XVII^th World Congress of the International Commission of Agricultural and Biosystems Engineering (CIGR)

Hosted by the Canadian Society for Bioengineering (CSBE/SCGAB)
Québec City, Canada June 13-17, 2010

A PREDICTIVE MODEL FOR THE VIBRATION RISK EVALUATION IN AGRICULTURAL MACHINERY USE

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CSBE101064 – Presented at Section V: Management, Ergonomics and Systems Engineering Conference

ABSTRACT Several well known national and international Standards provide different limits relevant to workers' vibration exposure. The agricultural activity is characterized by seasonal work peaks, in which operators widely exceed the traditional 8-hours work day, alternated to other long time periods of relatively light activity. On the other hand, agricultural machinery management involves many different tasks, in terms of procedures to be completed, considering the variety of operating conditions. As a consequence, the evaluation of the operator's vibration risk exposure is very difficult, and the results obtained are normally very poor, because they take into account the inputs from the vibration levels published on the machinery instruction manuals. On the basis of a suitable campaign of field trials, the present paper proposes the building of a predictive model for the vibration exposure, starting from the worldwide most popular agricultural machine, the tractor and one of the most frequently carried out operation, ploughing. This job represents a very effective example, as for its high frequency of execution, because ploughing is normally (both in-furrow and out-of-furrow) a very hazardous operation when considering vibrations point.

Keywords: Vibration, agricultural machinery, ploughing, decision support system.

INTRODUCTION Among the risks for the health of the agricultural operators, the mechanical vibration is very important, especially for the recent increase of the machinery use. For tractor drivers this risk is particularly significant.
The vibration risk assessment evaluation in agriculture is generally difficult, because of many sources and operating conditions. In many cases, the vibrational values of the dedicated databases are not sufficiently accurate to provide a valid basis on which calculate correct vibration exposure levels.
The enduring lack of data in specific literature confirms this difficulty. A study devoted to the prediction of the vibrational levels of the most common agricultural tasks, without specific field measurement, could be then a suitable solution.
To do this, the *multicriteria technique* was taken into account in this study. The fundamental assumption underlying this technique is that it is possible to decompose the analysis item in simple factors, named criteria, which describe it comprehensively, and

alternatives. The multi-criteria analysis is then an approach that includes a variety of techniques that are based on the same pattern: making explicit the contributions of the different options of choice, in respect of the different criteria or attributes. The criteria is the means by which the various alternatives are compared to each other, on the base of the decision maker purposes.

MATERIAL AND METHODS Multi-criteria Decision Analysis (MCDA) has undergone an impressive development during the last 30 years. MCDA is not a tool providing the 'right' solution in a decision problem, since no such solution exists. The solution provided might be considered best only for the decision maker, who provide their values in the form of weighting factors, while other decision maker values may indicate another alternative solutions. Furthermore, several weighting techniques have been developed to help decision makers involved in a MCDA procedure become aware and articulate their preferences.

Structural elements

The core elements in a MCDA problem are certainly the set of alternative actions and the set of criteria along which these actions have to be evaluated. However, there are a number of structural and external characteristics that go beyond an arithmetic definition of these basic elements. Several approaches are available to help the approach of these characteristics in a consistent and systematic way. *Criteria* represent the decision makers points of view along which it seems adequate to establish comparisons. There are two main approaches to determining the set of criteria, reflecting the two ways of building a MCDA problem.

The first is the **top-down approach**, in which criteria are built in a hierarchical structure, known as '*value tree'*, leading from primary goals to main objectives, which are further broken down to specific criteria.

The second is the **bottom-up approach**, that supports 'alternative-focused thinking', where criteria are identified through a systematic elicitation process, and may subsequently grouped in broader categories.

Alternatives are usually thought of as "given" in the sense that they are *a priori* and strictly defined. However, alternatives may result from the systematic exploration of the objectives pursued in the considered situation. Finally, alternatives may be defined as combinations of discrete actions.

