Analysis of Accidents Rate of Agricultural Off-Road Vehicles

Analýza nehodovosti poľnohospodárskych terénnych vozidiel

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Abstract

In this contribution, we deal with the analysis of the accident rate of agricultural off-road vehicles and fatality figure of service personnel. We analyse reasons of accidents of agricultural mechanisms, however mostly tractors, as well as their consequences. The research was oriented mainly to machine overturn (rollover). We also analyse injuries of service personnel that occurred following the vehicle rollover as well as following the disregard of occupational safety regulations. In the contribution, we present results of the research in Slovakia, which were registered by National Labour Inspectorate in years 2000 – 2012 as well as the unregistered one.

Keywords: off-road vehicles, operating safety, tractor overturn

Abstrakt

V príspevku sa zaoberáme rozborom nehodovosti poľnohospodárskych terénnych vozidiel a úrazovosti obslužného personálu. Analyzujeme dôvody nehôd poľnohospodárskych mechanizmov najviac však traktorov ako aj ich dôsledky. Výskum bol zameraný hlavne na prevrátenie stroja. V ďalšom analyzujem úrazy obslužného personálu, ktoré vznikli v dôsledku prevrátenia vozidla ako aj v dôsledku zanedbania predpisov o bezpečnosti práce. V príspevku uvádzame výsledky výskumu na Slovensku, ktoré boli evidované Národným inšpektorátom práce v rokoch 2000-2012, ako aj údaje neevidované.

Kľúčové slová: prevádzková bezpečnosť, prevrátenie traktora, terénne vozidlá

Introduction

The most of accidents and injuries are caused by agricultural machines and mechanisms on the sloping terrain. When working with off-road agricultural vehicles, one of the most important assumptions of safe, efficient and ecological operation is a stable state of the machine also during the work in the most extreme conditions. In this contribution, we will deal mainly with the agricultural vehicles working on the sloping terrain. The typical representative of agricultural off-road vehicle is a tractor.

The tractor is a motor vehicle used for a large amount of operations, starting with ploughing, pulling, carrying, pressing and ending with long-distance traffic in different conditions. It is designated for work and transport mainly in agriculture, forest or on some other uneven or unpaved terrain. The motion of off-road vehicle on the slope so that its rollover does not occur is markedly influenced by the position of the centre of gravity, tyre tread width and wheel base, and driving speed. That is why it is necessary to pay attention also to the issue of determination of the centre of gravity position. Following the change of the centre of gravity, situations in which the vehicle gets into a labile stability state can happen and also the risk of vehicle´s rollover can occur. Just rollovers together with the next most frequent type of the accident of agricultural vehicle – runover or striking the person by the vehicle are the main reasons of accidents in agricultural sector. In many times, occupational safety regulations are disregarded upon what another injuries and accidents can happen. European Agency for Safety and Health at Work (2012) introduces possible causes of overturning, which are clearly summarised in Table 1.

Table 1: Causes of overturning

Type of causal factor	Causal factors for overturning
1. Dangers intrinsic to tractors	- Stability problems caused by high centre of gravity and narrow wheel base - Lack of sensitivity in controls - Instability during towing operations
2. Irregular terrain	- Poor access to land - Irregular terrain, sloping land, presence of ditches
3. Inadequate training and preparation of the driver	- Failure of training - Lack of knowledge about the risks - Lack of knowledge about the limitations of the tractor
4. Technical fault	- Failure to maintain equipment
5. Unsafe acts or incorrectly implemented manoeuvres by the operator	- Combination of causal factors from (2) and (3) above

Smith (2009) states that a tractor rollover event occurs when its centre of gravity is displaced outside its base of stability. This holds true whether the tractor encounters a side rollover or rear rollover. As long as the tractor is operated such that the centre of gravity remains within the base of stability, the tractor will not roll over. The centre of gravity is defined as the point of equal weight distribution. This means that 50 % of the tractor's weight is distributed in front of this point and 50 % behind. This same principle applies from side to side and top to bottom. The base of stability illustrated in Fig.1 is defined as the area within the points where the tractor's wheels contact the ground. The base of stability depends upon the front- and rear-wheel spacing, and the axle-to-axle spacing.

