



Research Article

# Interdisciplinary Approach to Safety-Ergonomic Parameters of Tractors During Agro-technical Operations

Petrovic Predrag\*, Spajic Branko, Stjelja Zivko

Institute of Motor Vehicles, Belgrade, Serbia

## Abstract

In Serbia, there is a large number of tractors in operation with a considerable age structure, without a cab or a protective frame. These facts contribute to a significant increase in the number of accidents with injured and fatal persons during exploitation and transport, primarily due to the lack of evident subjective: safety, ergonomic, comfort, and other parameters. Tractors, due to their construction and traction characteristics (high geometric and mass center of gravity, large dynamic wheel radii, large clearance, high engine power, large transmission load variations, agro-technical operations on variable configurations, with falls and ascents, etc.), are very unstable working machines despite relatively low movement speeds. In order to influence the reduction of the number of accidents, ergonomics investigates the "man-machine-environment" relationship, which studies anatomical, physiological, medical, social, legal and other areas that contribute to the reduction of accidents and occupational diseases, while increasing efficiency, reliability, safety, etc. Special attention should be paid to the balance of forces within the analysis of the required static and dynamic stability of the tractor when moving up and down the sloping surface of the working terrain, especially tractors without a cab or a protective frame. In addition to the general state of tractor safety, this paper presents a draft of a short analysis of tractor exploitation when performing work operations on ups and downs in agro-technical and transport conditions, as one of the main reasons for accidents with injured and fatal persons. Also, the basic ergonomic-ecological parameters that are necessary to achieve the necessary, safety, ecological, medical, social, legal and other parameters are presented.

## Keywords

Safety, Ergonomics, Stability, Ecology, Tractor, Comfort

## 1. Introduction

According to the data of the Republic Institute of Statistics, Serbia recorded a total number of about 482,498 two-axle tractors, but what worries about 150,000-170,000 tractors do not have a cabin or a protective frame. However, despite this, the current technological development of modern tractors has achieved a high level of application of mechatronic and other systems, which has achieved significant improvements in

terms of: safety, ergonomics, comfort, economy, productivity, rationality, emissions of exhaust gases, noise, vibrations, etc. Bearing in mind the high average age of the mentioned tractors, the degree of safety during exploitation is not at the required level, as well as the non-fulfillment of basic ergonomic parameters, the number of accidents is unacceptably high with injured or fatal persons.

\*Correspondence: Petrovic Predrag (mpm@eunet.rs)

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## 2. Statistical Aspect of Accidents with Tractors in Serbia

Despite the great involvement of the Traffic Safety Agency (ABS), the number of accidents is unacceptably high, and despite the free allocation of protective frames for older tractors of domestic production. According to official data in accidents with fatalities from 1980-1990, there were 110, in 1990-2000, there were 75, and in the period 2013-2023, 44 fatalities. In Serbia, the number of accidents with tractors (Figure 1) is most pronounced in the Zlatibor District with the highest number of fatalities, followed by Eastern Serbia (Pozarevac, Zajecarski and Borski Districts), and Raski District. There are slightly fewer accidents with tractors in Jablanicko, Podrinjsko, Rasinsko, then Presevo region and Sumadia. The lowest number of accidents occurs in Vojvodina, which confirms previous findings that accidents occur most often in hilly areas, and the least in plains. [1]

The regions in Serbia where there are the most tractors without a cab or a protective frame are Macvan, estimated at 45-55%, followed by Central Serbia, >50%, and the least in Vojvodina, only 10-20%. Analyzing accidents by days of the week, months and years, they most often occur on weekends and Tuesdays, in the months of September and October.

When considering the ergonomic parameters of the tractor, the primary focus is on increasing safety and preventing occupational diseases of the operator. This is achieved by effective protection of structures in the event of overturning, primarily tractors with cab installation, but no less tractors with built-in protective frames. The aspect of ergonomic parameters mainly refers to: operator comfort (noise, vibrations, microclimate, temperature in the cabin, visibility, heating and cooling of the cabin, access to controls, access to the cabin, adequate seat, protection from meteorological conditions, etc. [2, 3]

## 3. Ergonomic Aspects of Tractors

In the previous paragraph, statistical data on accidents with tractors are listed, which are influenced by the operator's subjectivity above all, readiness for driving conditions, use of alcohol and intoxicants, compliance with regulations and other circumstances. Under those circumstances, the ergonomic parameters that affect the operator's safety and comfort certainly have a great influence on the number of accidents.

