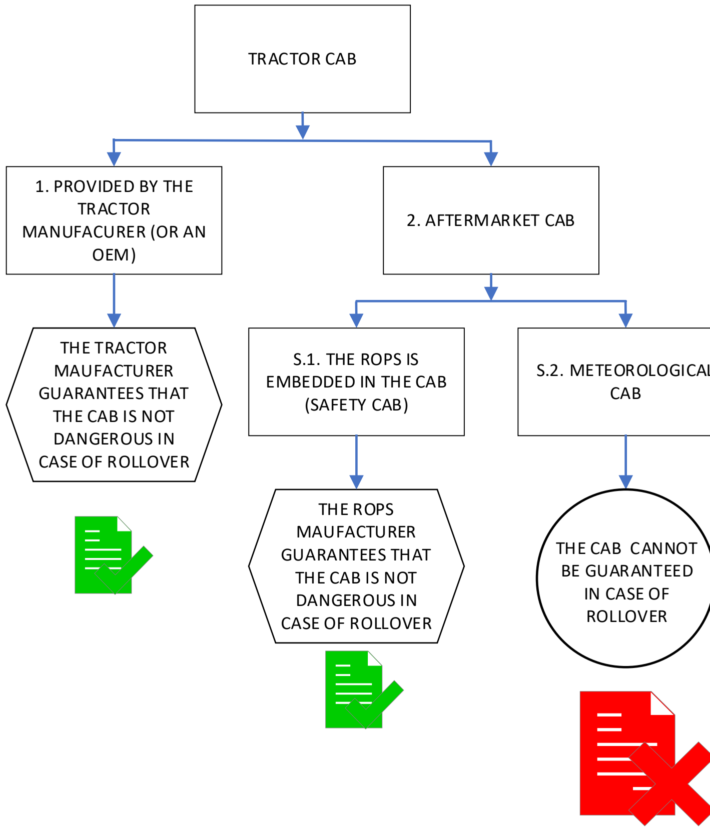

Figure 1. Safety requirements of tractor's cabs.

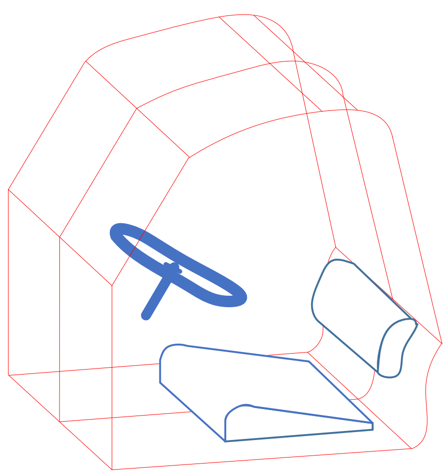

Figure 2. Scheme of the clearance zone based on the OECD standard code 4 (OECD 2020).

However, based on a survey among tractor dealers and aftermarket cabs' manufacturers, it emerged that the combinations C.1 C.3 and C.5 are very unusual. Hence, they were not considered further. Moreover, it has to be noted that the combination C.2. (four-post ROPS with the cab installed inside the ROPS) is usually referred to tracklaying tractors.

3.1 Four-post ROPS

When the cab encloses the ROPS, the hazardous situations that might arise in case of overturning are mainly due to the cab parts, such as the window glasses and other fragments, which can injury the operator when crashing on the soil. In fact, in this situation, if the operator uses the seatbelt correctly, the ROPS should protect the clearance zone

(EU 2009). Differently, if the cab is mounted inside the ROPS, the main problems for the operator are due to the likely reduction of the clearance zone: this scenario is dangerous not only in case of overturn (the operator can hit the cab frame), but also during regular operations as the operator's movements and visibility could be limited by the cab structure (Ehlers, and Field 2016; Fargnoli et al. 2012). In addition, the reliability of the ROPS could be reduced if the cab is not correctly mounted reducing the effectiveness of the protective structure, e.g. the cab is welded on the frame of the ROPS.

3.2 Rear two-post ROPS

With this type of ROPS, usually the aftermarket cab does not include the protective structure as it is installed as schematized in Figure 3.

