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Safety index for agricultural tractors

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ABSTRACT. The manufacture of agricultural machinery should follow the criteria that specify the existence and standardization of components and security systems, so as to make them safe. The aim of this study was to establish a *checklist* to classify agricultural tractors according to a safety index. The list was obtained through literature review and by checking norms and articles on Components and Security Systems (CSSs) that must be present on tractors in order to provide proper security. These CSS were grouped to form a *checklist* obtained by the Mudge diagram, whose function was to pair CSSs according to their relevance in order to organize them hierarchically. Subsequently, a spreadsheet with weighted CSSs was applied to 31 tractor models of 5 different brands, enabling the determination of their safety ratings by the addition of values of each CSS. A CSS *checklist* allowed obtaining a safety index listing tractors by the level of safety offered by each of them, thus enabling the tractor buyer to choose the one that offers lower risk of accidents in its use.

Keywords: risk of accidents, mechanized farming, Mudge diagram.

Índice de segurança em tratores agrícolas

RESUMO. A fabricação de máquinas agrícolas deve obedecer às normas que especificam a existência e padronização de componentes e sistemas de segurança. No entanto, as marcas e modelos de tratores não possuem os mesmos componentes e sistemas de segurança em seus produtos. Sendo assim, o objetivo deste trabalho foi estabelecer uma lista de verificação para classificar os tratores agrícolas de acordo com um índice de segurança. A lista foi obtida levantando-se os Componentes e Sistemas de Segurança (CSS's), que devem estar presentes nos tratores agrícolas. Estes CSS's foram agrupados em ordem crescente de importância formando uma lista de verificação, obtida por meio do diagrama de Mudge, cuja função é relacionar aos pares os CSS's, a fim de hierarquizá-los. Após a planilha com os CSS's ponderados foi aplicada a lista de verificação a 31 modelos de tratores agrícolas de cinco diferentes marcas, possibilitando o estabelecimento dos seus índices de segurança, por meio do somatório dos valores de cada CSS' presente. A lista de verificação dos CSS's permitiu a obtenção de um índice de segurança, que relaciona os tratores, em função do grau de segurança que cada um oferece, possibilitando ao responsável pela seleção do trator a escolha daquele que possua menores riscos de acidentes na sua utilização.

Palavras-chave: risco de acidentes, mecanização agrícola, diagrama de Mudge.

Introduction

The manufacture of agricultural machinery and equipment must follow certain patterns that specify and standardize several systems, among them protection and safety systems. Equipment standardization is determined by the adoption of specific regulations whose purpose is to improve compatibility between systems, costs saving and performance without jeopardizing or harming the operator's health. Also, there is a growing demand for comfort and safety in agricultural tractors (Rozin, Schlosser, Werner, Perin, & Santos, 2010).

Ministério do Trabalho e Emprego (Norm 31, 2011) is about, among other things, machines and implements that must work safely. Protection as well as safety devices and systems required by the norm cannot be considered optional items, so that access, operation, inspection, maintenance or other interventions to which machines and implements are submitted can be safely guaranteed.

According to the statistical yearbook of occupational accidents of the Ministry of Social Security (Anuário Estatístico de Acidentes do Trabalho, 2007), the number of accidents involving agriculture and forestry mechanization workers in Brazil was 3,380 in 2013. The causes of

mechanization-related accidents are varied. Among them is found unskilled operators, unsafe or unstable environmental conditions and inadequate machinery. However, most accidents involving tractors could be avoided if the tractors had included safety devices, use of protective equipment, and safety rules were followed (Rinaldi, Fernandes, Silveira, Junior, & Minette, 2008). According to the authors, the rollover protective structure, when added to agricultural tractors, can ensure the operator greater safety in case of accidents involving lateral or longitudinal tipping.

