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SAFETY AND ERGONOMICS AS IMPORTANT CRITERIA OF QUALITY OF AGRICULTURAL MACHINERY

Summary

The paper presents the results of determination of the weighing indicators of the features group associated with ergonomics and work safety of agricultural machinery ES (ergonomics and safety) in rating their global quality. The research was carried out on farm tractor, considered as energy farm machine. The experts recognize ergonomics and safety as important (14%), but not the most important characteristics of the four universal criteria of tractors. According to a group of selected experts (scientists, journalists and farmers) agricultural tractors should primarily be reliable (42%) and functional (38%). The same experts using the same method i.e. pair wise comparison method of Saaty, have determined an importance ranking of nine detailed criteria of ES characteristic. At this level of the hierarchy process the all of specific criteria ES_1 ES_9 may be accepted as equally important in assessing the quality of agricultural tractors, which means that they have been well chosen.
Key words: *tractor, ergonomics, safety, pair wise comparisons analysis, quality*

BEZPIECZEŃSTWO I ERGONOMIA JAKO WAŻNE CHARAKTERYSTYKI JAKOŚCIOTWÓRCZE MASZYN ROLNICZYCH

Streszczenie

W pracy zamieszczono wyniki badań określenia współczynników wagowych grupy cech związanych z ergonomią i bezpieczeństwem pracy maszyn rolniczych ES (ergonomics and safety) w ocenie ich jakości globalnej. Przedmiotem badań był ciągnik rolniczy, traktowany jako energetyczna maszyna rolnicza. Eksperci uznali ergonomię i bezpieczeństwo za ważną (14%), ale nie najważniejszą charakterystykę spośród czterech uniwersalnych kryteriów głównych ciągników rolniczych. Według celowo dobranej grupy ekspertów (naukowców, dziennikarzy i rolników) ciągniki rolnicze powinny być przede wszystkim niezawodne (42%) i funkcjonalne (38%). Eksperci tą samą metodą porównywania parami Saaty'ego określili wagi dziewięciu kryteriów szczegółowych charakterystyki ES. Na tym poziomie hierarchii procesu wszystkie kryteria szczegółowe ES_1-ES_9 można uznać za jednakowo ważne w ocenie jakości ciągników rolniczych, co oznacza, że zostały dobrze dobrane.
Słowa kluczowe: *ciągnik rolniczy, ergonomia, bezpieczeństwo, metoda porównywania parami, jakość*

1. Introduction

According to the study on the "Structure of Farms", in 2013 approximately 1.5 million farms existed in Poland, where various types of vehicles, machines and agricultural equipment were required for proper functioning [2]. Almost each farm owns a tractor, which is confirmed by statistical data - over 1.4 million of registered agricultural tractors. Technical equipment on the fleet of farms meets their owners' expectations to a greater or lesser extent. Considering a high supply of machines and several dozen various brands available on the Polish market, a purchaser is bound to take a difficult decision whose effects will affect him over many years of operation. This stage of machinery "life", verifying stages of construction and manufacturing, makes the basis for determining the principles and mechanisms of their quality assessment. The notion of quality has always accompanied humanity and it is currently defined precisely and explicitly by the Polish PN-EN ISO 9000:2015-10 [7] technological standard. According to this standard, "quality is a degree to which a set of inherent characteristics fulfils requirement".

Due to differences occurring between tangible products, i.e. devices, no single tested universal method for their quality assessment exists. They include descriptive (linguistic) and quantitative methods. In case of agricultural machines, mainly the first type is applied. Results of tests performed using the said methods are presented based on catalogue or detected technical and performance parameters and own opinions, usually in the form of pluses and minuses or other graphical forms [4].