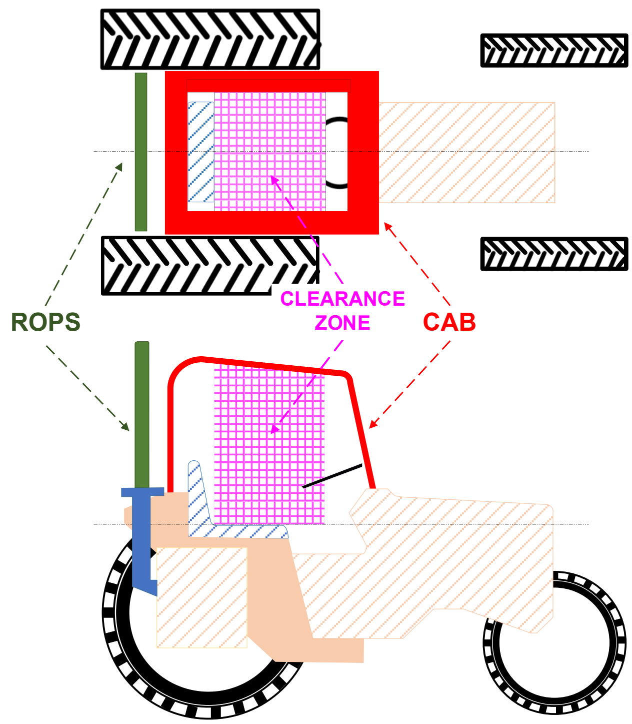

Figure 3. Scheme of the installation of the cab on tractor equipped with a rear two-post ROPS.

In this situation, given that the cab is large enough to guarantee the respect of the clearance zone, the hazardous situations are related to the violation of the "ground plane" in case of overturning. The "ground plane" is an imaginary plane, that in an upside-down position of the tractor should be considered as a "vertical simulated ground plane" (EU 2014). This plane is defined by the top cross-member of front part of the tractor likely to come in contact with flat ground at the same time as the ROPS and capable of supporting the upside-down tractor. This front part of the tractor is usually called "hard fixture", as it is considered that rigid part of the tractor that shall be regarded as a protective point, in the event of sideways or overturning (EU 2014). Accordingly, the "simulated ground line" can be depicted as shown in Figure 4. Consequently, n case of sideways the tractor hits the soil along with the simulated ground line, which is ideally sustained by the ROPS on the one side, and by the tractor's hard fixture on the other (Figure 5). In this situation, the ground plane is represented by the soil, and it is called "lateral ground plane". Hence, dangerous situations might arise when the cab's dimensions exceed the lateral and/or vertical ground plane.

3.3 Front two-post ROPS

Similar considerations can be made for a tractor equipped with a front two-post ROPS. The main difference is due to the fact that in this case the "hard fixture" is represented by a rigid section, a housing or another hard point regarded as a protective point, placed behind the driver's seat (Figure 6).

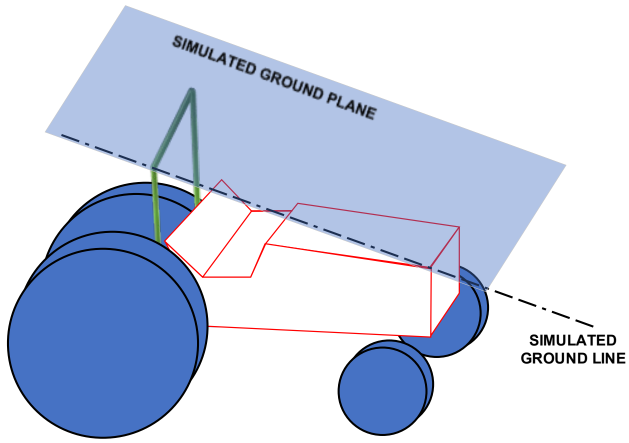

Figure 4. Scheme of the “simulated ground plane” of a tractor equipped with a rear two-post ROPS.

