Prevention aspects for avoiding run-over incidents in agriculture together for tractors, self-propelled harvesting machinery and material handling machinery

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Abstract: Run-overs are one of the most common incident scenarios with tractors, self-propelled harvesting and load transportation machines in Austrian agriculture. The aim of the study was to describe sustainable prevention measures against these kinds of incidents. For this purpose, the compliance with safety standards and directives in new machinery was investigated, currently available prevention equipment was identified and manufacturers were asked about the difficulties in the implementation of prevention measures against run-overs in new vehicles. In addition, a literature and internet research was done. The evaluation of new machines showed that self-propelled harvesting machines and tractors tended to be more frequently equipped with relevant safety technology, such as lights or mirrors, than evaluated load transportation vehicles. Additional technical equipment for detecting people, such as reversing cameras, were found only in about 10% of the tractors and vehicles for load transportation. Standards and directives to prevent run-overs were applied mostly by all manufacturers surveyed. Manufacturers designed the hoods and panels of the vehicles as clear as possible to achieve the best visibility for the driver. Blind spots cannot be avoided, so automatic detection systems and camera systems, and the combination of these two systems, are considered to be the most interesting safety assistance systems in the future. The main factors in run-over incident prevention remain the people. The fundamental requirement of preventing incidents is that the driver himself and the pedestrians in the environment follow safety rules.

Keywords: agricultural machinery, run-over, incident, prevention

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1 Introduction

Being run over is one of the most frequent incident scenarios with tractors, self-propelled harvesting and agricultural material handling machinery in the Austrian agriculture (Mayrhofer et al., 2013a; Mayrhofer et al., 2013b; Mayrhofer et al., 2014). International studies show a similar picture. Research from Canada revealed that 18% of all fatal agricultural incidents from 1990 to 2008 were machine run-overs (CAIR, 2011). Around 23% of all fatal tractor incidents in the Turkish province of Konya were run-over incidents (Dogan et al., 2010). The run-over is one of the most common fatal incident scenarios with construction vehicles. Camino et al. (2008) that analyzed the construction site incidents from 1990 to 2000 in Spain found that 1.2% were vehicle run-overs.

Tractors, self-propelled harvesting machines and machines for load transportation have similarities in main run-over incident causes that were elaborated together in preliminary studies (Mayrhofer et al., 2013a; Mayrhofer et al., 2013b; Mayrhofer et al., 2014). Faulty operation,

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distraction or inattention, technical defects and the sudden illnesses of involved persons in combination with a lack of vision were detected as the main causes of run-over incidents. The aim of this study was to present sustainable prevention measures against run-overs in a concise way together for tractors, self-propelled harvesting machinery and material handling machinery.

2 Materials and methods

To reach the aim of the study a comprehensive package of measures was necessary (Figure 1). First a new machine evaluation was done to investigate the compliance with safety standards or directives and to establish an overview of current safety technology. On this basis interviews with manufacturers of tractors, self-propelled harvesting machinery and material handling machinery were conducted about the implementation of safety measures in new vehicles. Finally a literature and internet research was done.

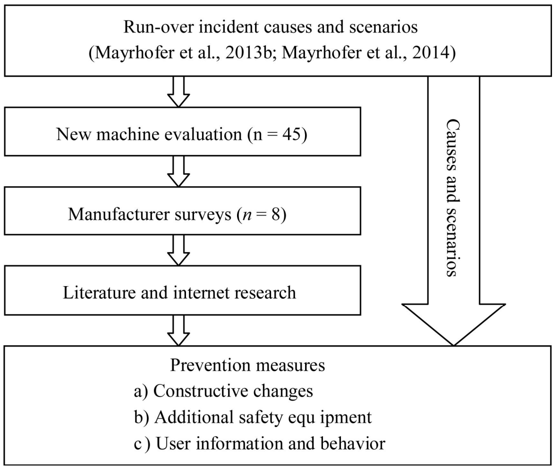

Figure 1 Flow diagram of materials and methods

The new machine evaluation was done for 45 new machines including 25 tractors, six self-propelled harvesting machines (three two-axle mowers and three transporters) and 14 machines for load transportation (nine wheel loaders and five telehandlers). About 56% of the tractors (14/25) had an engine power over 100 hp and 28% (7/25) had a continuously variable transmission. 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. At the evaluation it was recorded whether or not the machines had windshield wipers, working lights, rearview mirrors, wide angle mirrors, audible reverse warning systems and rearview cameras. These evaluation requirements were stipulated in EC (2006), ISO (2008a), ISO (2008b) and ISO (2008c). The frequencies observed were entered into a database, classified and described descriptively in percentages. To describe relationships between vehicle types, 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 new 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 steps at tractors and by Farmer et al. (1997) for evaluating brakes of cars.