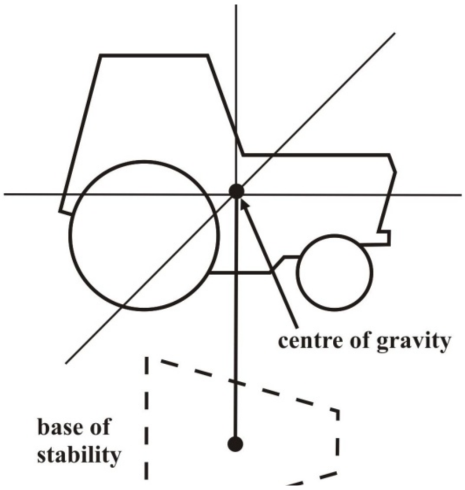

Figure 1: Illustration of centre of gravity and base of stability

As long as the tractor is operated in a manner whereby the tractor’s centre of gravity is within the base of stability, the tractor is not subject to rollover (Fig.2). However, circumstances that displace the tractor’s centre of gravity from within this safe zone will result in either a side or rear rollover incident.

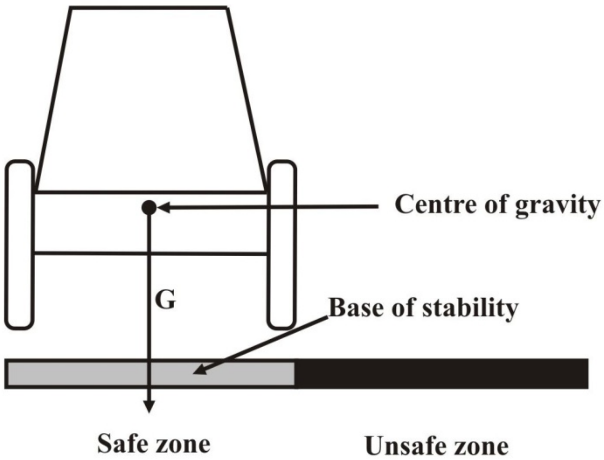

Figure 2: Safe and unsafe zone for tractor stability

In Fig. 3, there are illustrated side and rear overturns. According to N.C. Department of Labour, Occupational Safety and Health Division (2008), about four out of five overturns are side overturns. These overturns occur more frequently with tricycle-type tractors than with wide front-end (utility) type tractors.

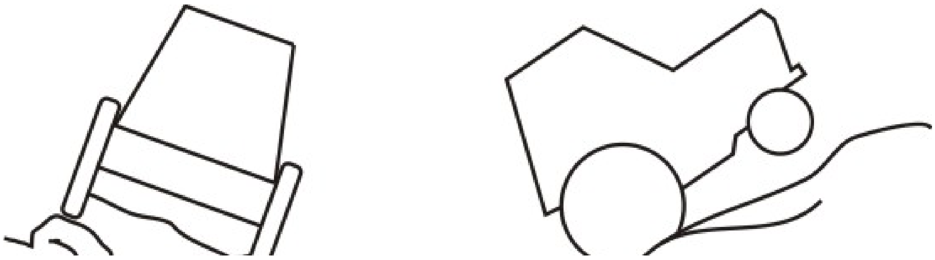

Figure 3: Side (left) and rear overturns

Side overturns take place primarily when the tractor is operated in the following conditions:

- too close to ditches, embankments or ponds;
- on too steep a slope;
- too fast for road or field conditions such as road curves, sharp turns or field depressions.

According to Smith (2009), approximately 85 % of all tractor rollovers are side rollovers. Side rollover occurs when the centre of gravity gets outside of the base of stability, as illustrated in Fig.4.

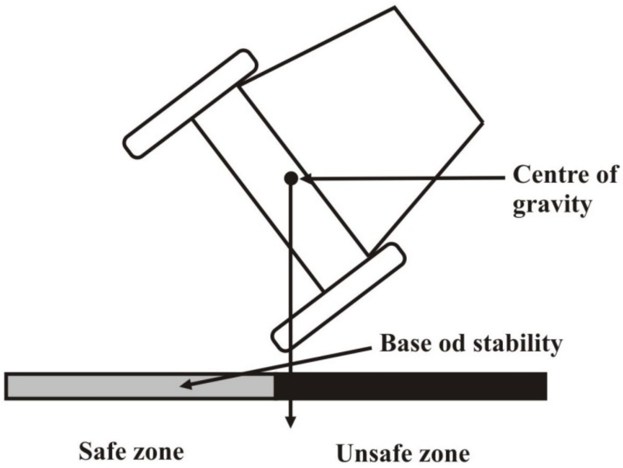

Figure 4: Position of centre of gravity during side rollover

N.C. Department of Labour, Occupational Safety and Health Division (2008) presents that rear overturns usually result from three conditions:

- when the tractor is incorrectly hitched to a load;
- when the rear axle is restrained while the wheels are stuck; or
- when the tractor is operated forward (up) or rearward (down) on too steep a slope.