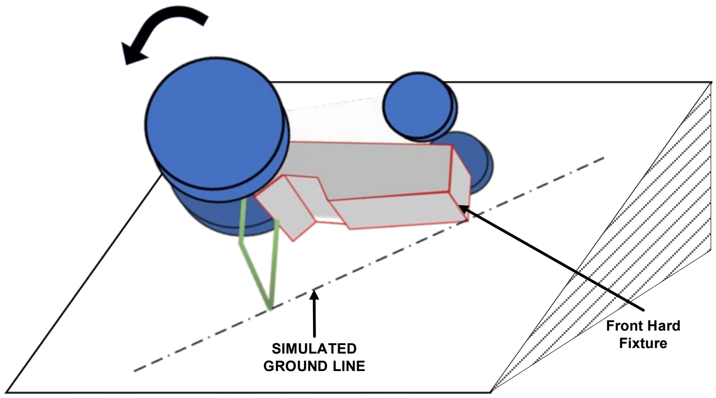

Figure 5. Scheme of the “simulated ground line” of a tractor equipped with a rear two-post ROPS in case of rollover.

4. Technical measures for risk reduction

In order to deal with the safety criticalities mentioned above, a research group issued by INAIL worked in the period 2018-2019 in collaboration with weather cab and tractor manufacturers, dealers, users, as well as with machinery safety and occupational health and safety experts and researchers. The goal of these activities consisted in providing technical criteria to be used to evaluate the safety level of aftermarket cabs, providing a reference framework for manufacturers, dealers and other stakeholders. Results achieved were further validated by means of several software simulations and experimental tests aimed at verifying the practical effectiveness of the proposed solutions. More in detail, the idea based on which the above criteria were verified relies on the adaptation of the technical parameters provided by the OECD ROPS Test Codes (OECD 2020) to guarantee the safety level of cabs. Accordingly, criteria for the respect of a safety zone for both the lateral and vertical withstanding of the weather cab for each of the above-mentioned combinations were depicted. As far as the former aspect is concerned, it should be noted that in this context the “safety zone” indicates an unobstructed space able to protect the operator in case of overturning whose dimensions might differ from those of the “clearance zone”, which are reported in the OECD codes. Then, following the superposition “principle” illustrated by Fritz et al. (1991), the minimum dimensions were evaluated taking into account the dimensions and shape of a safety zone defined in the OECD codes for testing ROPS structures independently from the type of tractor. To be more precise, the OECD Code 10 (OECD 2020) identifies the safety zone as follows: “for tractors equipped with ROPS tested in accordance with Codes3, 4, 6 and 7 the safety zone shall comply with the specifications of the Clearance Zone as described in point 1.6 of each of these codes”; while, “for tractors equipped with ROPS tested in accordance with Code 8 the safety zone shall comply with the Deflection-Limiting Volume (DLV), as described in ISO 3164:2013”.

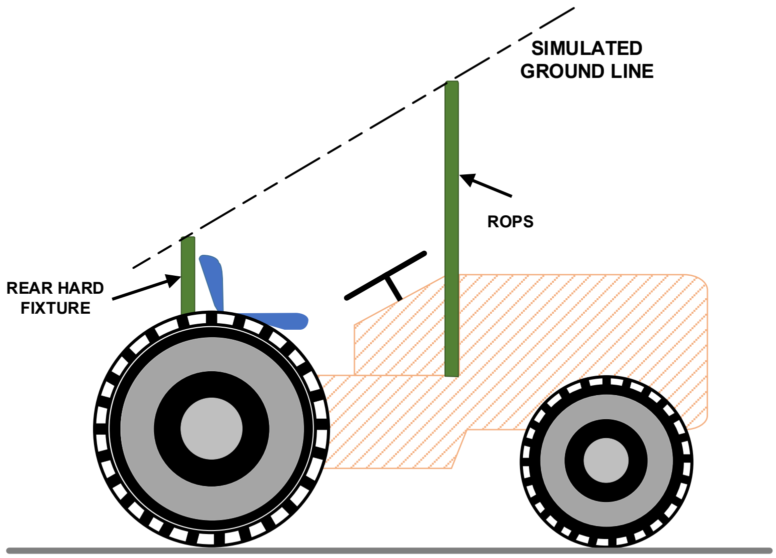

Figure 6. Scheme of the "simulated ground line" of a tractor equipped with a front two-post ROPS.