Manufacturer surveys were conducted to generate information about the difficulties of the implementation of preventive measures from standards or directives, about currently used and prospectively planned incident prevention technologies. Manufacturer surveys were also used by Quendler et al. (2013) and Leskinen et al. (2002) carrying out reasons for the selection of the design of boarding steps 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. Eight manufacturers were surveyed with two semi-standardized questionnaires. One questionnaire was designed for manufacturers of tractors and self-propelled harvesters and the other one for manufacturers of load transportation machines to address the specifics of the vehicle categories and their incidents. The majority of the questions were open questions and yes/no questions with a subsequent text field to justify the answer. For run-over incidents it was necessary to find out if manufacturers complied with the standards and directives in the vehicle design and what problems existed in the implementation. Questions were asked related to the prevention of future incidents and on the potential of specific technologies or tools to prevent run-over incidents. Eight out of 13 manufacturer contacted supported the study (Table 1).

Table 1 Manufacturers surveyed

Manufacturer	Tractors	Self-propelled harvesting machinery	Materials handling machinery
1	Tractors (55-670 hp)	Combines	-
2	Tractors (70-390 hp)	Combines Forage Harvesters	-
3	Tractors (40-260 hp)	Combines	
4	Tractors (75-145 hp)	Two axle mowers Transporters	-
5	-	Two axle mowers Transporters	-
6	-	Self-propelled sugar beet and potato harversters	-
7	-	-	Wheel loaders Excavators Telehandlers
8	-	-	Wheel loaders Telehandlers

The information provided was evaluated anonymously. The answers to the quantitative and qualitative questions were categorized and described descriptively by frequencies. Due to the small sample size, no analytical statistical testing was possible.

The literature and internet research is a suitable method for working out incident prevention measures. Suutarinen (2003) for example studied tractor incidents and used a literature and internet research to work out preventive measures. In this case, a literature and internet research was done to define prevention measures that can be applied together for tractors, self-propelled harvesting machinery or material handling machinery against run-over incidents. They should already be available on the market. There was no measure developed specifically for a vehicle category. A general representation was carried out. 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 as constructive changes (design of hood and panels, lights and frame construction), additional safety equipment (wide angel mirrors, audible reverse warning, camera systems, detection sensors and transponder systems) and user information or behavior.

3 Results and discussion

3.1 New machine evaluation

As shown in Table 2, self-propelled harvesting machines and tractors were significantly (p=0.0025, Fisher) more often equipped with a windshield wiper than the evaluated machines for load transportation. A windshield wiper was standard equipment on all vehicles with glazed cabins. Working lights on vehicles are necessary for visualization of the vehicle surrounding in a dark environment. The equipment level of the evaluated vehicles with at least two working lights front and rear corresponded to a very high level. At a rate of more than 90%, tractors (92.0%; 23/25) and machines for load transportation (92.9%; 13/14) had working lights mounted more frequently than self-propelled harvesting machines. For self-propelled harvesters, it was only one vehicle that did not have two working lights. The standard equipment with at least two working lights in the load transportation (92.9%; 13/14) and tractors (84.0%; 21/25) was significantly (p=0.0030, Fisher) more frequent than in self-propelled harvesting machines (33.3%; 2/6). Rearview mirrors are a suitable tool for detecting obstacles and persons in the vicinity of vehicles. All self-propelled harvesters had two rearview mirrors. The tractors were equipped with mirrors at a rate of almost 90% (88.0%; 22/25) and the specialized load transportation machinery at a rate of almost 80% (78.6%; 11/14). Two rearview mirrors as standard equipment were more common in tractors with a share of 84.0% (21/25) than in the load transportation (78.6%, 11/14) and self-propelled harvesting (66.7%, 4/6).