According to Corrêa, Yamashita, Franco and Ramos (2005), most farm tractors do not include safety and operator comfort and do not comply with the norm as to access to the operator's seat, where vertical grab handles on both sides of the steps are not usually present; height of first step is above specified standard; combustion exhaust gas escape below cabin canopy; the rollover protective structure is often absent (and the few tractors which have it do not hold any certification). Only new tractors tend to fulfill operator safety and comfort requirements for most evaluated items.

Parameters that can measure the level of tractor safety are important for their classification, given that the number of accidents related to agricultural activities, especially the operation of machinery and implements is significant Therefore, the development of awareness of the risk of accidents involved in activities related to the operation of agricultural machinery in operators, technician and extension workers is extremely important (Reis & Machado, 2009). These activities offer the greatest risk of accidents in rural areas (Ambrosi & Maggi, 2013).

Aiming to establish a classification of agricultural tractors as to their safety and ergonomics, Debiasi, Schlosser, and Pinheiro (2004) developed a partial safety factor following Brazilian norm specifications that establish minimum standards for items, systems and protective elements in order to make these machines safer and more ergonomic to the operator.

The *checklist* of components and safety systems present in agricultural tractors could provide a safety index whose main function would be to assist the buyer to select the tractor offering greatest operational safety.

The aim of this study was to establish a *checklist* capable of classifying agricultural tractors according to their safety components, thus providing a safety index for each type and model of tractor.

Material and methods

Initially, Components and Security Systems (CSSs) related to items whose absence could lead to accidents in agricultural tractors were collected through analyses of references, norms, catalogs and articles. These CSSs were then grouped to form a *checklist*.

Each item on the *checklist* was added to a relationship matrix called Mudge diagram (Alvarenga & Dedini, 2003). In the diagram, CSSs were related to each other in pairs in order to be prioritized according to their relevance.

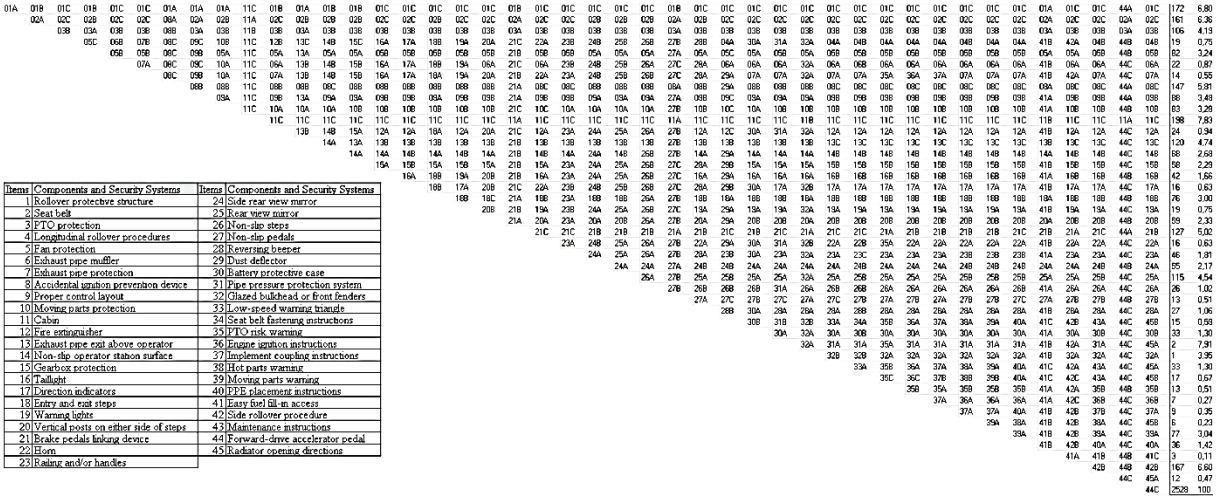
The level of importance of each item was obtained by the sum of percentage values obtained with the answers to the questions of all relationships to which each item was submitted. The questions on the relationship were, "What CSS is the most important?" and "How important is it?" The answer to the last question was divided into three weighted alternatives: Much more important (value 5); Moderately important (value 3) and A little more important (value 1). The sum of each CSS scores results in the value of importance. This value was divided by the sum of all the CSS and multiplied by one hundred to give the percent amount of CSS.