Smith (2009) claims that rear rollovers are particularly dangerous because they happen so quickly. Operators have no time to react to avoid being injured or killed. Research of rear rollovers show that it only takes 0.75 seconds to reach the critical point of no return – Fig. 5a (i.e. for the centre of gravity to move over the rear axle and outside the base of stability – Fig.5b). From the time the tractor begins to rollover, the incident can take as little as 1.5 seconds.

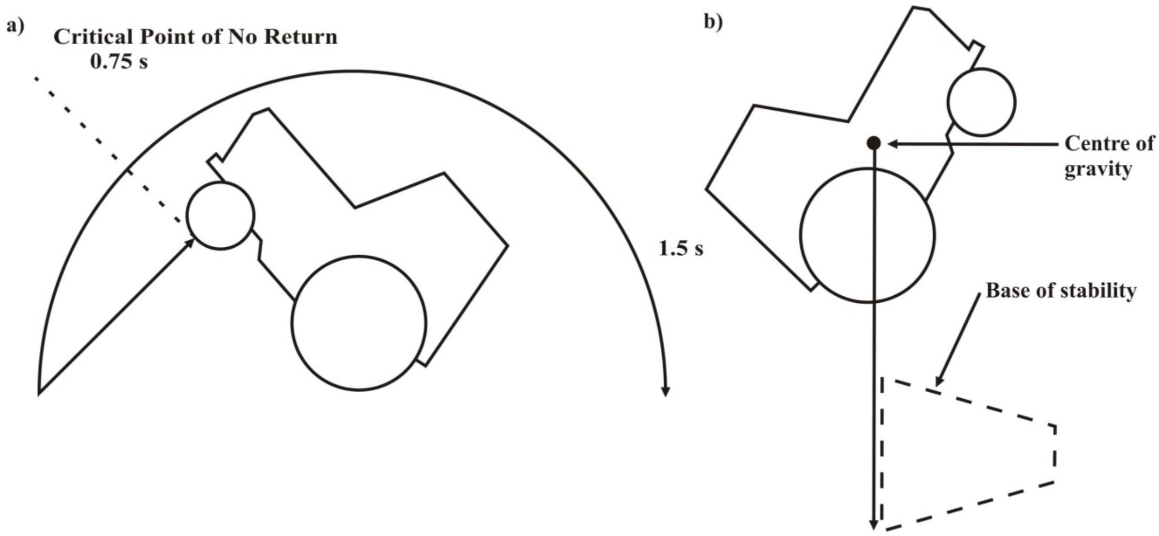

Figure 5: Illustration of rear rollover

One of the effective ways how to prevent the injuries during tractor rollovers is to work with tractors equipped with rollover protection structure that protects the drivers in case of overturn of agricultural and forest wheel tractor whereas the seat belt is also used. Directive 2009/57/EC of the European Parliament and of the Council presents in point 1.1 that rollover protection structure (safety cab or frame) means the structure on a tractor the essential purpose of which is to avoid or limit risks to the driver resulting from rollover of the tractor during normal use. These structures are characterised by the fact that in the event of rollover, they ensure an unobstructed space inside them large enough to protect the driver. Every rollover protection structure and its attachment to a tractor must be so designed and constructed as to fulfil the essential purpose – to avoid or limit risks to the driver. In the Slovak Republic, four regulations of the Government deal with rollover protection structures protecting the driver in case of overturn of agricultural and forest wheel tractor. These regulations are as follows: 323/2006, 237/2006, 328/2006 and 330/2006. They speak about technical requirements:

- on protection structures (323/2006);
- on protection structures tested by static tests (237/2006);
- on protection structures mounted in front of the driver´s seat of narrow-gauge agricultural wheel tractors and forest tractors(328/2006);
- on protection structures mounted on the rear part of narrow-gauge agricultural wheel tractors and forest tractors (330/2006).