Decision makers involved in the decision situation are those identifying the nature of the problem and driving the solution procedure towards the preferred direction.

Acknowledging *uncertainty* is another crucial element of MCDA problems. The main cause of uncertainty is limited knowledge about external parameters that may influence the performances of the considered actions. In addition, decision makers have to handle internal uncertainty caused by hesitations during the structuring process problem.

In this study a "top-down" method, an **Analytic Hierarchy Process (AHP)**, was adopted. It is a MCDA approach, introduced by Thomas L. Saaty in the '70s. AHP can be used in making decisions that are complex, unstructured and contains multiple-attributes. The decisions that are described by these criteria contain both physical and psychological elements. It is used a multi-level hierarchical structure of objectives, criteria, subcriteria and alternatives. The pertinent data are derived by using a set of pairwise comparisons. These comparisons are used to obtain the weights of importance of the decision criteria, and the relative performance measures of the alternatives in terms of each individual decision criterion. AHP provides a method to connect these elements, that can be quantified, and the subjective judgment of the decision maker in a way that can be measured. This method is composed of 3 steps: the description of a complex decision problem as a hierarchy, the prioritization procedure and the calculation of results.

A problem is put in a hierarchical structure (**Fig. 1**), in which the level I reflects the overall purpose of the decision; level II contains criteria for the decision, (level III is relevant to possible subfactors) and level IV is composed of the alternatives (*Nataraj S., 2005*). The comparison of criteria and alternatives is made using a fundamental scale of absolute numbers (**Table 1**). It converts individual preferences into ratio scale weights that can be combined into a linear additive weight for each alternative. It represents the importance of criteria.

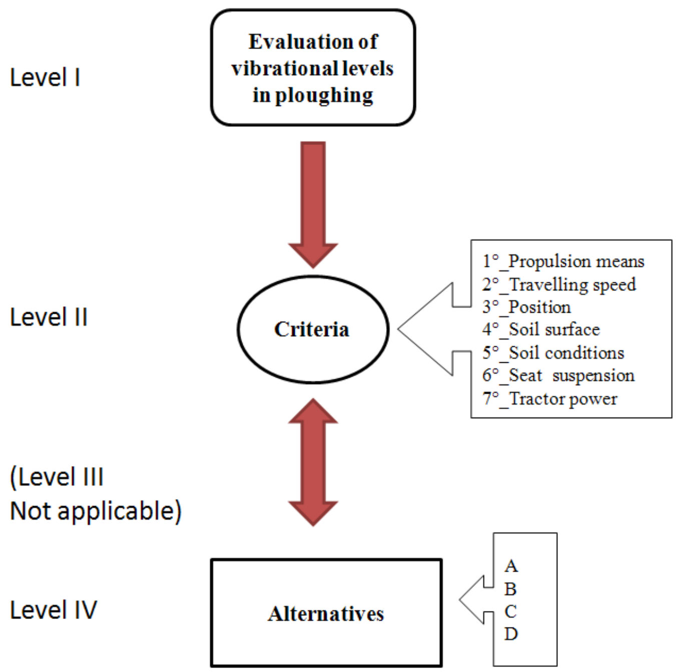

Figure 1. Scheme of the hierarchic model applied for the analysis.

Table 1. Relative importance scale (by Saaty).

Importance intensity	Definition	Description
1	Equal importance	Two activities contribute equally to the objective
2(*)		
3	Weak importance of one over another	Experience and judgment slightly favour one activity on another
4(*)		
5	Essential or strong importance	Experience and judgment strongly favour one activity on another
6(*)		
7	Demonstrated importance	An activity is strongly favoured and its dominance demonstrated in practice
8(*)		
9	Absolute importance	The evidence favouring one activity on another.

(*) = 2, 4, 6, 8: intermediate values

The AHP was adopted for analyzing the parameters influencing the vibrational levels during ploughing. The purpose of the present study was to assign a suitable weight to each of these parameters, starting from a certain number of cases of measured vibrational levels (**fig. 2**).

