Czesław RZEŹNIK, Piotr RYBACKI
Agricultural University of Poznań
Institute of Agricultural Engineering
e-mail: rzeznik@au.poznan.pl
e-mail: prybacki@au.poznan.pl
Anna MOLIŃSKA
Agricultural University of Poznań
Department of Mathematical and Statistical Methods
e-mail: krys@au.poznan.pl

ASSESSMENT OF THE EFFECT OF THE MATERIAL DIVERSITY OF AGRICULTURAL MACHINES ON THEIR RECYCLABILITY

Summary

Modern farming machines are manufactured from a continuously growing number of different materials. This is quite understandable because different parts and units of farming machines work in different conditions, at constantly changing loads and the application of appropriate material guarantee their optimal durability. This direction of development causes that these modern machines, once they have reached the end of their service life, are increasingly more difficult to recycle. Therefore, one of the major tasks of manufacturers is to reconcile these contradictory requirements. This can be achieved by developing a method which will allow to determine precisely, numerically the impact of the material heterogeneity of the farming machines on the recyclability. This study presents such a method which employs the information entropy of material heterogeneity of farming machines as a measure of recyclability.

PODATNOŚĆ NA RECYKLING JAKO FUNKCJA RÓŻNORODNOŚCI MATERIAŁÓW, Z KTÓRYCH ZBUDOWANA JEST MASZYNA

Streszczenie

Nowoczesne maszyny rolnicze są budowane z coraz większej liczby różnych materiałów. Jest to oczywiste, ponieważ części i zespoły maszyn rolniczych pracują w różnych warunkach, przy zmiennych obciążeniach, a odpowiednie materiały zapewniają im optymalną trwałość. Taki kierunek rozwoju sprawia, że maszyny te trudniej, po wyłączeniu z eksploatacji zagospodarować na drodze recyklingu. Zadaniem producentów maszyn rolniczych jest umiejętne pogodzenie tych sprzecznych wymagań. Można tego dokonać dysponując metodą, która pozwoli precyzyjnie, liczbowo określić wpływ różnorodności materiałowej maszyn rolniczych na ich podatność na recykling. W pracy przedstawiono taką metodę, która jako miarę podatności na recykling wykorzystuje entropię informacyjną różnorodności materiałowej maszyny rolniczej.

1. Introduction

Recycling is a widely accepted and increasingly commonly used pro-ecological method of disposing of products and articles which have reached the end of their service life, including agricultural machines, which consists in a repeated utilization of materials and energy of products withdrawn from utilization. This approach does not load the environment with wastes and, additionally, allows obtaining economic profits.

Recycling is usually divided, from the point of view of the employed method of disposal and management of materials and energy into the following types:

- Product,
- Material,
- Raw material and
- Energetic.

Product recycling consists in a repeated utilization of a product withdrawn from utilization, as an identical product following the restoration – after appropriate treatment and processing – of a condition which will allow its further utilization. A good example of this is the regeneration of parts of farming machines. This is the most effective both ecologically and economically method of recycling.

Material recycling involves repeated utilization of the material from products withdrawn from service as a material to manufacture other products. Utilisation of steel (sections, sheets etc.) from agricultural machines withdrawn from service to manufacture tools, equipment for animal production etc. provides good examples of material recycling.

A new utilisation of a material from products withdrawn from service to produce other materials is recycling of raw materials. Collection of scrap metals and their repeated processing in foundries to produce metallurgical materials is an example of raw material recycling. It is employed more and more widely for plastics, operating fluids, glass etc. even though it is more expensive in comparison to previous ones.

Energetic recycling refers to the utilisation of products withdrawn from service to produce energy. An example of this kind of recycling is burning of used tyres in special furnaces in cement mills

Modern agricultural machines are made of a variety of materials. This is the result of the achievements of materials engineering which offers to manufacturers of agricultural machines new, modern materials which are capable of meeting the requirements better and better. However, this heterogeneity which is advantageous from the point of view of the functionality, durability, reliability and economic efficiency of machines poses a number of difficulties when it comes to their disposal using recycling. This results from the fact that, irrespective of the applied recycling method, each kind of material must be first separated from the machine structure by disassembling it and, later on, its management employing appropriate recycling methods. This approach is also necessary in the case of raw material recycling which is dominant in the management of agricultural machines withdrawn from service.

In literature on the subject, the term "recyclability of machines" is sometimes used [3, 4] which is understood as such preparation of the machine during the process of its manufacture as to facilitate its recycling. There are also numerical methods allowing valuation of this trait. However, so far, no universal measure which would allow taking under consideration many criteria has been elaborated. Moreover, there is no method which would allow to assess the impact of the diversity of the materials employed to manufacture these machines on their recyclability. The applied methods are confined to a numerical (percentage) specification of proportions of individual 'recyclable' and 'non-recyclable' materials in a given machine [3].