The Regulations of the Government of the Slovak Republic No323/2006 and 327/2006 define that by the term protection structure is understood the safety cabin or frame the main purpose of which is to prevent or limit the risks for the driver resulting from tractor overturn during the ride, whereby it has to guarantee free space inside the structure that is large enough to protect the driver. Smith (2009) presents that early attempt to reduce tractor overturn deaths in the U.S. during the 1950s resulted in the development of rollover protection structures (or ROPS). ROPS are protective frames securely attached to a tractor for the purpose of preventing the operator from being crushed if the tractor overturns. A seat belt is used to prevent the operator from being thrown from the protective zone. ROPS typically limit overturns to 90 degrees.

Mashadi et al. (2009) claim that due to the fact that tractor rollovers cause over 50% of fatalities in agricultural accidents each year, rollover prevention, therefore, is an issue of major importance and the subject has been in focus of attention by several researchers. Rollover protective structure (ROPS) has been one of the most important advances in protecting the driver from tractor overturn accidents. However, some tractors are not equipped with this device. Some specific farming tasks do not allow tractors to be equipped with a ROPS.

Materials and Methods

Kupka (2012) presents that 50,175 people in the Slovak Republic worked in agricultural sector in 2011.The statistic year-book of soil fund in the Slovak Republic from the year 2012 (Úrad geodézie, kartografie a katastra Slovenskej republiky, 2012) presents total values of land types in 2011. Agricultural land was created by 2,410,812 ha, ploughland by 1,415,653 ha and forest land by 2,012,336 ha. In 2011, 0.4426 ha of agricultural land (0.2599 ha of it was the ploughland) fell on one inhabitant of the Slovak Republic. According to the last available data from 2009 (Ministerstvo pôdohospodárstva a rozvoja vidieka SR, 2012), Slovakia achieved a share only of 1.1% on the total agriculturally used land of the European Union countries.

Pursuant to European Agency for Safety and Health at Work (2011a),agriculture is one of the most hazardous sectors in terms of work-related accidents. Agricultural workers suffer 1.7 times the average rate of non-fatal occupational accidents and three times the rate of fatal accidents.

The main causes of these accidents according to European Agency for Safety and Health at Work (2011b) include:

- transport (being run over or vehicle overturns);
- falling from height (through fragile roofs, from trees, etc);
- struck by moving or falling objects (bales, trees, etc);
- trapped by something collapsing or overturning;
- livestock-related accidents and fatalities;
- asphyxiation / drowning.

Many news in media also testify about this situation. A lot of information talk about the killing of the driver as a result of tractor overturns on uneven or unpaved terrain. According to information of National Labour Inspectorate (Richterová, 2012), the total number of injuries in agricultural sector from 2000 was 12,874. Following the Act No 124/2006, occupational injury does not have to cause even short-time incapacity to work (injured employee is often returned back to work after treatment). This act presents that registered occupational injury is an injury that causes long-lasting missing from work when sickness absence is longer than three calendar days. National Labour Inspectorate in its records following the Act No 124/2006 divides registered occupational injuries into the following categories:

- fatal occupational injury (occupational injury resulting in death) – if occupational injury causes death;

- heavy occupational injuries (heavy bodily injury) – if occupational injury causes serious health disorder or disease;
- occupational injury with sickness absence at least 42 days;
- other occupational injuries (registered occupational injuries).

Occupational injury with heavy bodily injury, occupational injury resulting in death and occupational injury with sickness absence at least 42 days is collectively known as serious occupational health.

Results

As can be seen in Fig. 6, in the agricultural sector, there were 90 fatal occupational injuries between years 2000 and 2012. The number of occupational injuries with heavy bodily injury is 180 and the number of occupational injuries with sickness absence at least 42 days is 735. The remaining 11,869 injuries were less serious injuries, which were classified by the labour inspectorate into the category other (registered) occupational injuries.