4.1 Safety zone for wheeled tractors

In order to guarantee a safe area for the operator in case on overturning, the dimensions of the area at the disposal of the operator illustrated in Figure 7 cannot be smaller than the values reported in Table 2 (values are expressed in mm). Differently from the two-post ROPS and four-post ROPS, it has to be noted that in the case of tractors equipped with a front two-post ROPS, the above values are different and include an additional parameter, which was named V3, that considers the distance between the highest point of the steering wheel and the S point of the seat as shown in Figure 8.

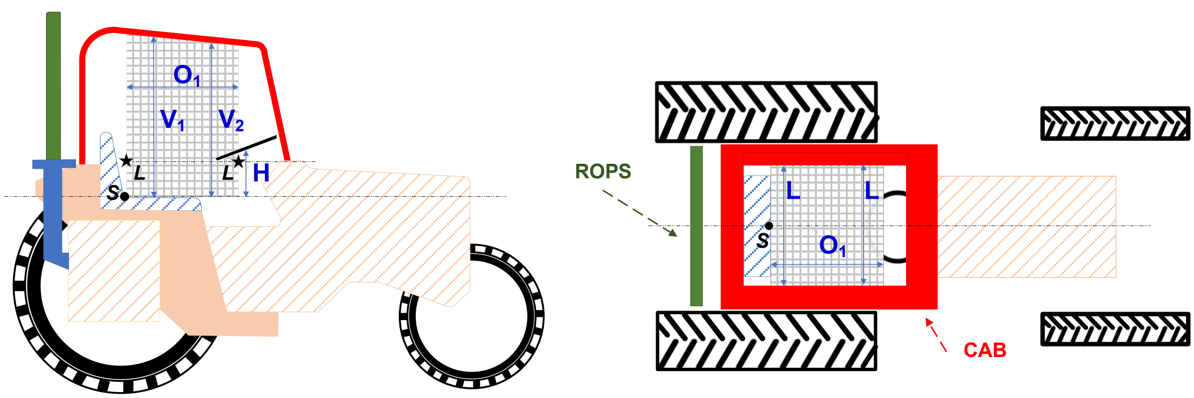

Figure 7. Scheme of the safety zone of a wheeled tractor equipped with a rear two-post ROPS.

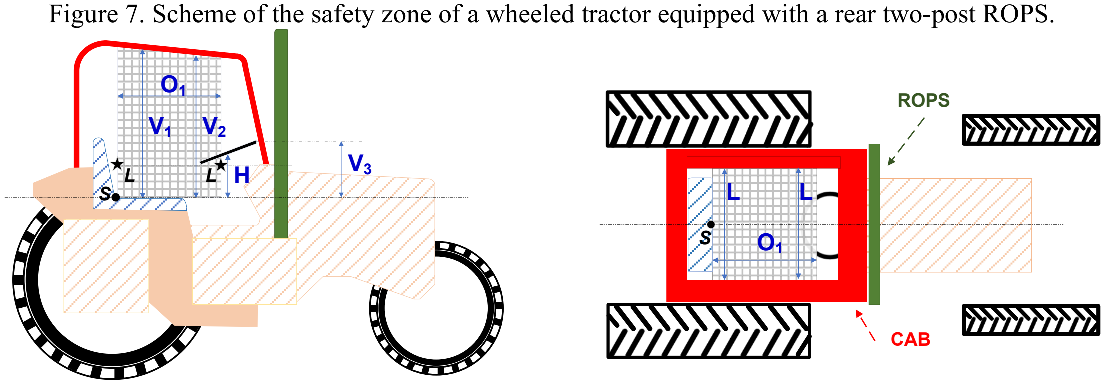

Figure 8. Scheme of the safety zone of a wheeled tractor equipped with a front two-post ROPS.

Table 2. Minimum dimensions of the safety zone for wheeled tractors' cabs.

	Rear two-fold	Front two-fold	Four-post
O1	550	900	550
L	500	500	500
V1	930	450	930
V2	930	400+V3	930
H	300	300	300

4.2 Safety zone for tracklaying tractors

In table 3 the values related to the minimum dimensions of the safety area for the operator of a tracklaying tractor are reported, where the related parameters are those shown in Figure 9.

Table 3. Minimum dimensions of the safety zone for tracklaying tractors' cabs.

