Prevention aspects for avoiding rollover incidents together for tractors, self-propelled harvesting and material handling machinery

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Abstract: Tractors, self-propelled harvesting and material handling machines are the most commonly used self-propelled machineries in Austrian agriculture that have similarities in main rollover incident causes. The aim of this study was to present sustainable prevention measures against rollovers together for tractors, self-propelled harvesting and material handling machinery based on a new machine evaluation, manufacturer surveys and a literature research. New machines were investigated concerning their compliance with legal regulations and concerning their current rollover prevention equipment. By interviewing manufacturers of tractors, self-propelled harvesting machinery and material handling machinery, the challenges with implementing safety measures and the opportunities for rollover incident prevention were worked out. In addition a literature research on rollover prevention measures was done. All new vehicles analyzed were equipped with a rollover protective structure as standard equipment. The manufacturer survey showed that all cabins for tractors were ROPS tested and that ROPS requirements were not adequately implemented on self-propelled harvesters. The technical possibilities to reduce the rollover risk together for tractors, self-propelled harvesting machinery and material handling machinery were the rollover protective structure, the safety belt, the general chassis concept, a weight sensor, driver assistance systems, and rollover warning devices. New ITC-based technologies like sensor tools for showing the stability condition of the vehicle can prevent a rollover, but the driver's inhibitions to face more dangerous situations are thereby increased.

Keywords: agricultural machinery, rollover, prevention, manufacturer survey, machine evaluation

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1 Introduction

Agriculture is one of the most hazardous industries (Myers and Hendricks, 2010). Tractors, self-propelled harvesting machines and material handling machines are the most commonly used self-propelled machineries in agriculture that represent an important cause of injuries and fatalities. Half of the injuries in agriculture and forestry occur when operating machinery, as a study from Canada showed (Pickett et al., 1999). Tractors are the most important agricultural machinery those are associated with more fatalities than any other machinery, with rollovers being the most frequent scenario (Jones et al., 2013). The agricultural tractor rollover accounts for more than 50% of all tractor deaths (Day et al., 2004). Self-propelled harvesting machinery like two-axle mowers and transporters for grassland harvesting in mountainous regions as well as combines and other harvesters used in grain and root crops harvesting in regions of arable farming play a big role. Italian statistics show that combine harvesters, grape harvesters or sprayers are involved in rollovers in increasing

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numbers because of their high overall mass, including the content of large tanks fitted on board, the high center of gravity and the development of high torque values (Gattamelata et al., 2012). Small self-propelled machines such as ride-on tractors, two axle mowers or comb-side-delivery rakes are also involved in rollovers not because of a large mass or a high centre of gravity but rather because of the roughness of the ground on which they travel at high speed, leading to skidding and bumps causing loss of control over the vehicle, especially when working on slopes during forage management operations (Pessina and Facchinetti, 2009). Independent of the area of production, there is an increasing trend towards the use of specialized material handling machinery in agriculture. This machinery type includes, among others, farm loaders, wheel loaders, forklift trucks, excavators, and telehandlers (Mayrhofer et al., 2013a).

In preliminary investigations, the causes of rollover incidents with tractors, self-propelled harvesting machines and material handling machinery were determined together by means of a database analysis, a survey of victims and an analysis of incident reports. Already in these preliminary investigations, the three different vehicle types were subjected jointly to the study and summarized in the presentation of results. By simultaneous investigation of the three different vehicle types, more detailed causes and scenarios could be identified. The preliminary studies showed that the vehicles have similarities in main rollover incident causes, although they are quite different in vehicle concept, operation and use (Mayrhofer et al., 2012). It was possible to work out 7 conjoint main causes and 15 subcauses that were identified and categorized into a structured class system. The first main cause is the driver who is responsible for rollover incidents due to distraction or inattention, sudden illness, and an incorrect or inappropriate vehicle use, for example too much load, faulty operation of the brake or the transmission. Some rollovers were influenced by the suboptimal environmental conditions like steep slopes and slippery or deep underground. These factors interact and determine the risk of rollover in a complex manner, influenced by the position of the tractor's center of gravity, forward speed and turning angle (Rondelli et al., 2013). The condition of embankments and ditches or road roughness also causes rollover incidents. Another important incident causes are technical defects. The different defects were found, for example, on brakes, tires or transmissions (Mayrhofer et al., 2012; Mayrhofer et al., 2013a; Mayrhofer et al., 2013b).