The safety index *checklist* of agricultural tractors (SICATRA) was applied to different brands and power in order to compare them with the obtained index. After submission to the *checklist* a graph was compiled dividing the tractors by power range, in order to observe the variation in the safety index regarding brand and power of agricultural tractors.

Results and discussion

Forty-five CSSs were obtained, most of them found in articles from the area where authors refer to components and systems that can jeopardize the operator's safety when missing or altered.

The Mudge diagram, containing a total of 900 relationships (cells) among the 45 CSSs, is shown in Figure 1. Each cells contains a number followed by a letter. The number represents the most important CSS in the relationship, while letters A, B or C correspond to relevance levels 1, 3 and 5, respectively. The last two columns show the sum of the importance level of each CSS and its equivalent percentage.



Items	Components and Security Systems	Items	Components and Security Systems
1	Rollover protective structure	24	Side rear view mirror
2	Seat belt	25	Rear view mirror
3	PTO protection	26	Non-slip steps
4	Longitudinal rollover procedures	27	Non-slip pedals
5	Fan protection	28	Reversing beeper
6	Exhaust pipe muffler	29	Dust deflector
7	Exhaust pipe protection	30	Battery protective case
8	Accidental ignition prevention device	31	Pipe pressure protection system
9	Proper control layout	32	Glazed bullhead or front fenders
10	Moving parts protection	33	Low-speed warning triangle
11	Cabin	34	Seat belt fastening instructions
12	Fire extinguisher	35	PTO risk warning
13	Exhaust pipe exit above operator	36	Engine ignition instructions
14	Non-slip operator station surface	37	Implement coupling instructions
15	Gearbox protection	38	Hot parts warning
16	Taillight	39	Moving parts warning
17	Direction indicators	40	PPE placement instructions
18	Entry and exit steps	41	Easy fuel fill-in access
19	Warning lights	42	Side rollover procedure
20	Vertical posts on either side of steps	43	Maintenance instructions
21	Brake pedals linking device	44	Forward-drive accelerator pedal
22	Horn	45	Radiator opening directions
23	Railing and/or handles		

Figure 1. Mudge Diagram including the relationship of the 45 CSSs collected by reviewing literature, norms, catalogs and articles.

The table in the lower left corner of Figure 1 lists the CSS corresponding to each of the lines of the Mudge diagram. Line 11 shows the unanimity of the presence of the cabin item when related to other CSS, thus demonstrating the importance of this protective system which, when added to the tractor, decreases the likelihood of occurrence of several work-related accidents.

Work-related accidents connected with the absence of the cabin include hearing accidents, since the cabin reduces the level of noise reaching the operator; respiratory accidents, once the cabin prevents solids suspended in the air from coming in contact with the operator; poisoning by harmful insects and sunstroke, as well as contamination during pesticide application. The cabin should contain the rollover protective structure in order to reduce the chance of crushing the operator in case of accident.

Schlosser, Debiasi and Parcianello (2002), in agreement with this study, reported that overturning is one of the most serious and frequent accidents involving agricultural tractors. The addition of devices that can make the tractor safer, such as the rollover protective structure and pictograms are necessary measures to reduce accidents with tractors.

Another item that should be taken into account to avoid injuries at rollover accidents is the seat belt effective use by the operator in the operator station, because the effectiveness of the rollover protective structure is practically nonexistent without this safety device. Moreover, it is worth mentioning that, according to the Brazilian Traffic Code (Brasil, 2008), the use of seat belts in motor vehicles, including agricultural tractors, is mandatory; this rule, however, does not apply to vehicles that have no rollover protective structure.

It is worth mentioning that the use of the cabin can reduce the viewing area by up to 35%, having thus a negative influence on the visual field, as compared to a tractor without cabin (Schlosser, Dallmeyer, Debiasi, Menegas, & Nietiedt, 2011). Thus, upon selecting a tractor, one should evaluate the visibility provided by the cabin as well as check the field of view of critical points that may offer higher accident risk, such as crushing or running over; in such cases, rear view mirrors will facilitate better viewing.

