

## CONSTRUCTION OF MODEL SERIES OF CARS, TRACTORS AND SELF-PROPELLED CHASSIS USING CONDITIONAL ENTROPY

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**Abstract.** This paper presents the results of research aimed at constructing dimensional series of agricultural tractors using the example of the “Fendt” company. The theoretical basis for the construction is similarity theory, the methods of which allow the formation of a system of scale coefficients. Scale modelling is used taking into account the scale coefficients of such parameters (mechanical quantities) as the linear dimensions of the model, mass, speed, moments of inertia, time, and others. The hook pull force was traditionally used for tractors when constructing dimensional series. The aim of the paper is to use scale factors when moving from the previous term of the series to the next one, using the maximum effective engine power as a standardisation parameter. The scale coefficient was determined based on the condition of constant entropy increase when transitioning from the previous member of the series to the next one. The series can be constructed starting from either the first  $b_1$  or the last  $b_n$  member, taking  $b_1$  as the base members, respectively. As a result, it is proposed to switch from an arithmetic series to a geometric series, which allows reducing the number of specified members. For the “Fendt” tractor model range,  $b_1 = 26$  kW and  $b_n = 136$  kW. The study examines the method of selecting scale coefficients for physical quantities included in the determination function and formulates requirements for measurement accuracy when testing scale models. The paper presents the results of calculating scale coefficients used in the construction of dimensional series of tractors. Calculations based on the “Fendt” tractor model range showed that using this method reduces the number of models (differing in maximum effective engine power) from 19 to 12. This represents a 36.8% reduction in the number of series elements. This will enable farmers and agricultural enterprises to avoid spending money on purchasing a tractor with an engine power that overlaps with the neighbouring traction class.

**Keywords:** tractor testing, large-scale modelling, measurement errors, similarity scale, self-propelled chassis.

### Introduction

The scientific and technological progress of modern manufacturing is accompanied by the creation of various types, kinds, brands, and sizes of machines and equipment to meet the needs of economic sectors in any country of the world. Therefore, one of the main tasks of standardization is to reduce the number of production objects to a reasonable minimum.

To reduce the diversity of products, model (dimensional and parametric) series are constructed based on the use of a main parameter that most fully characterizes the product. This article proposes a method for constructing model series using conditional entropy, in which the transition from the previous element of the series to the next is accompanied by a constant increase in conditional entropy, measured according to the main parameter of the machine.

The calculations performed using the model series of “Fendt” tractors demonstrated the possibility of reducing the number of series elements from 19 to 12 models.

### Literature review

Each type of product has a set of specific parameters [1]. The range of standardized parameters should be minimal but sufficient to evaluate the operational characteristics of a given type of product. A product parameter is understood as a feature of a product that quantitatively characterizes one of its properties or states. A main parameter is one that most accurately characterizes the given product, remains unchanged for a long time, and may change only when new modern products are developed.

For the truck, the main parameter is the load capacity; for a passenger car, the engine displacement; and for a bus, the overall length or passenger capacity. When considering tractors and self-propelled chassis, however, there is ongoing debate regarding the choice of their main parameter. Traditionally, the drawbar pull has been used as such parameter, but with the same value of this parameter a tractor or self-propelled chassis can move at different speeds. The emergence of high-power tractors capable of moving at speeds of 40 km/h and higher has raised doubts about the correctness of choosing drawbar

pull as the main parameter for standardization. Authors of some studies [2] propose using the maximum effective engine power as the main parameter for tractors. However, as shown by the studies [5], the power at the driving wheels can decrease by up to 20% during operation. A more objective parameter may be the gross vehicle mass for automobiles or the operating mass for tractors and self-propelled chassis. Tractors presented at international exhibitions [3; 4] are classified according to the maximum effective engine power. It should be noted that both the drawbar pull of a tractor and the maximum effective engine power are parameters that retain their values for a long time. As studies have shown [5], the power at the driving wheels of a vehicle can decrease by up to 20% during operation. Therefore, in our opinion, a more objective main parameter for standardization may be the gross mass of the vehicle and the operating mass of tractors and self-propelled chassis. The relationship between drawbar pull (maximum effective engine power) and mass can be easily determined using well-known relationships from the tractor theory. In the works [6; 7], the relationship between the three most important parameters of a vehicle has been established:

$$E_w = \frac{m_v \cdot V_{\max}^2}{2 \cdot N_{e\max}}, \quad (1)$$

where  $E_w$  – machine energy efficiency indicator;  
 $m_v$  – gross mass of the vehicle;  
 $V_{\max}$  – maximum vehicle speed;  
 $N_{e\max}$  – maximum effective engine power.

The value of  $E_w$  for different models of passenger cars from different production years ranges from  $18 \text{ J} \cdot \text{W}^{-1}$  to  $25 \text{ J} \cdot \text{W}^{-1}$  [6; 7]. The known indicator of specific vehicle power  $N_{\text{spec}} = N_{e\max}/m_v$  for the same car models varies within wider limits [6; 7], from  $27 \text{ kW} \cdot \text{t}^{-1}$  to  $115 \text{ kW} \cdot \text{t}^{-1}$ . Thus, assuming the relation (1), it is possible to determine one main standardization parameter based on the known values of the other two.