Wide-angle mirrors were available on the market as additional equipment for 50% (3/6) of the evaluated self-propelled harvesters and for 20% (5/25) of the tractors. But only two evaluated tractors (8.0%; 2/25) were equipped with this additional safety equipment (see Table 2). As an additional technical device for the detection of obstacles and people around the machinery an audible reverse warning system was mounted only at four vehicles for load transportation (28.6%; 4/14). As additional equipment, an audible reverse warning system was significantly (p=0.0064) more commonly available with almost 90% (85.7%; 12/14) in the load transportation than in self-propelled harvesters (66.7; 4/6) and tractors (48.0%; 12/25). A rearview camera was found in two evaluated load transportation machines and in two tractors each. It was not a standard equipment in any vehicles. As additional equipment, a rearview camera was more often available in the load transportation with approximately 86% (12/14) than in self-propelled harvesting machines (66.7%; 4/6) and tractors (48.0%; 12/25).

Table 2 Run-over standard and additional prevention equipment of evaluated new tractors, self-propelled harvesting and materials handling machinery

		Tractor		Self-propelled harvesting machinery		Materials handling machinery	
		N	%	N	%	N	%
Standard	Windshield wiper	22/25	88.0	6/6	100.0	7/14	50.0
	Working lights	23/25	92.0	5/6	83.3	13/14	92.9
	Two rearview mirrors	22/25	88.0	6/6	100.0	11/14	78.6
Additional	Wide angle mirror	2/25	8.0	0/6	0	0/14	0
	Audible reverse warning system	0/25	0	0/6	0	4/14	28.6
	Rearview camera	2/25	8.0	0/6	0	2/14	14.3

3.2 Manufacturer survey

The manufacturer survey showed that for the prevention of run-overs two thirds of the interviewed manufacturers of tractors and self-propelled harvesting machinery (66.7%, 4/6) took into account ISO (2008a) and ISO (2008b) where the operator must have an adequate field of vision to drive the machine and to see the work area. According to DIN (2010) self-propelled harvesting machines must be equipped with a warning device that has to be switched on automatically when reversing. The manufacturers which have to apply the standard indicated that they used the standard in their construction. With regard to run-over incidents that involve passers-by, drivers of load handling machinery must have sufficient visibility according to DIN (2009) together with the standard ISO (2006). All surveyed manufacturers of load handling machinery (100%, 2/2) took into account these requirements. The view from the driver's space in their vehicles was stated to be so good that the driver could operate the machine and its tools in their intended conditions without any danger to themselves and others. Technologies that are currently offered by manufacturers of tractors and self-propelled harvesters to prevent run-overs were optional wide-angle mirrors and optional camera-monitor systems. Manufacturers of load handling machinery used optical and acoustic reverse warning systems and at large wheel loaders and telehandlers wide-angle mirrors and rearview cameras. The rearview cameras were classified as inadequate by four manufacturers because it is difficult to focus on several monitors simultaneously while operating a vehicle. Further potential to prevent run-over incidents was seen in assistive technology, with special mirror systems, automatic recognition systems of living organisms in the environment of the machine and cameras. For the view behind the vehicle, cameras are an appropriate solution. The problem with current camera systems was that the distance could not be estimated. According to one third of the manufacturers (37.5%, 3/8), the future detection system should make use of sensors. Camera systems with distance estimation sensors and a corresponding presentation of the data in the cabin are possible future technologies. At the time of the surveys these technologies were very expensive to install in the vehicle and mostly not practicable for agriculture. Constructive improvements in vision can be achieved by tapering the hood and trim. This leads to a reduction of the non-visible area around the machine. Improvements in this area did not exist for the manufacturers because of the requirements concerning exhaust gases. Due to the required exhaust gas treatment, systems with a higher cooling capacity and larger coolers needed to be installed which had negative effects on the visibility for the drivers.

3.3 Prevention

3.3.1 Constructive changes

To avoid run-over incidents, the visibility from the driving position plays a crucial role. Teizer et al. (2010) and Leisering (2011) found that in incidents with machines used for load handling and earthmoving, people were injured because they had been working in the environment but had not been noticed by the driver in time. This happened also with tractors and self-propelled harvesting machines. The driver's limited field of vision in large agricultural machines is a major run-over cause (Quendler et al., 2009). Visual field constrictions in tractors result from surface vehicle components, such as the hood and side fenders. The most immediate visual field constrictions of tractors are found in the area of large rear wheels and in front of the hood (Quendler et al., 2009; Chang et al., 2010). Particular vision limitations arise in the load handling when driving with a raised load. For example, the mast in combination with a shovel strongly restricts the visibility for the driver (Wang et al., 2010). Other factors influencing the view of the driver of self-propelled machines are the driving environment, the design of the yards, planted or cultivated fields or buildings.