Another requirement is the presence of a cap or shield to cover the shaft power take-off (PTO) included in the ABNT NBR 4254-1 regulatory norm (1999), which also requires a protection against burns in the exhaust pipe, as well as the gas escape to be located above the operator in order to avoid contamination with combustion gases.

There must also be a sound absorbing system or muffler in the gas exhaust so as to prevent the operator from suffering hearing loss, once the engine exhaust system is one of the main noise-generating sources in agricultural tractors. Hearing loss can occur either in the short or long run, depending on the level and duration of noise exposure by the operator.

The first 9 CSSs listed in the Table of Figure 2 are material components, such as rollover protective structure, cabin and safety belt, whereas most CSS items coming last refer to systems such as component configuration and graphic symbols on the risk of accidents (pictograms). This result was obtained impartially through CSS paired relationship (Mudge Diagram), thus showing that

the presence of the component is more important than its configuration and/or information on how to use it and on hazards involved.

According to Alonço, Balestra, Dias, and Medeiros (2006), the graphic symbols used in agricultural machinery make the operation safer. However, according to Alonço, Machado, Ferreira, and Medeiros (2007), even though these pictographs are present in these machines, their understanding by the major agents in the process is greatly reduced.

The SICATRA ranking CSS according to level of importance obtained by the Mudge diagram is shown in the table included in Figure 2, along with additional agricultural tractor data: brand, model and power.

Blank spaces for the fulfillment of existing CSS in the tractor are shown in the last column to the right of the SICATRA so that their safety index sum could be performed, (Figure 2). The Figure 3 shows a chart with the rates obtained for each of the 31 tractors, grouped by power range.

A variation in security indices within each power range can be observed: The greater the tractor power range (50-75, 76-125, 126-150, 151-225 hp) the smaller the index coefficient variation; variation coefficient indices obtained were, 13.19, 8.77, 6.37 and 4.73% respectively. These rates are more affected by values at the top of the list due to the level of importance of these items (Figure 1) which are more relevant because of the accidents involved.

Brand:		Model:	Power:
N.	Component and Security Systems	Level of importance	Included/Not included
1	Cabin	7.83	
2	Rollover protective structure	6.80	
3	Forward-drive hand throttle	6.61	
4	Seat belt	6.37	
5	Accidental ignition prevention device	5.81	
6	Brake pedal linking device	5.02	
7	Exhaust pipe exit above operator	4.75	
8	Non-slip pedals	4.55	
9	PTO protection	4.19	
10	Proper control layout	3.48	
11	Moving parts protection	3.28	
12	Fan protection	3.24	
13	Easy fuel fill-in access	3.05	
14	Entry and exit steps	3.01	
15	Non-slip operation station surface	2.69	
16	Vertical post on either side of steps	2.33	
17	Gearbox protection	2.29	
18	Non-slip steps	2.18	
19	Side rear view mirror	2.14	
20	Rear view mirror	1.82	
21	Railing and/or handles	1.74	
22	Taillight	1.66	
23	Side rollover procedure	1.42	
24	Glazed bulkhead or front fenders	1.31	
25	PTO risk warning	1.31	
26	Battery protective case	1.07	
27	Reversing beeper	1.03	
28	Fire extinguisher	0.95	
29	Exhaust pipe muffler	0.87	
30	Longitudinal rollover procedure	0.75	
31	Warning lights	0.75	
32	Engine ignition instructions	0.67	
33	Direction indicators	0.63	
34	Horn	0.63	
35	Pipe pressure protection system	0.59	
36	Exhaust pipe protection	0.55	
37	Dust deflector	0.51	
38	Implement coupling instructions	0.51	
39	Radiator opening instructions	0.47	
40	Moving parts warning	0.36	
41	Hot parts warning	0.28	
42	PPE placement instructions	0.24	
43	Maintenance instructions	0.12	
44	Low-speed warning triangle	0.08	
45	Seat belt fastening instructions	0.04	

Figure 2. *Checklist* of safety index in agricultural tractors (SICATRA) with CSS ranking according to level of importance obtained by the Mudge Diagram.