We know intuitively that a machine manufactured from one kind of material will not require disassembling and separation into groups of materials prior to recycling and its "raw material" recyclability will be high. However, if a machine must be disassembled and separated into groups of materials prior to recycling, then the higher the number of materials used to manufacture this machine, the worse are its recyclability potentials. Still another problem, in the case of a specified number of kinds of materials, is their percentage proportion in the machine structure. It can be measured on the basis of its weight in relation to the weight of the entire machine or its load in relation to the environment. If the proportion of one type of material is dominant and that of the remaining material negligible, then the dismantling of one (dominant) type of material and its management by recycling will reduce considerably the amount of wastes. Hence, the recyclability of such a machine will be considerably higher in comparison with the machine in which the proportion of individual groups of materials will be similar or equal.

This kind of intuitive, descriptive information, although logically correct, is not sufficient when assessing the recyclability of agricultural machines. Recyclability, alongside functional properties as well as durability and reliability, is an important evaluation criterion of agricultural machines. There is no method in the available literature on the subject which allows objective, numerical valuation of this trait and, hence, the comparison of different constructional solutions of machines.

2. Aim and scope of investigations

The aim of the study is to develop a method which would allow to evaluate numerically the impact of the number of kinds of materials as well as the proportion of the kinds of materials used to manufacture the machine on its recyclability. Its development will provide a tool for an accurate assessment of the effect of the number of material kinds and changes in their proportion on recyclability. Ultimately, after developing methods allowing the determination of the impact of different factors on recyclability of machines, it will be possible to elaborate one method which will make complex evaluation of this feature of agricultural machines possible.

3. Method

At the beginning, the development of the method requires formalisation of the object of our study (agricultural machine) from the point of view of the problem to be solved. In our case, the machine can be treated as a set of *n* classes of materials, including the materials from which its parts were made. At this stage, the kind of material is assumed as the classification criterion. In this case, machine *M* can be represented using an equation as a set:

$$M = \{m_1, m_2, \ldots, m_n\} \quad (1)$$

where: m_i, $i = 1, 2, \ldots, n$, designate i-th kind of material.

Each kind of material has a certain share p_i, i = 1, 2,...., n in the entire machine The determination of p_i takes place by determining the ratio of the material weight m_i to the total weight of the machine; p_i can also be determined by adopting a criterion other than the weight, e.g. costs of recycling, load on the environment by the i-th kind of material etc.

In this study, the following assumptions were adopted:

- We distinguish *n* classes (kinds) of materials from which machine parts are made,
- All kinds of machine component materials undergo recycling,
- Each machine component part undergoing recycling can be included only into one class of material,
- The proportion of the i-th class of material in the entire machine is determined by the relative value p_i, $0 < p_i < 1$,
- $\sum_{i=1}^{n} p_i = 1.$

Information entropy [1] whose value was expressed by equation 2 was adopted as a measure which allowed to evaluate the material heterogeneity of a given machine.

$$H = -\sum_{i=1}^{n} p_i \log_2 p_i. \quad (2)$$

Information entropy increases with the increase in the number of kinds of materials used to manufacture the machine and with the equalisation of the proportion of individual kinds of materials in its weight. Information entropy assumes the highest value

$$H_{max.} = \log_2 n, \quad (3)$$

when the relative proportion of the individual kinds of materials in the structure of a given machine is the same, i.e. $p_1 = p_2 = \ldots = p_n$.

Information entropy allows numerical valuation of the assessments earlier expressed intuitively regarding recyclability of agricultural machines as a function of heterogeneity of materials used to manufacture them. Logical correctness of the presented line of thought is presented in Table 1.

Table 1. Weight proportions of various kinds of materials used to manufacture the machine and evaluation of material heterogeneity of the machine
Tab. 1. Udziały masowe różnych rodzajów materiałów wykorzystanych w budowie maszyny oraz entropie ich różnorodności

Share of i-th material Udział i-tego materiału / *Type of machine* Rodzaj maszyny		A	B	C	D	E	F
p_1		1.00	0.50	0.25	0.125	0.60	0.30
p_2		0.00	0.50	0.25	0.125	0.10	0.20
p_3		0.00	0.00	0.25	0.125	0.05	0.15
p_4		0.00	0.00	0.25	0.125	0.05	0.15
p_5		0.00	0.00	0.00	0.125	0.05	0.05
p_6		0.00	0.00	0.00	0.125	0.05	0.05
p_7		0.00	0.00	0.00	0.125	0.05	0.05
p_8		0.00	0.00	0.00	0.125	0.05	0.05
Entropy Entropia (bit)	H	0.00	1.00	2.00	3.00	2.07	2.66
	H_{max}	0	1	2	3	3	3