A prerequisite for proper operation of agricultural machines is their adjustment to safety regulations applicable in a given country as well as physical and mental capacity of an operator. They must meet the requirements which guarantee safety against potential injuries and adverse impact of, e.g. toxic substances, vibrations or noise. Because of the need to increase operating efficiency and effectiveness, machines have become more and more complicated in technical terms (many mechatronic solutions) and this requires continuous training and improvement of efficient and safe operation techniques. The scale of accidents in agriculture has been decreasing year by year, however, it remains a considerable social problem.

The testing laboratory of the Industrial Institute of Agricultural Engineering in Poznań carries out tests of agricultural and forestry machinery in the scope of their compliance with legal documents. Before Poland's accession to the European Union machines were subject to mandatory certification called safety sign. At present, producers per-

form certification on their own [5, 12]. Modelling of safety and ergonomics using the created theoretical (virtual) model was also performed. Proper selection of standards for the specific type of machines requires considerable experience. Such tests should be conducted at the stage of design and their results should be verified through the level of machine compliance prior to its marketing and use [3].

Summing up, both ergonomics and safety represent two important criteria affecting the quality of all technical devices applicable in agricultural works, both in plant and livestock production. Determining the importance of those criteria in relation to others will enable quantification of global quantity of agricultural machines. Therefore, their quantitative assessment is necessary using the adequate methodology.

2. Aim of work

The aim of work is to determine the percentage share of the group of features associated with ergonomics and safety in relation to other important criteria of agricultural machines, such as functionality, reliability or design. These criteria may be recognised as universal, i.e. common for any type of agricultural equipment. Thus, a methodology tested in logical and empirical terms is needed for quantitative determining the weights of those characteristics.

3. Methodology and scope of the studies

The first stage of agricultural machine quantification (determination of global quality factor - Q_{MR}) includes the mapping of the empirical model of the tested object to the abstract model, e.g. in the form of a directed graph [1]. Based on the practical knowledge concerning the exploitation process of agricultural machines and the review of literature in the scope of agricultural engineering, four main criteria were adopted, common for all agricultural devices, regardless their designation. They include:

- functionality F,
- reliability R,
- ergonomics and safety ES,
- design D.

With this assumption, the universal hierarchical arrangement of criteria used for the assessment of the global quality factor of agricultural machines will have a form shown in Figure 1.

Four universal criteria, also known as characteristics, are the criteria consisting of *n* detailed criteria (from several to several dozen), depending on the evaluated machinery group.

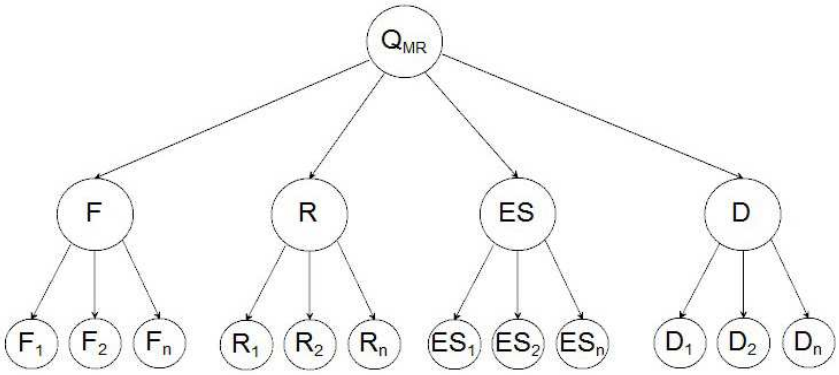
For quantitative determining of criteria weights, a PC (*Pairwise comparisons*) method was used, developed in 1980 by Saaty [10, 11]. The method compares simultaneously only two criteria (instead of all criteria simultaneously) and it is used in the AHP (*Analytic Hierarchy Process*) method. This method is classified in the American school of MCDM (*Multiple-criteria decision-making*) systems. It enables creating of a decision-making table and a vector of weightings through comparison of individual criteria in pairs [9]. A 9-stage measurement scale is used for the assessment of relative importance of the criteria (table 1).