## 4. Tractor Cab Microclimate Parameters

When it comes to the ergonomic parameters of the tractor cabin, they primarily refer to the microclimate, cabin design, acoustic protection, elastic support, heat-reflective glass, droopiness, noise, vibrations, comfort, etc. These are just some parameters that significantly affect the ergonomic convention between the interior of the cabin and the environment.

When it comes to microclimate, the primary condition for improving microclimatic changes in the cabin is to prevent the radiation of external heat as effectively as possible. The heat that still penetrates into the cabin must be controlled by prediction in the most efficient way possible, above all by adequate insulation and appropriate heat removal.

In situations where it is impossible to avoid high temperatures during operation (e.g. > 35 °C), continuous total solar radiation can be up to 1000 W/m<sup>2</sup>. Such conditions make working conditions even more difficult, because the cabin is usually closed, to protect against noise and air pollution, and on the other hand, due to the low speed of movement, natural ventilation is limited. [4]

The sum of the heat balance in the cabin in extreme steady state conditions consists of the so-called sensible heat  $Q_H$  and latent heat  $Q_{HW}$ , released by the operator, as shown in Figure 1.

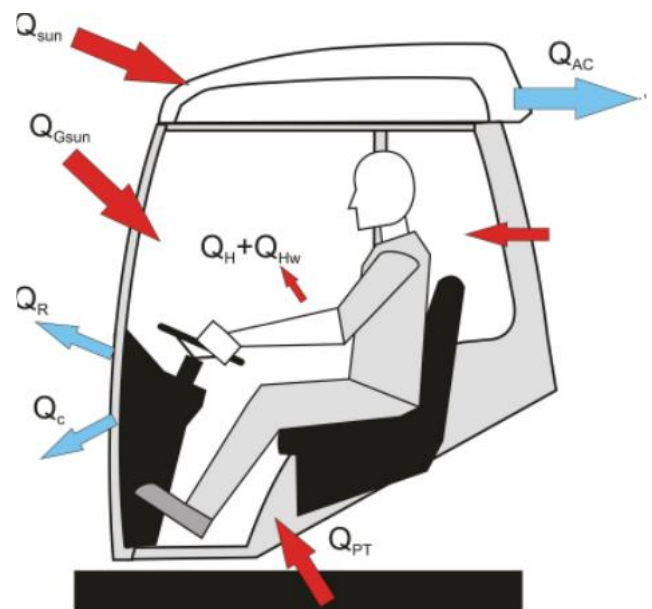


**Figure 1.** Thermal balance of the tractor extreme outdoor temperature [2].

The heat  $Q_K$  penetrates through the back structure of the cabin, and the heat caused by the radiation of the Sun  $Q_{SUN}$  penetrates from the front. Heat from the power unit  $Q_{PT}$  penetrates through the floor of the tractor by radiation and radiation through the glass  $Q_G$ . In order to maintain constant internal temperatures in the tractor cabin, the air conditioning system  $Q_{AC}$  must provide a constant heat balance with the total heat penetrating the cabin. According to some analyses, at extreme outdoor summer temperatures, it is a pitiful 23 °C—28 °C in the cabin, with fully realized air flow conditions in the cabin area. It is desirable that fresh air flows in the zone of the operator's respiratory organs from the front and from the side, to avoid a discontinuity of comfort that may cause irritation of the respiratory organs or eyes, therefore it is desirable that the

local flow in the cabin be 4-5 °C lower than the temperature of the surrounding air, but without disturbing the acceptable noise level. [5]

## 5. Access to Tractor Commands

Access to tractor controls is a very important factor from an ergonomic point of view. The modern development of transmissions greatly facilitates the access and ease of operation of the controls compared to the long-term applications of stepped transmissions. Today, continuous transmission stages, the well-known "Powershift" and others, are used, which are

based on one or more groups of planetary transmissions, with automatic inclusion in the drive of the corresponding group via hydraulic control couplings. Such a system enables continuous transmission of power in a wide range of speeds, depending on agro-technical conditions. Application of such a system on tractors significantly improves operator comfort and proper seating, easier access to controls, etc. Observing the structure of the human body and the characteristics of the shortening of its limbs (arms and legs), the structure of the human body can be shown with an aerodynamic model of "movable joints" of the upper limbs, where point H serves as a reference point, as shown in Figure 2a, 2b. [6, 7]