By aggregating the three vehicle categories tractor, self-propelled harvesting machinery and material handling machinery, there were on the one hand a large number of rollovers available for examination and on the other hand the results are more suitable for general rollover prevention that addresses directly to farmers. Based on this point of view from the preliminary studies, the three vehicle categories were also edited together in the presentation of prevention measures against rollovers.

The aim of this study was to present sustainable prevention measures against rollovers together for tractors, self-propelled harvesting machinery and material handling machinery in a concise way based on a new machine evaluation, manufacturer surveys and a literature research. The prevention measures should be applicable to tractors, self-propelled harvesting machinery or material handling machinery and should be already available as standard or desired equipment.

2 Materials and methods

In Figure 1, the procedure for working out the prevention measures is presented. First to establish an overview of current safety technology, it was necessary to investigate new machines. Further their compliance with legal regulations was examined. By interviewing

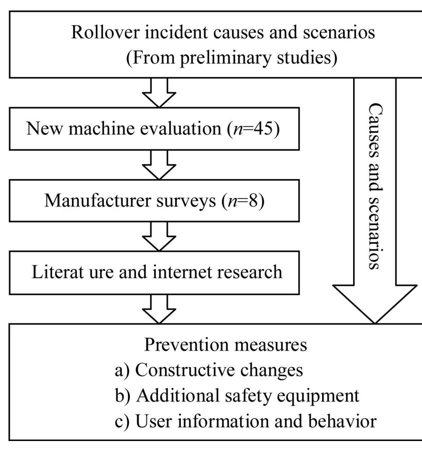

Figure 1 Flow diagram of material and methods

manufacturers of tractors, self-propelled harvesting machinery and material handling machinery, the challenges with implementing safety measures, legal regulations and opportunities for rollover incident prevention were investigated. In addition, a literature research on rollover prevention was done.

In the following section the materials and methods from Figure 1 are pointed out in detail:

2.1 New machine evaluation

The new machine evaluation was done with evaluation sheets examining new machines in stock in the winter of the years 2012 and 2013 at Upper Austrian farm equipment dealers. A total of 45 new machines were examined, including 25 tractors, 6 self-propelled harvesting machines (two-axle mowers and transporters) and 14 machines for load transportation. About 56% of the tractors (14/25) had an engine power over 100 hp. At the self-propelled harvesters about 17% (1/6) and at the load handling machines about 79% (11/14) had an operating weight under 2 t.

In the evaluation, the existence of a ROPS structure, cabin, seat belt, four-wheel-break, four-wheel-disc brake, front axle suspension, carrying capacity charts, and rollover sensors was checked. These evaluation requirements were stipulated in EC (2003), EC (2006), ISO (2008a), ISO (2008b) and ISO (2008c).

The observed frequencies of the new machine evaluation were entered into a database, classified and described descriptively with percentages. To represent relationships between vehicle types and size classes, cross tables were created. The dependencies of the observed events were analytically tested with a non-parametric test, the chi-square test, in SAS 9.2.

The machine evaluation is a suitable method to examine vehicles and machines more closely. This was confirmed by a literature research that showed that-regardless of the investigation of rollover incidents-machine evaluations were used by Quendler et al. (2013) for identifying incidental factors of boarding means from tractors and by Farmer et al. (1997) for evaluating brakes of cars.