Constructive improvements in vision can be achieved by tapering the hood and panels. Some manufacturers of tractors have developed clear-view concepts. Through the construction of a sloping hood, the driver's view to the front can be greatly enhanced and the size of the non-visible area around the machine reduced (Könnecke, 2007). This has security advantages and facilitates the view and operation of attached equipment. In addition to the view to the front, it is necessary to improve the overall visibility around the tractor (Miller and Fragar, 2006; Quendler et al., 2009). In the dark it is – in addition to the visibility for the driver – necessary to improve the visibility for pedestrians. Therefore the design as well as the luminosity and the brightness of the lights have to be improved, as Jaarsma and De Vries (2012) stated. LED-lights could be used on vehicles as work lights, as they offer good illumination while being low in energy consumption (Su et al., 2012). After Profi (2012) LED lights are expensive to purchase, but depending on the vehicle, the use and the frequency of use, there are good reasons to favor the use of LED lights in agricultural machinery. They are completely insensitive to vibrations, immediately 100% bright and extremely durable.

3.3.2 Additional safety equipment

In this section the most important additional safety devices against run-overs together for tractors, self-propelled harvesting machinery and materials handling machinery are presented. Their main advantages and disadvantages are given in Table 3.

Table 3 Main advantages and disadvantages of additional safety equipment

Additional safety equipment	Advantage +	Disadvantage -
Wide angle mirror	Easy to retrofit	Blind spot remains
Audio reverse warning	Automatic activation	Warning effect wizzles
Camera systems	Flexible and cost effective	Difficult distance estimation
Detection sensor	Activates only in case of danger	Not weather- and dirt-resistant
Transponder system	No blind spots	People must wear a transponder

A simple additional safety equipment to prevent run-over incidents is the wide-angle mirror that is added to the main mirror as additional or retrofit equipment (Teizer et al., 2010; Olejnik, 2005). An electronic device for the run-over incident prevention is the audio reverse warning that is activated automatically with the reverse gear. People who are in the vicinity of the vehicle are warned by the audible reverse warning device when the vehicle reverses (Miller and Fragar, 2006). The disadvantage is that the warning effect fizzles, so that people often no longer react to the audio warning (Cohrs, 2012). Another possibility to recognize persons are rear view monitoring systems with cameras that allow the driver to view on a screen in the cab the area that the camera captures (Teizer et al., 2010; Yang et al., 2012). The cameras can be mounted to different places of self-propelled agricultural machines, for example at tractor attachments, on the forklift mast or at the rear of large self-propelled harvesting machines such as combine harvesters. After Quendler et al. (2006), simple camera-monitor systems are the most cost-effective products available for viewing the vehicle's environment. The disadvantage of simple camera systems is that the distance estimation is difficult via the monitor (Katzwinkel et al., 2012). Due to the difficult distance estimation with simple camera systems, a manufacturer of electronic components offers a multi-functional camera with image processing that recognizes objects based on predefined and trained object classes like pedestrians or vehicles (Bosch, 2014; Garcia-Alegre et al., 2012).

Sensors that are used in the automobile and construction industries are another possibility for obstacle detection. The sensor system informs the driver of the distance between the vehicle and a possible obstacle. There are different technological opportunities that are based on ultrasound, laser, radar and infrared (Braun, 2011; Arnold, 2004). The advantage of these active warning systems is that they point out the danger when it is given. The driver does not have to pay attention permanently to a screen, such as it is the case with camera systems (Cohrs, 2012). According to Könnecke (2007), the disadvantage of these devices is that they can be disturbed by effects of weather and are unable to distinguish between an object and a person located behind the vehicle. After Quendler et al. (2006), sensor systems require substantial cabling. A combination of camera and ultrasonic system is offered as a driving assist system for commercial vehicles. This system is used for monitoring the rear end of sugar beet harvesters. The distance values measured by the 12 ultrasonic sensors used can be transmitted to the vehicle control, where they are displayed in superposition with a rear-mounted camera to the driver (Inmach, 2013).