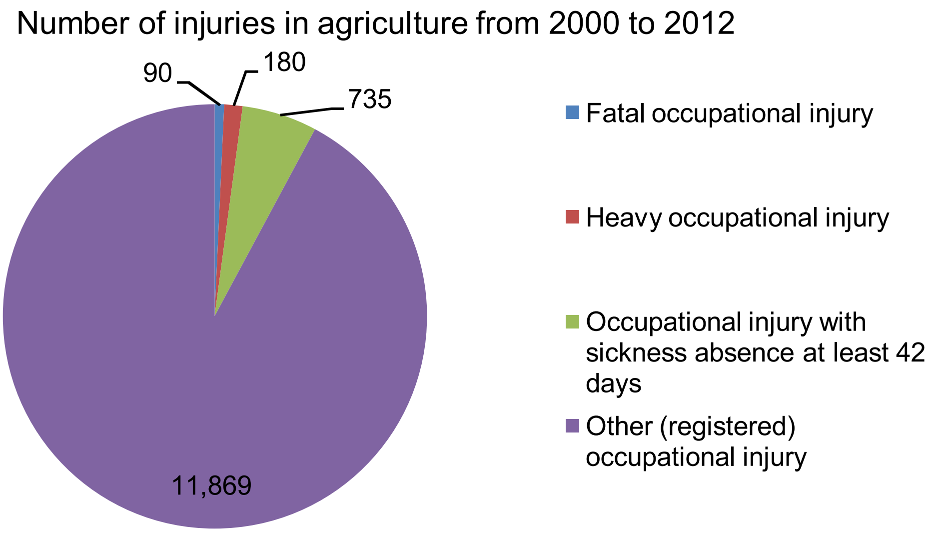

Figure 6: Outline of the number of injuries in the SR from 2000 to 2012 in agriculture

In Table 2, there is displayed the outline of the number of occupational injuries in particular categories in years from 2000 to 2012. For years 2000 till 2006, National Labour Inspectorate did not provide the outline of occupational injuries with sickness absence at least 42 days. From the total number of 12,874 occupational injuries in agricultural sector, 66 were caused by agricultural machines. The numbers of injuries in particular categories are illustrated in Fig. 7. During years 2000 – 2012, agricultural vehicles caused 4 fatal occupational injuries, 17 heavy occupational injuries, 14 occupational injuries with sickness absence at least 42 days and remaining 31 injuries were classified by the labour inspectorate into the category other.

Table 2: Outline of occupational injuries from 2000 to 2012 in agriculture

Year	FOI	HOI	OI-SA 42 days	SOI in total	OROI	OI in total
2000	6	24	-	30	1,952	1,982
2001	15	17	-	32	1,830	1,862
2002	10	14	-	24	1,639	1,663
2003	5	10	-	15	1,345	1,360
2004	10	21	-	31	938	969
2005	7	6	-	13	811	824
2006	6	15	49	70	758	828
2007	7	16	158	181	607	788
2008	10	15	150	175	470	645
2009	4	12	149	165	390	555
2010	1	12	126	139	440	579
2011	4	9	103	116	332	448
2012	5	9	0	14	357	371
In total	**90**	**180**	**735**	**1,005**	**11,869**	**12,874**

FOI - Fatal occupational injuries, HOU - Heavy occupational injuries, OI-SA 42 days - Occupational injuries with sickness absence at least 42 days, SI – Serious occupational injuries, OROI - Other (registered) occupational injuries, OI –Occupational injuries

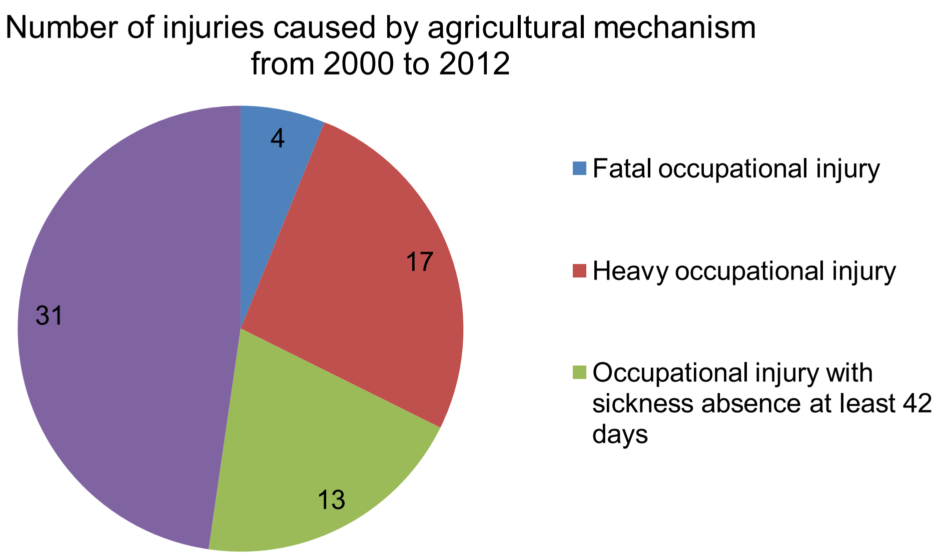

Figure 7: Outline of the number of injuries in the SR caused by agricultural mechanism from 2000 to 2012