2.2 Manufacturer survey

Eight out of 13 manufacturer contacted supported the study. One third of the contacted manufacturers (38.5%; 5/13) denied cooperation. Two of the manufacturers that supported the study produced exclusively machinery for load transportation (wheel loaders, tele wheel loaders, telehandlers and excavators). Four interviewed manufacturers produced tractors and self-propelled harvesters (tractors, combines, forage harvesters, two-axle mowers and transporters) and two manufacturers produced only self-propelled harvesting machines (two axle mower, transporters and sugar beet harvester). The manufacturers surveyed had either their head office or a production site in Germany or Austria.

For the manufacturer survey two questionnaires were created. The first questionnaire was designed for manufacturers of tractors and self-propelled harvesters and the other one for manufacturers of machines for load transportation. These two different questionnaires were necessary to address the specifics of the vehicle categories. In the presentation of the results, the statements of the manufacturers were merged for all investigated vehicle categories.

The majority of the questions were open questions and yes and no questions with a subsequent text field to justify the answer. Both questionnaires consisted of the same introductory questions. In addition to general information about the manufacturer and experience with incident statistics, the manufacturers were asked about the relevance of the safety technology when purchasing a vehicle and were confronted with the results of preliminary studies. The main part of the questionnaire included a special section for rollover incidents, especially about the standards and guidelines of the new machine evaluation to find out consisting problems of implementation. In addition, questions were asked related to the prevention of future incidents and any potential in specific technologies or tools, such as electric motors or reversing alarms, to prevent incidents. Various problems in the design of vehicles that turned out to be causal in the incidents studied were mentioned, such as the confusing design of fenders, panels and bonnets.

The questionnaires were filled out by a competent representative of the manufacturer, mainly the designing or constructing engineers. The information provided was evaluated anonymously. The answers to the quantitative questions were categorized and described descriptively by frequencies. Due to the small sample size, no analytical statistical testing was possible. The qualitative statements of the manufacturer survey were summarized and prepared in a unified language level for the presentation of the results.

Manufacturer surveys are an appropriate method to work up such a subject scientifically. Regardless of the investigation topic, manufacturer surveys were used by Quendler et al. (2013) and Leskinen et al. (2002) carrying out opportunities and problems in the design of boarding means of agricultural vehicles and by Haslam et al. (2005) doing surveys in the construction industry to reduce the risk of incidents through changing the design of construction machinery.

2.3 Prevention

An internet and a literature research were done to define mechanical and ICT-based measures for preventing rollovers. The prevention measures were chosen and presented which can be applied together for tractors, self-propelled harvesting machinery or material handling machinery. They should also already be available as standard or desired equipment. There was no measure developed specifically for a vehicle category. A general representation was carried out.

There exist standardized rules for the risk assessment in EC (2006) and in ISO (2007). For the derivation of preventive measures, the risk assessment according to ISO (2007) was applied. Depending on whether risk reduction was necessary, appropriate protective measures were selected. The achievement of adequate risk reduction was performed by the so-called three-step procedure:

a) Constructive changes: Risk is reduced through construction measures and changes or through the replacement with less dangerous substances or materials. Structural changes are all incident prevention measures that engage in the vehicle concept and especially change the weight, center of gravity, driving behavior or appearance.

b) Additional safety equipment: If a constructive change is not possible, the risk must be reduced by the application of technical and complementary protective measures that sufficiently reduce the risk, for example electronic safety devices.

c) User information and behavior: If the application of technical or supplementary protection measures and constructive changes are not feasible or the risk cannot be sufficiently reduced, the user information must include a reference to contain any residual risk. The correct behavior in dangerous situations plays an important role in incident prevention.

The literature research is a suitable method for working out incident prevention measures. For example, Suutarinen (2003) studied tractor incidents and used a literature and internet research to work out preventive measures.