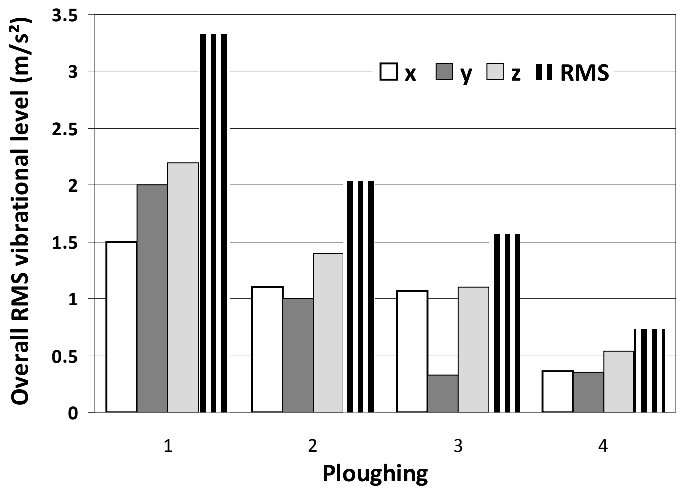

Figure 2. Whole-body vibrational levels measured on the tractor driver's seat during ploughing.

Each criteria can be described using different options, summarized in **Table 2.** The structure of the typical decision problem consists of a number of alternatives, and a number of criteria (**Table 3**). Through the choice among these options decision maker can describe each criteria.

Table 2. Criteria options.

Criteria	**Options**
Draft gear	tyre, track
Travelling speed	low (v <5 km/h), medium (5 km/h < v < 8 km/h), high (v >8 km/h)
Plough working	in furrow, out of furrow
Soil surface profile	regular, rough, very rough
Soil conditions	good, not good, poor
Seat suspension type	mechanical, pneumatic
Tractor power	numerical value (kW)
Overall RMS vibration level	recorded value (m/s²)

Table 3. Matrix about criteria and alternatives considered in the present study.

		Alternatives			
	Case	**a**	**b**	**c**	**d**
Criteria	Draft gear	tyre	tyre	tyre	tyre
	Travelling speed	medium	low	medium	medium
	Plough working	in furrow	in furrow	in furrow	in furrow
	Soil surface profile	very rough	very rough	very rough	regular
	Soil conditions	poor	good	poor	good
	Seat suspension type	pneumatic	pneumatic	pneumatic	pneumatic
	Tractor power	119 kW	92 kW	96 kW	141 kW
	Overall RMS vibration level	3.33 m/s²	2.04 m/s²	1.57 m/s²	0.73 m/s²

RESULTS AND DISCUSSION All the elements of the hierarchical model have been compared. In a simple situation, all the criteria are expressed in the same unit, but in many real problems, and also here, many criteria may be expressed in different dimensions. Saaty's scale helps comparing both criteria (**table 4**) and alternatives, because it links absolute number with linguistic description about the relative importance of each elements.

Comparisons among criteria and alternatives produce weighting factors (**table 5**), which are multiplied, in order to obtain a single weight for each criteria and for a single alternative.

Table 4. Application of comparison among criteria, using Saaty's scale.

	DG	TS	PW	SS	SC	SE	TP
Draft gear (DG)	1	6	7	7	8	8	9
Travelling speed (TS)	1/6	1	5	6	6	7	8
Plough working (PW)	1/7	1/5	1	3	3	4	4
Soil surface profile (SS)	1/7	1/6	1/3	1	3	3	3
Soil conditions (SC)	1/8	1/6	1/3	1/3	1	3	3
Seat suspension type (SE)	1/8	1/7	1/4	1/3	1/3	1	2
Tractor power (TP)	1/9	1/8	1/4	1/3	1/3	1/2	1

Table 5. Single criteria weights (W) and their normalized values (W_n).