Table 2. Weight proportion of individual materials in the total weight of the Pilmet 412 sprayer
Tab. 2. Udział masowy materiałów w ogólnej masie opryskiwacza „Pilmet 412"

Kind of material Rodzaj materiału		*Machine variant* Wariant maszyny		
		Basic Podstawowy	Variant A	Variant B
Polyethylene Polietylen p_1 (100%)		17.31	17.31	17.31
Polyamide Poliamid p_2 (100%)		2.50	2.50	2.50
Polyvinyl chloride Polichlorek winylu p_3 (100%)		0.58	0.58	2.50
Other plastics Inne tworzywa sztuczne p_4 (100%)		1.92	0.00	0.00
Rubber Guma p_5 (100%)		2.31	2.31	2.31
Oil Olej p_6 (100%)		0.19	0.19	0.19
Metals and alloys Metale i stopy p_7 (100%)		75.19	75.11	75.19
Entropy Entropia (bit)	H	1.15	1.02	1.13
	H_{max}	2.8	2.8	2.8

Machine A manufactured from one kind of material is most recyclable and its entropy assumes the value of zero. As the number of the employed materials increases, and assuming their equal proportion, the recyclability of the machine decreases, while its entropy increases (machines: B, C and D). At the assumed number of the kinds of materials (e.g. n = 8), when the proportion of one of them is dominant (machine E), the recyclability of this machine is higher in comparison with the machine where the proportion of materials is equal (machine D). If the domination of one kind of material declines (Machine F), then the recyclability of this machine also decreases. The value of entropy is reverse to the recyclability of the machine. The performed analysis is logically correct. Information entropy may be employed as a numerical measure of recyclability of a machine resulting from material heterogeneity.

4. Example

An important, albeit not ultimate, test of the substantive correctness of the new method is its practical application and the evaluation of the obtained results. For this purpose, a Pilmet 412 sprayer was employed. The machine is characterised by a high material heterogeneity [2, 6]. If we assume that all materials used to manufacture the sprayer are recyclable, then the precondition for the recycling process is to disassemble the machine and separate individual groups of materials. Our intension is to increase the recyclability of this sprayer and this can be achieved by one of two ways. The variants are presented in the Table 2.

The envisaged modernisation of the sprayer consisted in limiting the number of materials employed for its manufacture. The group "other plastics" was eliminated and replaced by metals and alloys in Variant A or by polyvinyl chloride of the same weight in Variant B. Then information entropies for all the three cases were calculated. The highest value of this parameter was determined for the Basic Variant. Modifications introduced in Variants A and B limited the number of the employed materials which improved the recyclability of the machine. These changes are well described by the entropy values calculated for them which decrease in both cases. These values are the smallest in Variant A which is characterised by the best recyclability. Therefore, it is this Variant that should be selected for the practical modernisation of the sprayer.

5. Recapitulation

The method presented in this study allows valuation of the recyclability of machines via the function of their material heterogeneity. The performed analysis and the presented example show that the method can be utilised for an objective, numerical assessment of this trait for any machine with the aim to implement appropriate or required construction solutions. This is important, especially in view of the fact that ecological effectiveness, alongside economic efficiency, are becoming important criteria of assessment of each product. The elaborated method can be used to valuate this trait. The objective and determined character of the method allows to take it into account for the complex evaluation of the recyclability of machines. Such assessment should include: the number of the applied kinds of materials as well as their percentage proportion in the structure of the machine with their division into recyclable and non-recyclable materials, accessibility of the individual groups of materials understood as the ease with which they can be disassembled from the machine structure. The recyclability must also take into account the type of the recycling process possible to employ and stimulate and encourage product and material recycling as the most ecologically and economically effective and friendly.

6. References

[1] Borowkow A. A.: Rachunek prawdopodobieństwa. PWN, Warszawa, 1975.

[2] Bugajski S.: Tworzywa modyfikowane i kompozyty w maszynach rolniczych – jako nośnik jakości. Prace PIMR, nr 1/1999.

[3] Mikucki K.: Ekologiczne projektowanie maszyn i urządzeń rolniczych. VII Sympozjum im. prof. Cz. Kanafojskiego, Politechnika Warszawska, 1998.

[4] Rybacki P.: Metoda oceny podatności maszyn rolniczych na recykling. Rozprawa Doktorska. Poznań, 2004.

[5] Rzeźnik C., Rybacki P.: Structural method of evaluating the susceptibility of agricultural machines to recycling. Electronic Journal of Polish Agricultural Universities, Seria Agricultural Engineering, Issue 2, Volume 7, 2004.

[6] Rzeźnik C., Rybacki P.: Ocena podatności maszyn rolniczych na recykling metodą strukturalną. Acta Scientiarum Polonorum, Technica Agraria, 2004, 3 (2/2), s. 49-55.