In Table 3, there are listed the numbers of occupational injuries caused by agricultural mechanism and their three main reasons:

- rollover of agricultural mechanism;

- runover or striking the person by the agricultural vehicle;
- violation of safety regulations (OHSAS – Occupational Health and Safety Assessment Service).

Data from Table 3 are graphically represented in Fig. 8.

Table 3: Reasons and outline of occupational injuries registered by the labour inspectorate caused by agricultural vehicles from 2000 to 2012

Type of injury / Cause of injury	FOI	HOI	OI-SA 42 days	SOI in total	OROI	OI in total
Rollover	0	2	1	3	10	13
Runover / striking the person	2	1	3	6	4	10
Disregard of OHSAS	2	14	10	26	17	43
In total	**4**	**17**	**14**	**35**	**31**	**66**

FOI - Fatal occupational injuries, HOU - Heavy occupational injuries, OI-SA 42 days - Occupational injuries with sickness absence at least 42 days, SI – Serious occupational injuries, OROI - Other (registered) occupational injuries, OI –Occupational injuries

Figure 8: Occupational injuries registered by the labour inspectorate caused by agricultural vehicles from 2000 to 2012

Besides accidents and injuries caused by agricultural vehicles, which are registered by the labour inspectorate, we have to notice also accidents and injuries that happened within the frame of private agricultural sector. We frequently encounter the cases when basic safety regulations are not observed – as for the technical conditions of vehicle when the tractor is homemade and so on. Table 4 contains the reasons and outline of fatal and other injuries caused by agricultural vehicles. The data from Table 4 are clearly processed in the graph in Fig. 9. Information is collected from different internet portals from 2006 to 2012.

Table 4: Reasons and outline of injuries caused by agricultural vehicles from 2006 to 2012

Injury / Cause of injury	**Fatal injury**	**Other injury**	**Injuries in total**
Rollover	10	5	15
Runover/ striking the person	2	3	5
Disregard of OHSAS	2	2	4
In total	**14**	**10**	**24**

Figure 9: Agricultural injuries unregistered by the labour inspectorate caused by agricultural vehicles from 2006 to 2012

When we compare the accidents caused by vehicle´s rollover with the accidents caused by runover or by striking the person by the going tractor, the cases of rollovers were in both categories (registered and unregistered by the labour inspectorate) more than cases of runovers or striking the person.

Discussion

To prevent the most frequent types of accidents caused by agricultural machines and mechanisms, it is good to utilize the modelling, simulation and testing of prototypes of designed mechanisms. In technical engineering praxis, in dependence on the given science section, under the term modelling we understand the modelling of processes, actions, creating of CAD models of component parts or construction of models in a certain scale and its examination. When modelling in engineering praxis, we always encounter with the couple model – real world (original). Following this aspect, Neuschl (1988) divides models into two groups:

- models which enable to analyse the real system, i.e. concretize and put more precisely our visualization about already existing system;
- models created in consequence of projecting and design, whereby the implementation of modelled devices is still being planned. This activity is usually supported by computer technique (in literature, they are often presented by the abbreviations CAD, CAP, CAM and so on)

By the term original we denote an initial object of examination that will be investigated indirectly. By the term model we denote the object which is similar to the initial object. It is the portrayal of the initial object on which experiment will be performed directly. The original and model have a specific relationship – analogy.