3 Results and discussion

3.1 New machine evaluation

The new machine evaluation showed that all evaluated vehicles (100.0%; 45/45) were equipped with a protective structure. These included glazed or unglazed cabins and roll bars. All these protective structures were standard equipment. In terms of hazards caused by falling objects, the evaluation showed that the vehicles for load transportation (100.0%; 14/14) had significantly ($p = 3.965E-06$ Fisher) more often a falling object protective structure than tractors (84.0%; 21/25) and self-propelled harvesting machines (0.0%; 0/6). All the falling object protective structures were standard equipment.

The self-propelled harvesters (100.0%; 6/6) and the tractors (92.0%, 23/25) were equipped with a glazed cabin significantly ($p = 0.0012$, Fisher) more often than the vehicles for load transportation (50.0%, 7/14) (see Figure 2). Regarding the basic equipment, tractors (84.0%; 21/25) had the cabin significantly ($P = 0.0052$, Fisher) more often as basic standard equipment than the self-propelled harvesters (50.0%; 3/6) and the load transportation vehicles (50.0%; 7/14).

The seat belt was significantly ($p = 0.0264$ Fisher) more often a standard equipment in load transportation (100.0%; 14/14) and in tractors (96%; 24/25) than in self-propelled vehicles (66.7%, 4/6).

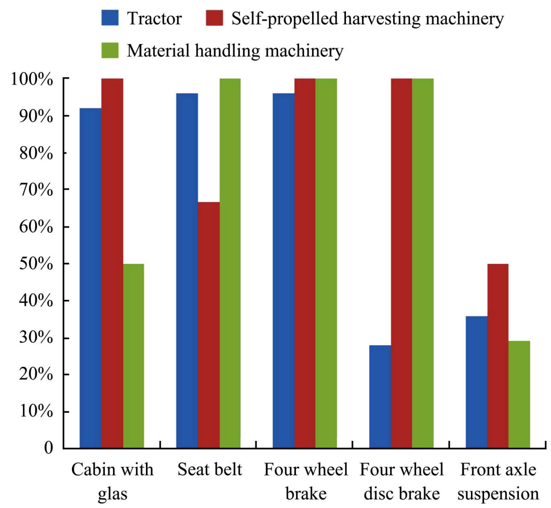

Figure 2 Evaluated rollover prevention equipment (n=45)

In the cabin of the vehicles, the presence of a sticker referring to the use of the safety belt was examined. With about 70% (15/22), tractors had significantly (p=6.683E-06 Fisher) much more often such a sticker in the cabin than the vehicles for load transportation and the self-propelled harvesting machines, none of which had such a sticker. Information stickers in the cabins that instruct the driver to hold on in case of a rollover and not to jump off were rarer. These stickers were found only in 20% (18.18%, 4/22) of the tractors evaluated and in none of the self-propelled harvesting machine or the load transport machines.

All self-propelled harvesting machines and machines for load transportation and 96.0% (24/25) of the tractors were equipped with four-wheel brakes. The differences in the equipment level of these vehicle groups were not significant (p = 0.5556 Fisher). The evaluated self-propelled harvesting machines (100.0%; 6/6) and the vehicles for load transportation (100.0%; 14/14) had significantly (p = 2.801E-07 Fisher) more often a four-wheel brake as standard equipment than the tractors (28.0%; 7/25). All evaluated self-propelled harvesting and load transportation machines with a four-wheel brake basically had a four-wheel brake installed through stepless hydrostatical transmission. Only 36.0% (9/25) of the tractors had front axle suspension. Compared with the self-propelled harvesters (50.0%; 3/6), this is a smaller share (not significant; p = 0.0633 Fisher), although the result was not significant (p=0.3317 Fisher). The self-propelled harvesting vehicles were equipped with front axle suspension much more often than the tractors. Only 20% (5/25) of the evaluated tractors had front axle suspension installed as standard equipment. The machines for load transportation were evaluated for the presence of a level compensation system, which existed in about one third (28.6%, 4/14) on machines as a standard equipment. Carrying capacity charts and rollover sensors had approximately 40% of these vehicles (42.9%, 6/14).