	Rear two-fold	Front two-fold	Four-post
O1	400	550	400
L	500	500	500
V1	990	920	990
V2	990	817	990
H	300	300	300

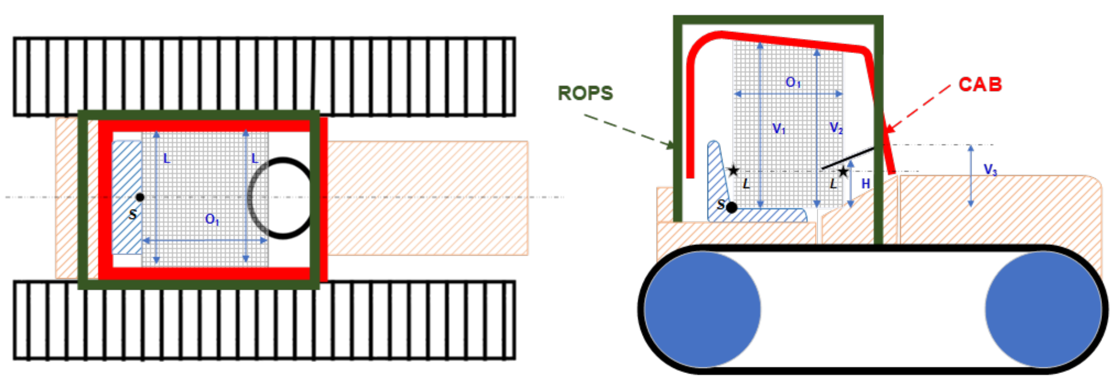

Figure 9. Scheme of the safety zone of a tracklaying tractor equipped with a four-post ROPS.

4.3 Vertical withstanding

Since the OECD Code 6 requires that the tractor's hard fixture placed behind the driver's seat shall be capable of withstanding, without breaking or entering the clearance zone, a downward force Fi = 15 M (where M represents the "maximum tractor mass recommended by the tractor manufacturer" expressed in kg), a similar criterion is foreseen for the verification of the cab' s withstanding. In detail, the cab shall withstand a downward force Fi ≥ 15 M applied to the top of the frame in the central plane of the tractor. The initial angle of application of force shall be 40° calculated from the roof plane parallel to the ground, without breaking or entering the clearance zone (Figure 10).
Similarly, adapting the same provisions of the OECD Code 6 for the rear two-post ROPS, the weather cab has to bear a force Fi ≥ 15 M applied with a 40o degree angle considering the roof plane, without breaking or entering the clearance zone (Figure 11). In both cases, if a deformation of the cab occurs when applying Fi, the manufacturer has to verify that the deformed weather cab has not invaded the simulated ground line/plane.

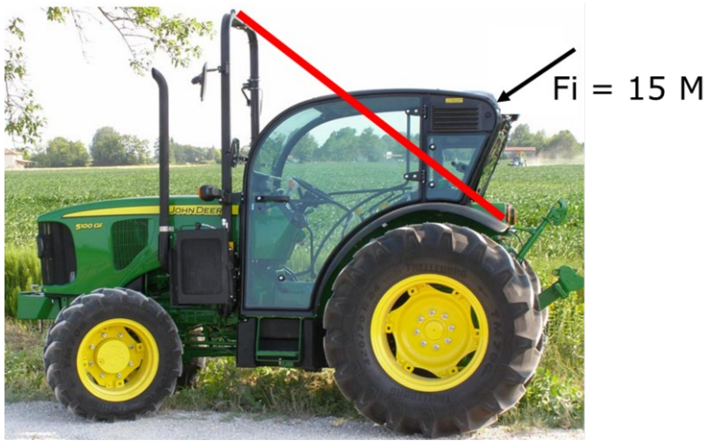

Figure 10. Scheme of the application of the force Fi aimed at verifying the vertical withstanding of the cab in case of a front two-post ROPS.

Figure 11. Scheme of the application of the force Fi aimed at verifying the vertical withstanding of the cab in case of a rear two-post ROPS.