Table 1. The scale of measurement to assess the level of importance two comparison criteria [8]
Tab. 1. Skala pomiarowa do oceny poziomu ważności porównywanej pary kryteriów [8]

Verbal assessment	Numerical assessment
Equivalence	1
Validity is insignificant	2
Validity weak or moderate	3
Validity moderate to significant	4
Validity important, essential or strong	5
Validity strong to very strong	6
Validity determined or very strong	7
Validity very strong to absolute	8
Validity absolute	9

The necessity to perform many comparisons within a short period of time triggers the risk of obtaining inconsistent (illogical) assessments. The level of assessment inconsistency is measured using the IR (*Inconsistency ratio*). According to the author of this method, the value of this ratio should be lower than 0.1, which means maximum 10% of inconsistent answers [6, 8]. If IR>0.1, the assessment matrix should be subject to analysis in order to explain (or, in the best case, remove) sources of non-compliance and contradiction in assessments.

The weights of criteria were obtained through determining the own vector (*eigenvector*) of the comparison matrix. In case of many assessments performed with the use of this methodology by several experts, the final weights of criteria are averaged.



Source: own work / Źródło: opracowanie własne

Fig. 1. The hierarchical structure of the criteria for assessing the quality of agricultural machines
Rys. 1. Hierarchiczna struktura kryteriów oceny jakości maszyn rolniczych

The subject of tests is an agricultural tractor treated as a powered agricultural machine, within which four main universal criteria, i.e. F, R, ES and D can be also specified. Due to the aim of work, detailed criteria of ES characteristics were also determined, including:

- visibility from a driver's seat - ES_1,
- size of compartment - ES_2,
- ventilation efficiency - ES_3,
- legibility of indicators - ES_4,
- absorption - ES_5,
- noise - ES_6,
- number of lockers - ES_7,
- light for work at night - ES_8,
- arrangements of control levers - ES_9.

The primary set of ES characteristics comprised 12 detailed criteria. However, this number was limited to 9, in accordance with the assumptions of the PC methodology, according to which 9 is the maximum number of features which can be compared within a short period of time without making mistakes arising from inconsistent answers (so-called Miller principle 7±2). The attempt to estimate weight indicators of the main and detailed criteria was undertaken by nine experts from various environment. The evaluators included three persons representing the scientific staff of the of the Institute of Biosystems Engineering of the Poznań University of Life Sciences (U1÷U3), three journalists of the Top Agrar Polska monthly (D1÷D3) and three farmers (R1÷R3).

4. Results

Still before the application of the PC method, the following weights of individual characteristics adopted by the authors on an arbitrary basis served as a benchmark: F = 40%, R = 30%, ES = 20% and D = 10%. It was recognised that the agricultural tractor should be mainly functional and, in addition (due to the specific nature of agricultural works) it should demonstrate a low failure rate. Ergonomics and safety during a tractor's performance were ranked as low as third, with the share of only 1/5. The design of its make is equally important. The weights determined by authors in this way (with grading at each 10%) raised controversies.

The application of the very precise PC method based on pairwise comparison changed the originally assumed ranking of main criteria. In table 2, an example of a spreadsheet with subjective assessments of one of the experts is provided.

Table 2. The square matrix of pairwise comparisons of the main criteria for the tractor done by the expert U1
Tab. 2. Kwadratowa macierz porównań parami kryteriów głównych ciągnika rolniczego eksperta U1

	F	**R**	**ES**	**D**
F	1	1/3	5	7
R	3	1	7	9
ES	1/5	1/7	1	3
D	1/7	1/9	1/3	1

Source: own work / Źródło: opracowanie własne

The method used for determining the weights based on subjective assessments of U1 expert, i.e. determining own vector of the pairwise comparison matrix, is included in table 3.