3.2 Manufacturer survey

Rollover protective structures (ROPS) offer protection in case vehicles roll over or tip over. Appropriate requirements for these structures are anchored in standards and guidelines. In total 80.0% (4/5) of the manufacturers of tractors and self-propelled harvesters took into account ISO (2008c) and EC (2006) according to them the vehicles should be equipped with a ROPS. Slightly more than 80% (83.3%, 5/6) of the manufacturers surveyed reported that their vehicles were equipped by default with a ROPS. All cabins for tractors were ROPS tested. According to ISO (2008c) tractors should be available with a Falling Object Protective Structure (FOPS) to operate in environments where the hazard of falling objects exists (e.g. forestry applications). This requirement fulfilled two-thirds of the tractor manufacturers surveyed (66.7%, 4/6). To determine whether the structure complies with the requirements of EC (2006), for each type of structure appropriate tests should be carried out. Half of the manufacturers (50.0%, 3/6) carried out these tests for tractors and self-propelled machines and one manufacturer only for tractors. Manufacturers also provided information in relation to the risk of overturning in accordance with ISO (2011) in the manual safety instructions.

A four-wheel brake was offered by all manufacturers surveyed. A wheel brake on the front axle with discs to brake was provided by 50% (3/6) of the three manufacturers of tractors and self-propelled harvesting machines. One tractor manufacturer offered disc brakes for tractors over a 50 km h^{-1} design speed. One manufacturer of self-propelled harvesting machines had this option only for harvesters with a design speed of over

25 km h^{-1}.

The surveyed manufacturers of load transportation confirmed using CEN (2006). The vehicles of these manufacturers were standard equipped with a ROPS, as determined by EC (2006) and CEN (2006). Both manufacturers confirmed testing of the overhead protection structures and cabins according to the legal guidelines. The manufacturers labeled their tested cabins with a corresponding notice, as stipulated in EC (2006). On the machine, the maximum working load must be labeled in an easily visible place. This marking must be legible, indelible and in an un-coded form. If the maximum load depends on the operating condition of the machine, for example for telescopic handlers, the driver's space must provide a table or diagram specifying the load permitted for each operating state. One manufacturer fitted a diagram in the cabins and the other one included it in the operation manual.

In addition to the currently available equipment options for rollover prevention, the manufacturers provided information about the design-related features and technical tools that offer the potential to better prevent rollover incidents in the future. The gravity and the weight distribution of the vehicle together with attachment and mounting devices will continue to play the biggest role in rollover prevention for manufacturers of tractors and self-propelled harvesting machinery. Tools for showing the achievement of critical terrain values or for indicating the vehicle's stability condition were not seen by manufacturers as a promising future prevention technology. Hydrostatic and infinitely variable transmissions were already partially offered by all manufacturers of tractors and self-propelled harvesting machinery as standard equipment. These transmissions were offered according to market and customer demand. Hydrostatic and infinitely variable transmissions allow risk-free stopping and smooth starting as well as prevent distraction from shifting gears and using the clutch. Electric drives are increasingly popular in vehicle application. Single-wheel electric motors, for example, can be individually controlled very precisely. This offers safety advantages on slopes and in the plane, and it is perfect for the optimization of the traction. The manufacturers surveyed were critical of the role that these technologies will play in the design of tractors and self-propelled harvesters in the future. All manufacturers indicated that these technologies still need to be developed further before their use can enter into series production. This view was supported by the fact that these technologies were currently too expensive and the benefits for the customer were too low to justify the high market price.

Neither of the two manufacturers of load handling machinery offered in standard small wheel loaders an overload warning device that alarms the driver when he exceeds the permissible load and thereby prevents incidents. It was only standard equipment in telescopic handlers and telescopic wheel loaders of the two manufacturers according to CEN (2008). To meet these requirements, a controlled and progressive system for lowering the boom for positioning was used by the manufacturers. The operating speed is adjusted to the load in each case. The system indicates to the user the extension of the boom achieved with regard to the respective load, and interrupts the aggravating movements of the machine in order to avoid possible tilting of the vehicle.