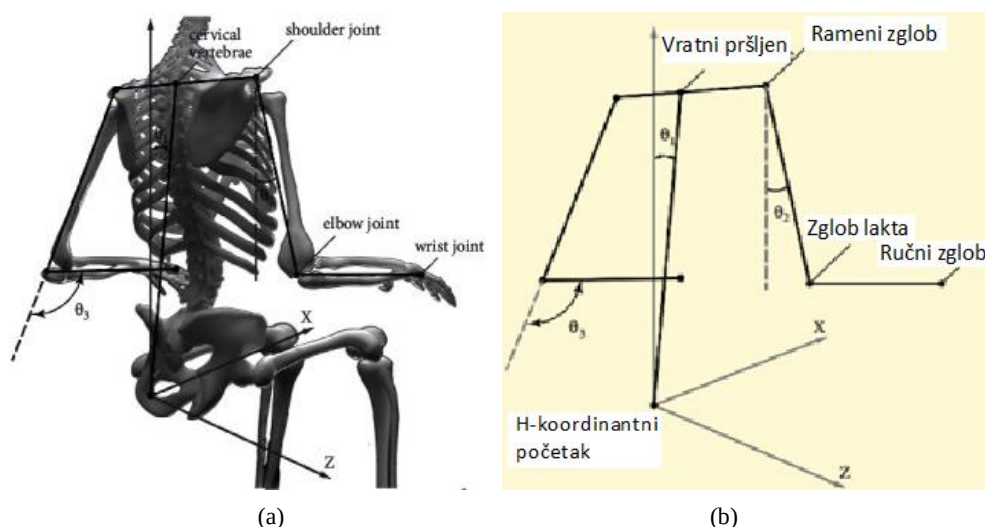


Figure 2. Aerodynamic model of the movable joints of the upper limb structure (a and b).

## 6. Ergonomic Aspect Cab Visibility

Today, cabins are of a very modern design, with very good ergonomic requirements and very good visibility. Rounded windows on the tractor cab create a more favorable visual overview while increasing the volume of the cab. Visibility must be comprehensive and allow the operator good visibility

in all directions, as shown in Figure 3a, as well as the visibility in front of the tractor, which should be as close as possible to the front wheels, as well as the visibility of the back of the cab, also, as close as possible to the rear wheels, in order to enable the operator to more easily follow the work procedures during agro-technical operations, (Figure 3b). Such visibility parameters certainly influence the increase in efficiency, rationality, productivity, safety.

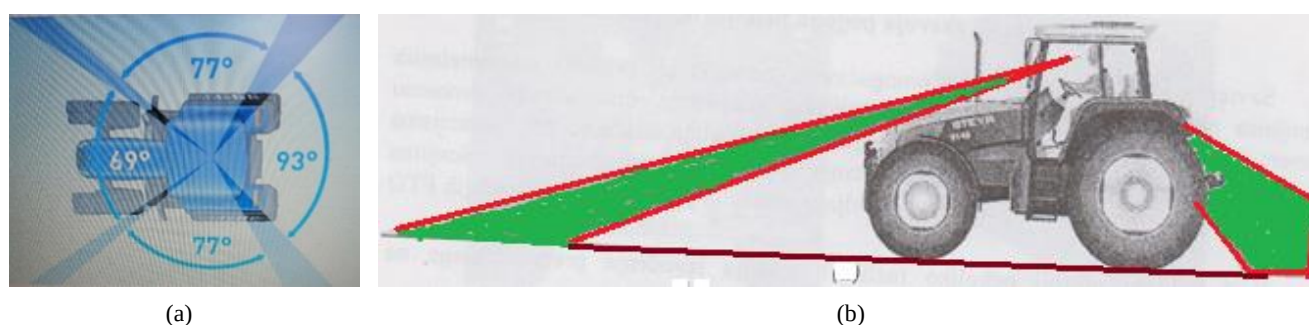


Figure 3. Visibility of the tractor in all directions (a), front and rear visibility (b).