Table 3. Matrix multiplication for the reply from table 2 and the ranking of the main criteria when IR = 0.06
Tab. 3. Kwadrat macierzy dla odpowiedzi z tab. 2 oraz wagi kryteriów głównych przy IR = 0,06

	F	**R**	**ES**	**D**	**Totality**	**Weight**
F	4,00	2,16	14,67	32,00	**52,83**	**29%**
R	8,69	4,00	32,00	60,00	**104,69**	**58%**
ES	1,26	0,69	4,00	8,69	**14,63**	**9%**
D	1,15	0,32	2,16	4,00	**7,63**	**4%**
					179,77	**100%**

Source: own work / Źródło: opracowanie własne

On the other hand, table 4 presents final weights of the main criteria of an agricultural tractor of all experts participating in the study, their minimum and maximum values as well as span.

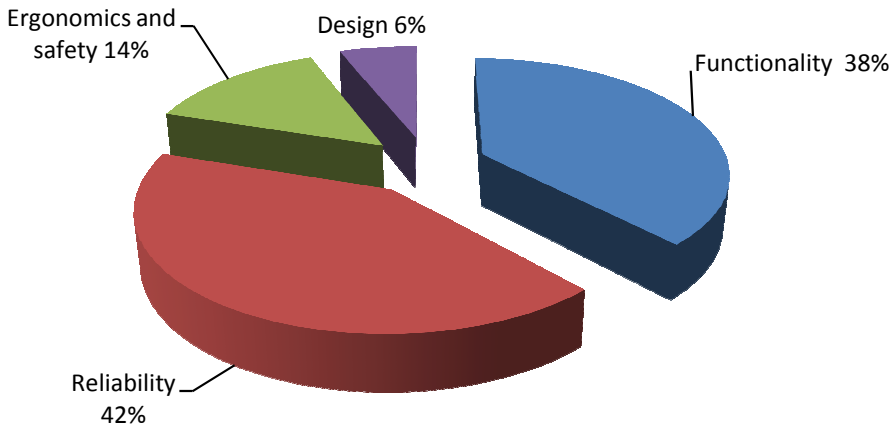
Taking into account the weights of main criteria of all experts from table 4, they were averaged to obtain the final values shown in the chart (Figure 2).

In addition, using the same pairwise comparison (PC) method, the experts determined weights of nine detailed criteria of ES characteristics. Results of those operations are included in table 5 and in Figure 3.

Table 4. Eigenvectors matrix of pairwise comparisons of the main criteria in % of all experts participating in the survey
Tab. 4. Wektory własne macierzy porównań parami kryteriów głównych w % wszystkich ekspertów biorących udział w badaniu

	Expert											
	U1	**U2**	**U3**	**R1**	**R2**	**R3**	**D1**	**D1**	**D1**	**Min**	**Max**	**Interval**
F	29	20	48	40	24	37	54	59	40	**29**	**59**	**30**
R	58	58	27	41	60	37	28	26	41	**26**	**60**	**34**
ES	9	17	17	11	11	21	14	10	11	**9**	**21**	**12**
D	4	5	8	8	5	5	4	5	8	**4**	**8**	**4**

Source: own work / Źródło: opracowanie własne



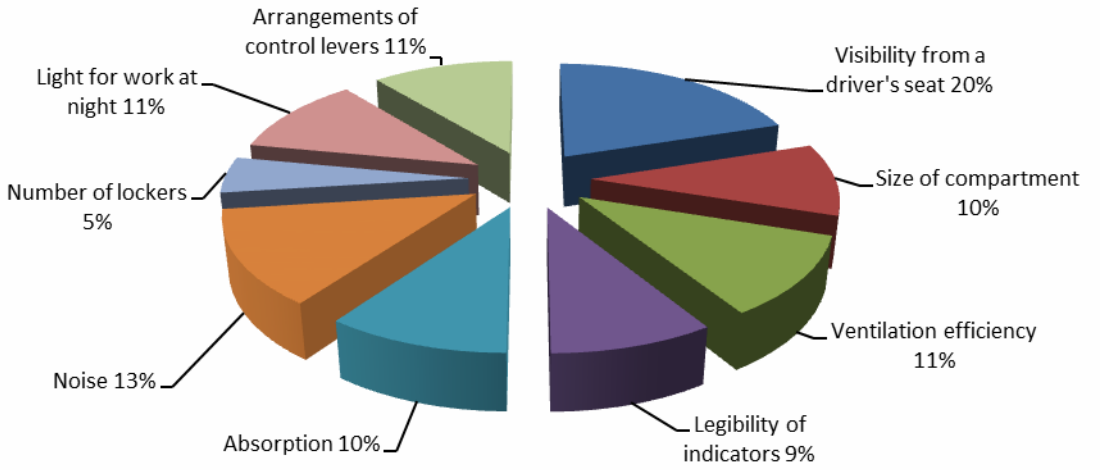
Source: own work / Źródło: opracowanie własne