3.3 Prevention

The prevention measures are presented in three sections: constructive changes (rollover protective structure, safety belt and chassis concept), additional safety equipment (weight sensor with overload warning, driver assistance systems and rollover warning systems) and user information and behavior.

3.3.1 Constructive changes

ISO (2008a) and ISO (2008c) stipulate that ROPS must be mounted on tractors and self-propelled harvesting machines if there is a risk of rollover. For load transportation vehicles, these requirements are included in EC (2006) and in CEN (2006). ROPS can be designed, for example, as cabins or as simple roll bars. The rollover protection was designed to protect the tractor driver from serious injury in case of a rollover. A rollover protection absorbs the energy of the shock and prevents the operator coming into contact with the ground or objects thereon. A ROPS provides a safety zone and a buffer zone for the driver (Dogan et al., 2010).

A cabin protects better than a roll bar, because it keeps the driver within the safety area of the cabin (Springfeldt, 1996; Springfeldt et al., 1998). Roll bars prevent the vehicle to roll over multiple times and if the driver wears the seat belt it keeps the driver within the safety area (Myers et al., 2009). Many tractor cabs, especially for small tractors and increasingly in non-European countries, such as Turkey, are usually simple sun and rain protection covers (Dogan et al., 2010). The major disadvantage of these security structures is that tractors with roll bars or cabins cannot be used in low-rise buildings or under trees (Özdes et al., 2011). Research has been conducted for automatically upturning roll bars that extend in unsafe situations (Mashadi and Nasrolahi, 2009). Another option is to develop a foldable ROPS that can be folded up and down with the push of a button (Ayers et al, 2012) or to develop fixed ROPS that can be used for harvesting specialty crops thanks to their special shape (Gattamelata et al., 2012). A specially designed foldable protective device for small wheel loaders for rollover protection and protection against falling objects, which was designed according to EC (2006), is available on the market. The protective device can be quickly adapted to changing operations. Even if the protective structure is folded, a minimum level of rollover protection remains (Landtechnikmagazin, 2011). Pessina and Facchinetti (2013) pointed out that the use of ROPS-approved structures for self-propelled machines in agriculture is fairly new. Due to the different self-propelled machines available on the market, characterized by very different mass, dimension and working functions, the fitting of a ROPS and consequently the ascertainment of its protection level is quite complicated. For example, the location of the driver's place on tractors compared with that of self-propelled machines is often quite different.

ROPS are most effective in combination with a safety belt that keeps the driver within the safety zone of the ROPS. For agricultural machines in general, ISO (2008a) stipulates the necessity of mounting points for a restraint system and its existence on the seat if the machine is equipped with a ROPS. In countries with a high majority of the tractors equipped with cabins, the fasten seat belt rate is very low because wearing a seat belt interferes with the working process in which the belt has to be put on and off very often (Day, 1999). Day et al. (2004) showed in their studies that the proportion of wearing seat belts in tractors is very low in the Canadian province of Victoria. If a person is thrown out of the cabin and the safety zone during an incident, the person may be crushed under the vehicle. To encourage drivers to wear seat belts, they must be designed so as to be comfortable and to guarantee easy removal (Miller and Fragar, 2006). Myers et al. (2009) pointed out, however, that a safety structure does not guarantee injury-free rollovers together with a belt.

To ensure the slope stability of tractors, a chassis concept was developed by a company in which the central two-piece frame is coupled with a central pivot. There can be achieved at the same time a low overall height and a low center of gravity. The two driven and steerable axles are permanently integrated into the frame halves and fitted with four equally sized wheels (Knüsel, 2006).