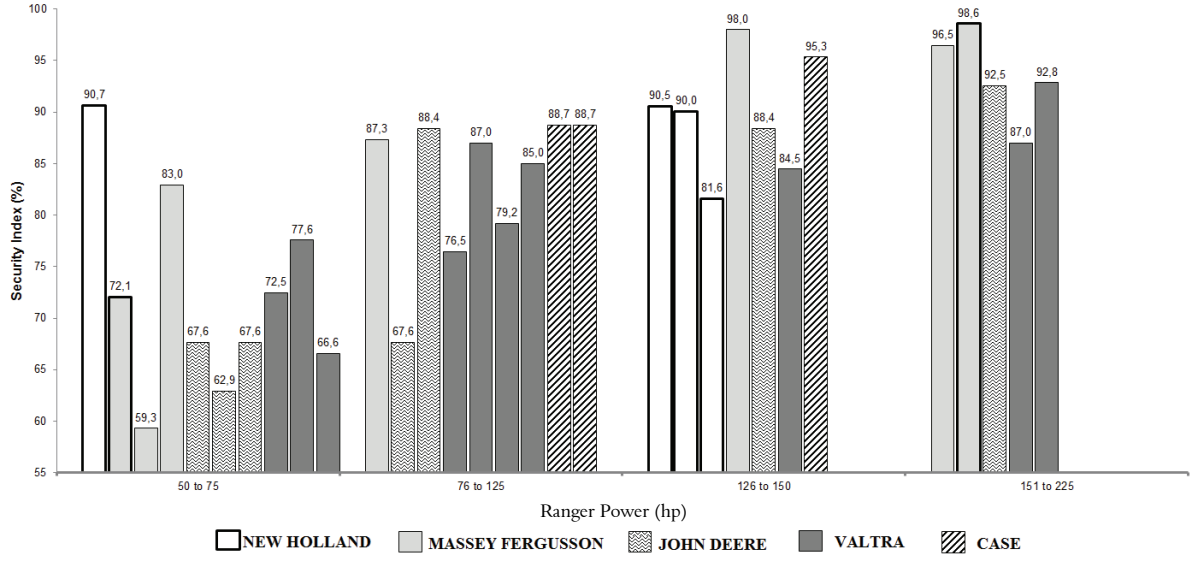


Figure 3. Safety index graph obtained by applying the safety index *checklist* for each tractor. Grouped by power range.

Figure 4 shows the quadratic polynomial regression curve ($p < 0.0001$) of the relation between tractor power data and their safety indices. It is observed that there is a tendency to increase tractor safety indices when the tractor power was increased.

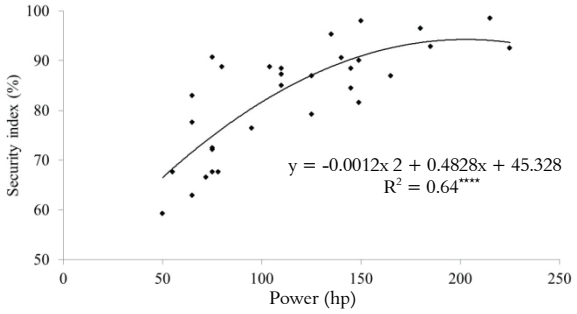


Figure 4. Graph relating the safety index with power of different tractors.

Care with the safety of high-powered tractors could be detected by regression analysis. since the increase in concern about the risk of accidents is proportional to the increase of energy involved in the system.

It is assumed that the low-powered tractors show a low safety index, inasmuch as the operators are frequently the owners themselves. Thus CSSs are often not given very serious consideration when the tractor is chosen which means that there is greater demand for better security conditions in these machines.