4.4 Lateral withstanding

In a similar manner, the criterion provided by the OECD Code 6 and 7 for ROPS applied to wheeled narrow tractors was used to prevent the intrusion in the clearance zone in case of sideways overturning when the cab is larger than the ROPS, i.e. when its dimensions exceed the virtual lateral plan (Figure 12).
In this case, the weather cab has to be able to absorb at least an amount of energy equal to $E \geq 1.75$ M caused by a force applied horizontally, in a vertical plane perpendicular to the tractor's median plane, without breaking or entering the clearance zone.

5. Discussion of results and conclusions

Computer simulations and experimental tests were carried out to verify the effectiveness of the above criteria and the results achieved showed their reliability. This analysis is in line with the provisions by Fritz et al. (1991), who argued that when developing a novel safety volume for the operator of an agricultural tractor or a construction, earthmoving, forestry and mining machine, a superposition of the safety zone according to different standards can be performed if the resulting safety volume is substantiated by ergonomic evaluations. Similarly, the superposition of different safety zones is also proposed by Guzzomi et al. 2019, who analyzed ROPS' performances of an articulated narrow track tractor.

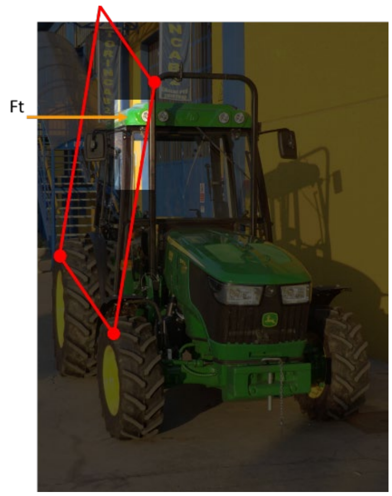

Figure 12. Scheme of the application of the force Ft aimed at verifying the lateral withstanding.

Moreover, the importance of a reverse engineering approach for machinery safety based on ergonomic issues is confirmed in literature by several studies (Fargnoli et al. 2012; Casazza et al. 2016; Fargnoli et al. 2020). Based on this, the analysis carried out to depict and verify the safety criteria for the proper use of aftermarket weather cabins and their interferential relationship with the tractor's protective structure provided a scientific support to the implementation of a technical guideline issued by INAIL. In fact, this document is currently being validated by the Italian National Unification association and it will be published as a technical standard recognized at the national level. Such an output provides a solution to the lack of a technical reference for the safe use of weather cabs in agriculture, providing a guidance not only for the manufacturers of this type of products, but also for the users/entrepreneurs when performing risk assessment of their working equipment. In fact, as underlined by Caffaro et al. (2017b), occupational health and safety (OHS) has to be considered from both sides, finding new effective strategies and tools to reduce accidents and injuries associated with the use of hazardous machinery. This is also in line with Kogler et al. 2016, who highlighted the importance of providing information tools, such as guidelines, aimed at improving the safety level of farmers. Accordingly, the contribution of the research work described in the present paper consists in enhancing knowledge on the safe selection and use of work equipment. Hence, the criteria illustrated in the previous section can be used also for other types of machinery, such as the ones used in mining, construction, and other earthmoving activities (e.g., scrapers and graders, equipped with aftermarket cabs).

References

Caffaro, F., Bagagiolo, G., Cremasco, M.M., and Cavallo, E., Participatory ergonomic design of a safety training tool for migrant workers in agriculture, Chemical Engineering Transactions, vol. 58, pp. 25-30, 2017a.

Caffaro, F., Micheletti Cremasco, M., Roccato, M., and Cavallo, E., It does not occur by chance: a mediation model of the influence of workers' characteristics, work environment factors, and near misses on agricultural machinery-related accidents, *International Journal of Occupational and Environmental Health*, vol. 23, no. 1, pp. 52-59, 2017b.

Caffaro, F., Lundqvist, P., Micheletti Cremasco, M., Pinzke, S., Cavallo, E. Machinery-related perceived risks and safety attitudes in senior Swedish farmers, *Journal of Agromedicine*, vol. 23, no. 1, pp. 78-91, 2018a.

Caffaro, F., Roccato, M., Cremasco, M.M., and Cavallo, E., Part-time farmers and accidents with agricultural machinery: A moderated mediated model on the role played by frequency of use and unsafe beliefs, *Journal of Occupational Health*, vol. 60, no. 1, pp. 80-84, 2018b.