3.3.2 Additional safety equipment

In load transportation with special vehicles for load transportation or tractors with front end loaders, the wrong weight distribution is a huge source of danger. Additional safety equipment offers ways to reduce the risk of incidents. A weight sensor can detect the load carried and warns the driver when exceeding the permissible load (Könnecke, 2007). Related to the load, the lifting height and speed of the vehicle can be adjusted in order to prevent rollovers (Horberry et al., 2004). A device for overload protection which stops the movement of a loader and reduces the charging power is available on the market. Telescopic wheel loaders have to have assistance systems installed according to CEN (2008), which automatically retract the telescopic arm slightly before reaching the overload without interrupting the work flow.

The ground on which vehicles move is influenced by many factors that are partly responsible for difficult operating conditions. Soils and streets are wet; vehicles slide off and roll over. There is a possibility to equip tractors, self-propelled harvesting and load transportation machines with driver assistance systems that affect vehicle dynamics and thus avoid dangerous situations. A sensor system for detecting the current drivability of soils would be a solution for working on fields and meadows. Brunotte (2011) developed a sensor system which was designed to identify the compaction of the soil during driving and to adjust the load situation with the air pressure of the tires. With the development of ultrasonic and laser measurement techniques for trace depth or dynamic tire deformation, the technical requirements are created to develop sensor systems for incident prevention. Nichol et al. (2005) developed a device that informs the driver of possible instability via a display. The device is equipped with sensors to detect the dynamic characteristics of the tractor which it processes by means of a predictive mathematical model of the risk to inform the operator of a potential instability of the tractor and to propose corrective measures.

The slope of the land plays a causal incident role. There are already rollover warning systems that calculate the angle between the ground and vehicle, and draw the driver's attention to the danger with the help of a warning signal (Özdes et al., 2011). In this case, a microprocessor may be used including an inclinometer to calculate the static stability. Further, the load of the wheels can be calculated. From these parameters, the static slope limit of the vehicle is accurately calculated (Owen and Hunter, 1988). In South Tyrol, an electronic rollover prevention device was developed to prevent rollovers by using continuous monitoring and displaying the dangers which are calculated by comparing the soil properties and driving style of the operator. The system includes sensors, GPS and a switching unit with microprocessor. A large color display provides the driver constantly with clear and easy-to-understand information about the dangers (Cobo, 2012).

3.3.3 User information and behavior

Warning stickers on the machine and warnings in the operating manual are used very often to indicate dangers. These are perceived differently. They are only a juridical safeguarding for the manufacturer, but no active prevention measure for the majority of drivers. The more warning stickers are on a machine, the more they are being ignored by drivers. For load-carrying, the weight of the load and the distribution of the load play a relevant role in incident prevention. For example, in many load handling vehicles the driver's space must provide a table or diagram specifying the load permitted for each operating state. In the immediate danger situation when the driver is under stress, this kind of sticker or diagram does not help at all. The driver must know simple rules of behavior and improve this experience every day. This is not possible with warning stickers. Basic requirement for the prevention of incidents with special vehicles for load transportation or for tractors with front end loader is the appropriate vehicle ballasting to prevent a rollover forward or to the side. A rear ballasting must be done to avoid a discharge of the axle and braking force reduction.

The safe operation of vehicles strongly depends on the driver. The skills, experience or reaction time are often crucial to prevent incidents (Murphy et al., 1985). Nichol et al. (2005) are sure that while most experienced tractor operators develop an intuitive feeling in perceiving hazardous situations, there are many inexperienced young or casual workers who have no specific training in driving a tractor safely.

The fundamental requirements of incident prevention for all three investigated vehicle categories are simple rules that must be followed by the driver. Safety belts must be used, the ballast of the vehicle must be matched to the equipment as well as the load, the speed must match the circumstances and all of the approved maximum legal loads must be respected and should not be exceeded. On slopes, if possible, machines should be driven into the fall line uphill or downhill. On the mountain, the vehicle has to be driven straight to the least inclined point down and not across. Turning maneuvers on slopes should be avoided. There is an increased risk of a rollover when the load is elevated, especially in load handling. In addition, the load should always be taken as close to the forks as possible (Huber, 2010).