	W	$\mathbf{W_n}$
DG	0.450	**0.268**
TS	0.240	**0.143**
PW	0.110	**0.066**
SS	0.758	**0.453**
SC	0.055	**0.033**
SE	0.036	**0.021**
TP	0.026	**0.016**

The overall RMS vibration levels calculated during real tests were considered. As a result of previous trials, it was found that vibration levels during ploughing are generally higher than 0.42 m/s^2. Considering a reduction of this value of about 10 % (due to measurement and instrument calibration inaccuracy), 0.38 m/s^2 might be considered the minimum overall RMS vibration level measured during ploughing (*offset*). The difference (D) between the obtained RMS levels and the defined offset for each of the examined cases is then shown in **Table 6**.

Table 6. Difference D between the overall RMS vibration levels and the defined offset (m/s^2).

	a	**b**	**c**	**d**
Overall RMS vibration level	3.33	2.04	1.57	0.73
Offset	0.38	0.38	0.38	0.38
D	**2.95**	**1.66**	**1.19**	**0.35**

Starting from these values (D) thus obtained, using the criteria weights previously calculated (**Table 5**), it was possible to estimate the influence of each criteria within each of the 4 tests carried out (**Table 7**).

Table 7. Criteria influence on the overall RMS vibration level of the 4 tests examined.

Criteria	Normalized weight	Overall RMS vibration level contribution			
		a	b	c	d
Draft gear	0.268	0.78	0.45	0.32	0.09
Travelling speed	0.143	0.41	0.24	0.17	0.05
Plough working	0.066	0.18	0.12	0.08	0.02
Soil surface profile	0.453	1.33	0.75	0.54	0.16
Soil conditions	0.033	0.09	0.05	0.04	0.01
Seat suspension type	0.021	0.06	0.03	0.02	0.01
Tractor power	0.016	0.04	0.02	0.02	0.01
Σ	1	**2.95**	**1.66**	**1.19**	**0.35**

CONCLUSION Purpose of this study was to define a given number of criteria and their relevant weighting in order to ascertain the influence on overall RMS vibration levels recorded during the agricultural operations. Aim of this model is to predict the vibrational level produced at the driver's seat of a tractor coupled to a specific implement. The Analytic Hierarchy Process (AHP) model was then applied, taking into account the measured overall RMS vibration values during 4 cases of ploughing. This is just a demonstration, so conducted with very few data; the next step will be to acquire enough data to cover suitably all the options considered, in order to define as exactly as possible the influence of each criteria. The studied method could also be applied for changing the decision makers points of view referred to the considered criteria. Furtherly, it should be extended to all field/farming agricultural operations. The ultimate goal will be the creation of a complete database with a careful selection of the criteria options. The database will be the means to predict the vibrational level of each agricultural operation, without instrumental measurements. Finally, the last step will be to evaluate the overall operator's vibration exposure, by taking into account his/her agricultural tasks carried out, weighted over the working time dedicated to each of them.

REFERENCES

Pessina, D., D. Facchinetti, and V. Bonalume, 2008. Improved database for the assessment of operator's vibration risk in agriculture. In: International Conference, Innovation technology to empower safety, health and welfare in agriculture and agro-food systems. ElleDue, ISBN 978-88-903151-1-7, Ragusa, Italy, 114.

Pessina, D., D. Facchinetti, and M. Belli, 2006. Contribution for the definition of a vibrations standard for Big Self-propelled Harvesting Machines, Proc. CIGR-EurAgEng World Congress, ISBN 3-18-091958-2, Bonn, pp. 6.

Nataraj, S., 2005. Analytic hierarchy process as a decision-support system in the petroleum pipeline industry. Issues in Information systems, 16-21.

Niemira, M., and T. L. Saaty, 2004. An analytic network process model for financial-crisis forecasting. International Journal of Forecasting, NH Elsevier, 573-587.

Triantaphyllou, E., and S. Mann, 1995. Using the analytic hierarchy process for decision making in engineering applications: some challenges. International Journal of Industrial Engineering, ISSN 1072-4761, 35-44.