Šesták et al.(1993) tested real vehicles during the working ride in the direction of contour line of the terrain with a slope of 17° and 30°to34° and during this ride also with alternating obstacles. Following the performed experiments, they determined the dynamic stability coefficient to the tipping axis. Jánošík et al. (2008) performed the test of the prototype of mobile industrial machines. They concentrated on the measurement of tipping loading and on the measurement of the maximum draw force. Prins (2010) dealt with the testing of off-road vehicle, whereby there was controlled the vehicle speed when starting, stopping and off-roading. Drives were realised over obstacles and through difficult terrain (high rolling resistance) as well as going uphill and downhill. The testing of a new active suspension system ACOCAR is addressed by Vandermissen et al. (2010). The technology ACOCAR offers ultimate comfort combined with excellent handling, it is a full active suspension system with low power consumption, where eco driving mode with almost no power consumption is possible. NATC – Nevada Automotive Testing Centre (2013) deals with the testing of prototypes and their subsequent improvement. NATC facilities in Carson City, Nevada include integrated capabilities to develop vehicles for ride, durability, handling, mobility, environmental and EMI functional specifications. NATC can develop and test vehicles to FMVSS, CMVSS and military standards, as well as manufacturer specific standards.

Facilities and capabilities of NATC include:

- Engineering – CAD, Virtual Proving Grounds, Simulation;
- Fabrication;
- Electrical and mechanical integration;
- Physical test, including instrumentation;
- Proving grounds based development for ride, handling, durability and mobility.

These capabilities facilitate the rapid development of vehicle system from concept to production. The co-located and integrated capabilities create a level of efficiency unrivalled in the industry. The staff and facilities are geared towards an innovative and rapid development of concepts to meet both industry standard and unique requirements. NATC has applied these capabilities to programmes ranging from heavy haul trucks through experimental hybrid electric concepts to modifications of light trucks for specialized needs.

Šesták et al. (1993) proved the validity (verification) of their designed model in comparison with real vehicles such as a self-propelled collecting car SSV-4, UNIHOT-80 or tool carrier MT8-046 with applied frontal contra-rotating bar SP2-212.The variability of computer simulation of static models and determination of their static stability in the resulting polar diagram enables the constructor to change the configuration of construction economically and with high precision. An unessential difference between the measurement on the tilting plain and the result from model simulation in the range of 10 % authorizes the constructor to fully utilize the modelling results. From this, it is obvious that constructor´s work is faster and more effective. Following the performed tests, the standard STN 47 0170 was approved. The modelling, simulation and testing of vehicles is addressed also by the company dSPACE GmbH. According to Schulze (2012), the simulation of vehicle behaviour becomes more important due to a limited number of test vehicles and road tests. Increasing of model variants, limited resources, cost constraints and time-to-market goals require model based vehicle dynamic development tools and methods. He uses the laboratory (HIL simulation) and mathematical (SIL simulation) modelling and compares the results with road tests (Tab.5).

Table 5: Comparison of real testing with mathematical and laboratory testing

Road (Driving test)	**Lab (HIL Simulation)**	**Math (SIL simulation)**
- limit number of test vehicles	- cheap and reliable electronic testing	- nearly unlimited number of tests possible
- most realistic results	- handling models	- complex models
- testing of variants difficult	- testing of variants easy	- testing of variants easy
	- quick running models	- calculation time demanding

Conclusion and Recommendations

The research of the issue of safe operation of agricultural off-road vehicles is important in regard to the high number of accidents and injuries, which are caused mainly by agricultural machines and mechanisms. In this contribution, we have performed the accidents rate analysis of occupational injuries in the Slovak Republic during the years 2000 – 2012. This analysis also proves the high occurrence of accidents and injuries, often also fatal, when working with agricultural vehicles. It results from the performed analyses that it would be necessary to provide the training of employees in the area of occupational and health safety. Many accidents can often happen as a consequence of disregard of occupational safety regulations. However, some accidents do not have to be just the result of inattention, but they can occur when working in difficult, sloping terrains of mountain and foothill areas. In this contribution, we analysed the most frequent causes and consequences of agricultural vehicle accidents such as vehicle overturn (rollover) and runover or striking the person by the vehicle. To prevent this type of accident, we recommend putting a higher emphasis on the testing of prototypes of machines according to the standard STN 47 170 and utilize a software that is based on the mentioned standard. Up to now, it is not known whether producers of agricultural vehicles use this simulation and authentication programs. Simulation is however only one part of the overall process and does not have always a reliable informative value. Following the former research, the combination of experimental measurement with the simulation software provides a relevant result that can be used in the certification process of the machine prototype. To increase the stability of the mechanism and the operating safety of vehicles working on the sloping terrain, it would be necessary if the European Union would put into practice an obligatory implementation of the active stability control system of vehicle into the machine´s control unit for producers of agricultural machines and mechanism.

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