Soil condition, capacity and structure should always be judged before entering a field, meadow or forest (Huber, 2010). A machine should not be driven on unknown terrain, where the operator cannot be sure about potential dangers. The nature of the terrain cannot be influenced, in some areas however improvements are possible, like through the maintenance of road surfaces and of entry and exit routes (EU-OSHA, 2012).

A driver gains experience not only from years of work but also from practice. Safetyand risk training with agricultural vehicles are a way to learn about the dangerous situations in a work environment. For Jaarsma and De Vries (2012), driving safety trainings should be integrated into the driving license training. This would add a better hazard and risk education to the driving instruction. In particular, sudden lurching and breaking out of the trailer or the right way of using the brakes should be practiced (Chi and Han, 2013). It would be best if safety trainings were attended with the own vehicles because every vehicle type reacts differently in hazardous situations. If this is not possible, the training participant should practise with the vehicle that matches their own vehicle as closely as possible. Furthermore, it is important that the vehicles used for the safety trainings are equipped with trailers and implements that match each other in size. In addition to the training on asphalt, there should also be a training session in fields or meadows, preferably on steep terrain. In addition, important information on cargo securing and personal health should be addressed (Schagerl, 2010).

4 Conclusions

In preliminary investigations, the causes of rollover incidents were determined by means of a database analysis, a survey of victims and an analysis of incident reports. On this basis, an overview of contemporary safety equipment was created with the evaluation of new machinery. It was found that the implementation of recommendations by standards and guidelines for the design of vehicles was not always done to a satisfactory level, which was confirmed by the manufacturer surveys. Standards and guidelines were interpreted differently. The reason for this was the number and the complexity of standards and guidelines, as well as their classification and assignment to the respective types of vehicles. The manufacturers stated that for rollover incident prevention constructive changes and additional safety equipment have to be integrated into the vehicle design already in the factory. But the development and integration of the prevention measures into the vehicle entail high costs for the manufacturer. These costs must be carried by the customer. It is the cost-benefit ratio of the technical solutions that decides about their market acceptance.

Based on the manufacturer survey and the new machine evaluation further prevention measures for rollover incidents were researched. No prevention measures were developed newly or specifically for a vehicle category. They can be applied together for tractors, self-propelled harvesting machinery or material handling machinery and they were already available as standard or desired equipment. The preventive measures were prepared for presentation according to a predetermined legal scheme as constructive changes, additional safety equipment and user information: the constructive changes to reduce the rollover risk with tractors, self-propelled harvesting machinery and material handling machinery were the rollover protective structure, the safety belt and the general chassis concept. As additional safety equipment weight sensors, driver assistance systems and rollover warning devices were mentioned. In the field of user information and behavior the focus was on the general rules of behavior for rollover incident prevention.

The simultaneous investigation of the three different vehicle types, tractor, self-propelled harvesting machinery and material handling machinery, offered on the one hand a larger number of rollovers available for examination and on the other hand more suitable results for general rollover prevention. But in further studies, prevention measures should be worked out in detail and individually for tractors, self-propelled harvesting machinery and material handling machinery. There should be a concentration on the rollover problems and solutions for a specific target machine type. If a new technology is being developed to prevent incidents, the developers have to design it individually for a specific vehicle category. For tractors, self-propelled harvesting machinery and material handling machinery and both for new machinery and for older vehicles, the most important incident factor is the driver. The driver must be trained and sensitized for the dangers. The human factor is, as mentioned by the interviewed agricultural machinery manufacturers and in spite of all the technical possibilities, the biggest unknown factor in rollover prevention. The driver is primarily responsible for not entering into dangerous situations when operating a vehicle. Although, a technical advice can reduce the risk of injury to the driver and sometimes even prevent a rollover, the driver's inhibitions to enter into more dangerous situations are massively increased as a consequence.

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