Another approach of technology for detecting people are transponder systems that are being considered for children who move frequently unobserved on farms as well as for people working or being present in the vicinity. Cooperative radar wave transponders are combined for the rapid detection in the direction of travel and for the identification in the electric near field. When the stray fields of humans and machine intersect, the mutual influence can be detected and their presence can be communicated to the driver. The aura fills every corner on agricultural vehicles and equipment carried, so that there are no blind spots (Quendler et al., 2009).

3.3.3 User information and behavior

For the prevention of run-over incidents behavioral changes among farmers are necessary. In order to communicate this there were several campaigns in different countries. For example safety directives for farming operations in Ontario were worked out to help employers, supervisors and workers on farms to recognize hazards (Ontario Ministry of Labour, 2006) or a handbook on the safe use of tractors with attachments was designed by the Government of Western Australia (2009). The purpose of this handbook was to outline the legal requirements and to provide known industry solutions and strategies to ensure the safe operation of tractors with attached implements on farms. In order to identify the potential hazards in their own vehicles and in the work environment, operators should analyze them in more detail and discuss them other people involved (Teizer et al., 2010). A checklist was published by IAREH (2010) therefore as a safety management tool for farmers to evaluate the safety risks of the own farm vehicles. A separate section is devoted only to run-over incidents. There were education materials with tips for the tractor drivers to prevent run-overs published within the Farm and Ranch Safety program at Texas A&M University (Smith, 2004). In the United States there was the National Safe Tractor and Machinery Operation Program for youth ages 14 and 15 on agricultural hazards, tractors, connecting/using implements with tractors and materials handling (Harshman et al., 2011). Especially to minimize the incident risks with children and young persons, it is important that the work area on the farm is not used as a playground (Dogan et al., 2010). But it is very difficult to set up separate living and work areas on farms, especially on family farms. After Miller and Fragar (2006), both fences and closed doors should separate the living and work areas, and pedestrians should only move around in areas where there is no vehicle traffic. If pedestrians move around vehicles, they must be wearing high-visibility clothing. People who approach vehicles should always try to make eye contact with the driver before they move close to the vehicle. Approaching from behind should be avoided.

4 Conclusion

Tractors, self-propelled harvesting machines and material handling machines show similarities in main run-over incident causes. The view for the driver and the presence of blind spots are the most important incident risks (Mayrhofer et al., 2013b). New machines are equipped with technology for run-over incident prevention, like lights or mirrors but it depends on the type of the vehicle, the standard equipment and the opportunities in equipping with additional prevention measures. Additional safety equipment for the detection of persons was found only in a few vehicles, because this was not offered as standard equipment. The advantage of the new machine evaluation was that an overview of contemporary safety equipment and the compliance with standards and guidelines was worked out without disassembling the machines. The sample size was large enough to be representative for the Austrian situation.

As it became apparent in the new machine evaluation, standards and directives to prevent run-overs in the vicinity of vehicles were applied by all manufacturers surveyed depending on the vehicle category. Manufacturers designed the vehicles as clear as possible to achieve the best visibility for the driver. There were also extra security technologies offered as optional equipment. The biggest challenge for the manufacturers was the adaption of the vehicle design to standards and directives for the exhaust after-treatment.

Based on the manufacturer survey and the new machine evaluation further prevention measures for run-over incidents were undertaken research. No prevention measures were developed newly or specifically for a vehicle category. They were able to be applied together for tractors, self-propelled harvesting machinery or material handling machinery and they were already available as standard or desired equipment. Generally the basic design of the vehicle as well as the design of hoods and panels must be improved. The vision must be the best possible to be able to view both the tasks necessary for the actual work process and the environment. Automatic detection systems, camera systems and the combination of these two systems are the most interesting technologies to prevent run-over incidents with pedestrians in the future. A disadvantage of these systems is that they cannot replace the driver's vision, but only offer assistance. These technologies need to be further studied and improved, because they can be used in all the three investigated vehicle categories. And they need to be made practicable for agriculture and designed to withstand the strain posed by dust, dirt and shock during agricultural work processes. The retrofitting of existing vehicles should be also possible.

The most important incident factors are the drivers and the pedestrians. Simple rules should be followed as long as assistant prevention technologies are not reliable. People are not to be allowed to stay and walk in the vicinity of vehicles without eye contact to the driver. Drivers of vehicles must be informed of the presence of persons in the vicinity. This has to be taught in the agricultural sector and has to be taken into account in the education of children.

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