Casazza, C., Martelli, R., and Rondelli, V. Evaluation of a commercial tractor safety monitoring system using a reverse engineering procedure, *Journal of agricultural safety and health*, vol. 22, pp. 215–225, 2016.

Cavallo, E., Langle, T., Bueno, D., Tsukamoto, S., Görücü, S., and Murphy, D., Rollover protective structure (ROPS) retrofitting on agricultural tractors: goals and approaches in different countries, *Journal of Agromedicine*, vol. 19, no. 2, pp. 208-209, 2014.

Day, L., Rechnitzer, G., and Lough, J., An Australian experience with tractor rollover protective structure rebate programs: process, impact and outcome evaluation, *Accident Analysis & Prevention*, vol. 36, no. 5, pp. 861-867, 2004.

EU 2009, Directive 2009/144/EC of the European Parliament and of the Council of 30 November 2009 on certain components and characteristics of wheeled agricultural or forestry tractors, 2009. Available: https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX:32009L0144, 13 January 2021.

EU 2013, Regulation (EU) No 167/2013 of the European Parliament and of the Council of 5 February 2013 on the approval and market surveillance of agricultural and forestry vehicles. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32013R0167, 13 January 2021.

EU 2014, Commission Delegated Regulation (EU) No 1322/2014 of 19 September 2014 supplementing and amending Regulation (EU) No 167/2013 of the European Parliament and of the Council with regard to vehicle construction and general requirements for the approval of agricultural and forestry vehicles. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32014R1322, 13 January 2021.

Fargnoli, M. and Lombardi, M., Safety Vision of Agricultural Tractors: An Engineering Perspective Based on Recent Studies (2009–2019), *Safety*, vol. 6, no. 1, pp. 1, 2020.

Fargnoli, M., Vita, L., Gattamelata, D., Laurendi, V., and Tronci, M., A reverse engineering approach to enhance machinery design for safety, *Proceedings of DESIGN 2012, the 12th International Design Conference*, Dubrovnik, Croatia, pp. 627-636, 2012.

Fargnoli, M., Lombardi, M., and Puri, D., Applying Hierarchical Task Analysis to Depict Human Safety Errors during Pesticide Use in Vineyard Cultivation, *Agriculture*, vol. 9, no. 7, pp. 158, 2019a.

Fargnoli, M., Lombardi, M., Haber, N., and Puri, D., The impact of human error in the use of agricultural tractors: A case study research in vineyard cultivation in Italy, *Agriculture*, vol. 8, no. 6, pp. 82, 2018.

Fargnoli, M., Lombardi, M., Puri, D., Casorri, L., Masciarelli, E., Mandić-Rajčević, S., and Colosio, C. The safe use of pesticides: a risk assessment procedure for the enhancement of occupational health and safety (OHS) management, *International journal of environmental research and public health*, vol. 16, no. 3, pp. 310, 2019b.

Fargnoli, M., Lombardi, M., Haber, N., Guadagno, F. Hazard function deployment: a QFD-based tool for the assessment of working tasks - a practical study in the construction industry. *International Journal of Occupational Safety and Ergonomics*. Vol. 26, no. 2, pp. 348-369, 2020.

Franklin, R.C., Stark, K.L., and Fragar, L., Intervention strategies for the retro-fitment of Rollover Protective Structures (ROPS) and fleet characteristic, farm tractors, *Safety science*, vol. 44, no. 9, pp. 771-783, 2006.

Fritz, E.A., Case, J.I., and Switalski, W.G., Small agricultural tractor ROPS-new operator protective zone, *SAE Transactions*, vol. 100, no. 2, pp. 201-218, 1991.

Guzzomi, A.L., Rondelli, V., and Capacci, E., Operator protection in rollover events of articulated narrow track tractors, *Biosystems engineering*, vol. 185, pp. 103-115, 2019.

Hard, D. L., McKenzie, E. A., Cantis, D., May, J., Sorensen, J., Bayes, B., Stone, B., and Maass, J., The NIOSH CROPS Demonstration Project: a study in New York and Virginia with an emphasis on youth, *Journal of agricultural safety and health*, vol. 22, no. 3, pp. 173-186, 2016.