Fig. 2. Average weights of major criteria for tractors
Rys. 2. Uśrednione wagi kryteriów głównych ciągników rolniczych

Table 5. Eigenvectors matrix of pairwise comparisons of detailed criteria of ES characteristics in % of all experts participating in the survey
Tab. 5. Wektory własne macierzy porównań parami kryteriów szczegółowych charakterystyki ES w % wszystkich ekspertów biorących udział w badaniu

	Expert											
	U1	**U2**	**U3**	**R1**	**R2**	**R3**	**D1**	**D1**	**D1**	**Min**	**Max**	**Interval**
ES_1	13	14	18	20	18	19	28	30	20	**13**	**30**	**17**
ES_2	10	15	8	15	4	5	6	28	6	**4**	**28**	**24**
ES_3	10	15	16	4	5	16	9	8	14	**4**	**16**	**12**
ES_4	12	15	10	6	7	5	11	5	11	**5**	**15**	**10**
ES_5	12	12	10	10	13	8	9	6	8	**6**	**13**	**7**
ES_6	11	11	15	21	13	18	6	6	14	**6**	**21**	**15**
ES_7	6	10	5	5	3	3	2	5	3	**2**	**10**	**8**
ES_8	11	5	7	12	9	10	17	6	20	**5**	**20**	**15**
ES_9	13	3	11	7	28	16	12	6	4	**3**	**28**	**25**

Source: own work / Źródło: opracowanie własne



Source: own work / Źródło: opracowanie własne

Fig. 3. Average weights of detailed criteria of ES characteristics for tractors
Rys. 3. Uśrednione wagi kryteriów szczegółowych charakterystyki ES ciągników rolniczych

5. Summary and conclusions

The studies performed allowed for formulating the following final conclusions:

1. The primary forecasts concerning the importance of the main criteria in the global quality assessment of agricultural tractors were not confirmed. The heuristic approach, although producing fast results, is unreliable. If precision is important for the evaluator, slightly more time should be devoted and analytical methods should be used, such as the pairwise comparison method of Saaty criteria.
2. According to the experts, the reliability of the tractor, rather than its functionality, is of utmost importance. It may be presumed that agricultural machines should be mainly

functional, instead of tractors cooperating with them. The successive studies will aim at confirming the legitimacy of this hypothesis.

3. A surprisingly low weight share, namely, only 14% was attributed to the criterion of ergonomics and safety of agricultural tractor performance. On the other hand, weights of nine detailed criteria of these characteristics distributed in a foreseeable manner, recognised by experts as significant and equivalent. This confirms the assumption that while trying to perform the global assessment of agricultural machines (determining the Q_{MR} global quality) no need to determine their weights exists. Such a methodological approach is used in the developed and implemented NBOR IT system. The Independent Farmers' Opinion Survey (website: www.nbor.pl), developed by authors of this paper enables each user of an agricultural tractor to express an individual opinion based on four main characteristics and several dozen detailed criteria. Ultimately, the system will be expanded by adding consecutive modules allowing for quantification of various groups of agricultural vehicles, machines and equipment.

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