Safety indices for tractors over 150hp show a stabilizing trend once they come close to their maximum value.

Finally as new CSSs are developed and introduced into tractors to improve safety for operators, the *checklist* can be expanded so that tractors offering better work safety conditions can be chosen.

Table 1 shows CSS percentage for each power range. It can be observed that there is a significant increase in the cabin, accidental ignition prevention device and rear view mirror as the tractor power increases. The presence of these items in tractors is directly related to the final cost of purchase the tractors would include all possible CSS items so that there could be a reduction in the number of accidents.

This is in agreement with studies by Debiasi et al. (2004) and Mattar, Dallmeyer, Schlosser, and Dornelles (2010) who reported that safety items are not priority upon the agricultural tractor acquisition, since the consumer prioritizes the product with lowest final cost. Thus, dealers often leave security items aside.

Variations in the safety index according to power range are due to legal, commercial and consumer awareness issues. The lack of specific legislation requiring the use of security items entails the sale of agriculture tractors with low safety level once manufactures seek to provide low-cost products, as a result of the demand by safety-unaware consumers.

Thus SICATRA can serve as a decision criterion for the selection of tractors with similar technical characteristics, i.e., the pre-selection of features, necessary for good operational performance of the activities developed by the user.

Table 1. Percentage of presence of item in tractors divided into power groups.

N°	Components and security system (CSS)	Power range (hp)			
		50 to 75	76 to 125	126 to 150	151 to 225
1	Cabin	10	56	86	100
2	Rollover protective structure	90	100	100	100
3	Forward-drive hand throttle	80	78	100	100
4	Seat belt	100	100	100	100
5	Accidental ignition prevention device	40	56	86	80
6	Brake pedal linking device	100	100	100	100
7	Exhaust pipe exit above operator	80	89	100	100
8	Non-slip pedals	90	100	100	100
9	PTO protection	100	100	100	100
10	Proper control layout	90	100	100	100
11	Moving parts protection	100	89	100	100
12	Fan protection	60	89	86	100
13	Easy fuel fill-in access	60	89	100	100
14	Entry and exit steps	100	100	100	100
15	Non-slip operation station surface	90	100	100	100
16	Vertical posts on either side of steps	90	89	57	100
17	Gearbox protection	80	100	100	100
18	Non-slip steps	90	100	100	100
19	Side rear view mirror	10	78	86	100
20	Rearview mirror	90	56	43	60
21	Railing and/or handles	100	100	100	100
22	Taillight	100	100	100	100
23	Side rollover procedures	50	33	43	40
24	Glazed bulkhead or front fenders	60	100	100	100
25	PTO risk warning	40	56	71	100
26	Battery protective case	20	67	71	60
27	Reversing beeper	100	100	100	100
28	Fire extinguisher	0	0	14	20
29	Exhaust pipe muffler	40	33	43	60
30	Longitudinal rollover procedure	40	56	14	80
31	Warning lights	90	100	100	100
32	Engine ignition instructions	30	44	71	80
33	Direction indicators	100	100	100	100
34	Horn	100	100	100	100
35	Pipe pressure protection system	0	22	14	20
36	Exhaust pipe protection	10	22	57	20
37	Dust deflector	90	100	100	100
38	Implement coupling instructions	30	67	57	100
39	Radiator opening instructions	70	78	86	80
40	Moving parts warning	10	22	43	0
41	Hot parts warning	10	22	29	0
42	PPE placement instructions	0	0	0	0
43	Maintenance instructions	60	56	29	100
44	Low-speed warning triangle	20	11	14	40
45	Seat belt fastening instructions	30	33	57	40

Conclusion

The list of components and security systems present in agricultural tractors allowed obtaining a safety index which classifies the tractors according to the level of safety provided by each of them enabling the individual in charge of the selection to choose the tractor that offers the least amount of risk of accidents upon use.

Among the farm tractors evaluated by SICATRA, a safety index increase was found to occur proportionally to an engine power increase.

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