Inail, ROPS' Installation guidelines, 2014. Available: https://www.inail.it/cs/internet/docs/allegato_indice-e-premessa.pdf, 13 January 2021.

Irwin, A. and Poots, J., Investigation of UK farmer go/no-go decisions in response to tractor-based risk scenarios, *Journal of Agromedicine*, vol. 23, pp. 154-165, 2018.

Ivascu, L. and Cioca, L.I. Occupational accidents assessment by field of activity and investigation model for prevention and control, *Safety*, vol. 5, no. 1, pp. 12, 2019.

Jones, C.B., Day, L., and Staines, C., Trends in tractor related fatalities among adults working on farms in Victoria, Australia, 1985–2010, *Accident Analysis & Prevention*, vol. 50, pp. 110-114, 2013.

Kabir, M.S.N., Ryu, M.J., Chung, S.O., Kim, Y.J., Choi, C.H., Hong, S.J., and Sung, J.H., Research trends for performance, safety, and comfort evaluation of agricultural tractors: A review, *Journal of Biosystems engineering*, vol. 39, no. 1, pp. 21-33, 2014.

Kogler, R., Quendler, E., and Boxberger, J., Occupational accidents with agricultural machinery in Austria, *Journal of Agromedicine*, vol. 21, pp. 61-70, 2016.

Kumar, A., Mahajan, A., Prasanth, S., Darekar, S., Chellan, J., Kumar, K.A., and Kumar, J.K.R. Agricultural tractor cabin structure design for durability and rollover protective structure test, *SAE Technical Paper*, no. 2015-26-0163, 2015.

Mann, A., Dee Jepsen, S., Using expert panel data to guide youth agricultural safety and health training resources in the US, Safety , vol. 3, no. 1, pp. 4, 2017.

Myers, J.R., Factors associated with the prevalence of non-ROPS tractors on farms in the US, *Journal of agricultural safety and health*, vol. 16, no. 4, pp. 267-280, 2010.

Myers, M.L.and Purschwitz, M.A., ROPS deficiency of gray-market tractors, *Journal of agricultural safety and health*, vol. 18, no. 2, pp. 129-140, 2012.

OECD 2016, OECD Agricultural Codes and Schemes. Available: http://www.oecd.org/agriculture/tractors/OECD-Tractor-Codes-Brochure-EN.pdf, 13 February 2020.

OECD 2020, OECD standard code for the official testing of falling object protective structures on agricultural and forestry tractors. Available: https://www.oecd.org/agriculture/tractors/codes/10-oecd-tractor-codes-code-10.pdf, 13 January 2021.

Pessina, D., After-market cabs: a safety issue, Mondo Macchina/Machinery World, vol. 4-5, 2018. Available: https://www.mondomacchina.it/en/after-market-cabs-safety-issue-c2019, 13 January 2021.

Sorensen, J.A., May, J.J., Jenkins, P.L., Jones, A.M., and Earle-Richardson, G.B., Risk perceptions, barriers, and motivators to tractor ROPS retrofitting in the New York state farm community, *Journal of agricultural safety and health*, vol. 12, no. 3, pp. 215-226, 2006.

Tinc, P.J., Ayers, P.D., May, J.J., Purschwitz, M.A., and Sorensen, J.A. Creating a national coalition to address tractor overturn fatalities, *Journal of agricultural safety and health*, vol. 21, no. 2, pp. 105-112, 2015.

Tinc, P.J., Gadomski, A., Sorensen, J.A., Weinehall, L., Jenkins, P., and Lindvall, K., Applying the Consolidated Framework for implementation research to agricultural safety and health: Barriers, facilitators, and evaluation opportunities, *Safety science*, vol. 107, pp. 99-108, 2018.

Vigoroso, L., Caffaro, F., Micheletti Cremasco, M., Bagagiolo, G., and Cavallo, E., Comprehension of safety pictograms affixed to agricultural machinery among Pakistani migrant farmworkers in Italy, *Journal of agromedicine*, pp. 1-14, 2019.

Yoder, A.M., and Murphy, D.J., Using social marketing to address barriers and motivators to agricultural safety and health best practices, *Journal of Agromedicine*, vol. 17, no. 2, pp. 240-246, 2012.

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