## 7. Ergonomic Aspect of Tractor Noise and Vibration

Agricultural tractors are mostly equipped with diesel engines of different constructions and characteristics, depending on the application and tractor category. The very principle of operation of the diesel engine directly and indirectly affects the various processes of noise and vibration that are transmitted through the structure of the tractor and adversely affect the operator's comfort. In order to reduce the excitation of noise and vibrations, there are several possibilities: reduction of the excitation caused by mechanical impacts in certain systems and components; reduction of excitation of the intake and exhaust system; engine construction that enables modern fuel injection systems; by reducing the response by using materials with higher internal damping; change in dynamic response of individual components; application of suitable insulating materials and different acoustic coatings, construction of cabins that absorb part of the energy; special performance of the engine fairing using acoustic materials and other possibilities.

Of all the requirements of ergonomics with regard to the general improvement of the comfort of the tractor operator, quantitative oscillatory loads are very important. Measurement locations and modes of vibration loads are defined by the ISO standard. Tractor vibrations can be divided as a combination of translation in three orthogonal axes ( $x$ ,  $y$ ,  $z$ ) and rotation around the ( $X$ ,  $Y$ ,  $Z$ ) axis, as shown in Figure 4. If the tractor is viewed as a whole, it has six degrees of freedom of movement-oscillation, in the  $X$  direction (longitudinal movements), in the  $Y$  direction (lateral) and in the  $Z$  direction (vertical), as well as angular vibrations  $\alpha$  around the  $X$  axis (swing, drift – eng. oll), angular  $\beta$  around the  $Y$  axis (galloping, stumbling – eng. pitch) and angular vibrations  $\gamma$  around the  $Z$  axis (swimming - eng. yaw). Factors that affect the intensity of vibrations are: unbalanced dynamic forces and engine torques, which are created during the work process engine, then, the way the engine is supported, the cabin and transmission, adequacy of seat quality, elasticity and tire pressure, etc. [8, 9]



**Figure 4.** Tractor vibrations in relation to measurement points coordinate system ( $X$ ,  $Y$ ,  $Z$ ) [3].

## 8. Conclusion

In this case, ergonomics represents the "man-tractor" relationship that defines conditions that include parameters related to the ease and optimality of handling hand and foot controls, the visibility and optimality of the microclimate in the cabin, protection from noise and vibrations and other factors, which avoids potential occupational diseases. Excepting the microclimate, all the mentioned parameters also apply to tractors with a built-in protective frame, regardless of the fact that they are tractors of older production. Considering the above, it is obvious that great attention is paid to operator safety, not only through the installation of cabins and protective frames, but also the implementation of ergonomic parameters that affect not only safety and professional disease, but also on productivity and efficiency in agro-technical operations.

## Abbreviations

|                               |                                                                  |
|-------------------------------|------------------------------------------------------------------|
| ABS                           | Traffic Safety Agency                                            |
| QH                            | Heat felt by the Operator                                        |
| QHW                           | Latent Heat Released by the Operator                             |
| QK                            | Heat That Penetrates Through the Rear Structure of the Cab       |
| QSUN                          | Heat by Solar Radiation from the Front of the Cab                |
| QPT                           | Heat of the Power Unit Through the Floor of the Tractor          |
| Q.G                           | Heat of the Power Unit by Radiation Through the Glass of the Cab |
| QAC                           | Air Conditioning System                                          |
| $x$ , $y$ , $z$               | Orthogonal Vibrations                                            |
| $X$ , $Y$ , $Z$               | Rotational Vibrations                                            |
| $\alpha$ , $\beta$ , $\gamma$ | Angular Vibrations Around the Axes $X$ , $Y$ , $Z$               |
| Powershift                    | Continuous Transmission Gear                                     |

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## Author Contributions

**Petrovic Predrag:** Conceptualization, Data curation, Supervision, Writing – original draft

**Spajic Branko:** Investigation, Methodology, Writing – review & editing

**Stjelja Zivko:** Validation, Visualization, Writing – review & editing

## Conflicts of Interest

The authors declare no conflicts of interest.

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