The selection of one main standardization parameter becomes possible when the other two are known.

The construction of a model series of automobiles, tractors, and self-propelled chassis can be considered as a problem of scale modelling, in which the first (base) element of the series acts as the prototype, while each subsequent element may be regarded as a scaled model relative to it [8]. In this case, the base element of the series may be a product with either the smallest or the largest value of the main standardization parameter, whereas the remaining design and operational parameters are determined using a system of scaling coefficients established for the corresponding physical quantities [8]. The theoretical basis of this approach is similarity theory, or the theory of generalized variables, which makes it possible to establish invariant relationships between the geometric, kinematic, and dynamic characteristics of the prototype and its models and ensures the correct transfer of research results obtained from the model to the real object.

The application of similarity principles in vehicle research has a long history. One of the earliest examples is the experimental work carried out at the Institution of Automobile Engineers in Great Britain, where a scale model of a vehicle was used to investigate the influence of braking of the front and rear wheels on the stability of motion during braking [9]. These studies demonstrated the possibility of transferring results obtained from scale models to real vehicles and laid the foundation for the further development of scale modelling methods in vehicle dynamics research. Subsequently, similar approaches were applied to the study of tractors and self-propelled chassis, making it possible to evaluate their dynamic behaviour and determine rational design parameters at the early stages of development. Scale modelling has also been used to analyse braking systems, determine the distribution of forces acting on the running gear, and assess vehicle stability under various operating conditions.

The dynamic behaviour of vehicles is governed by universal physical properties of mechanical systems, including mass, inertia characteristics, interaction forces with the supporting surface, and kinematic parameters of motion. For this reason, relationships established for automobiles can also be extended to other classes of mobile machines, including tractors and self-propelled chassis. The effectiveness of such approaches is confirmed by studies in which modelling methods have been used to analyse the stability and anti-rollover behaviour of agricultural tractors [10], to evaluate the

passability and dynamic characteristics of universal self-propelled chassis [11], and to investigate the motion and controllability of autonomous unmanned ground vehicles designed for various applications [12]. These studies show that scale modelling makes it possible to predict the behaviour of mobile machines under different operating conditions and to evaluate their operational properties before the production of a full-scale prototype. In addition, the use of scaling coefficients makes it possible to preserve the relationships between the main physical parameters of vehicles when transitioning from a prototype to a model. This significantly reduces the cost and duration of experimental research at the design stage. The obtained results can be used to substantiate the parameters of new model series of mobile machines, including automobiles, tractors, and self-propelled chassis, with different power and mass characteristics. Furthermore, the application of similarity principles facilitates the optimisation of the structures of vehicles and self-propelled chassis while maintaining the required dynamic and operational properties. Therefore, scale modelling remains an effective tool in the development and investigation of modern transport and agricultural machines, as well as self-propelled chassis.

### Purpose and objectives of the study

The purpose of the study is to develop a method for constructing model (dimensional or parametric) series of automobiles, tractors, and self-propelled chassis using conditional entropy.

To achieve this goal, the following tasks must be solved:

- arrange the dimensional series of machines according to the main parameter of standardization;
- using the example of a model series of tractors, to demonstrate the advantage of using conditional entropy in its construction.

Main part A parametric (model) series of machines constructed according to the main parameter  $b$  has the following form:

$$U\{b_1; b_2; \dots; b_i; \dots; b_n\} \quad (2)$$

where  $b_1, b_n$  – extreme elements of the series (the first and last);  
 $n$  – number of elements of the series.

The construction of the series may begin either with the first element  $b_1$  or the last element  $b_n$ , taking them as the base element. Let us assume that the parametric series is constructed starting from the first element  $b_1$ , which is taken as the base and has the smallest value.

Let us assume that the transition from the previous element of the series to the next is accompanied by an increase in the conditional entropy of the object with respect to the main parameter  $b$ . In general, this set can be written as

$$\delta b = \frac{\Delta b_i}{b_{i-1}} = q = const \quad (3)$$

where  $\Delta b_i$  – difference in the values of the main parameter  $b$  between the next and previous elements of the series;  
 $b_{i-1}$  – value of the main parameter  $b$  of the previous element of the series.

Thus,

$$b_2 = b_1 + \Delta b_2 \quad (4)$$

$$b_3 = b_2 + \Delta b_3 \quad (5)$$

$$b_i = b_{i-1} + \Delta b_i \quad (6)$$

$$b_n = b_{n-1} + \Delta b_n \quad (7)$$

Equations (4) - (7) can be transformed into the following form:

$$b_2 = b_1 \left( 1 + \frac{\Delta b_2}{b_1} \right) = b_1 (1 + q) \quad (8)$$

$$b_3 = b_1(1+q)^2 \quad (9)$$

$$b_i = b_1(1+q)^{i-1} \quad (10)$$

$$b_n = b_1(1+q)^{n-1} \quad (11)$$

If, during the construction of the dimensional series, the first and last elements (their main parameter values) are specified, then from the last formula (11) we obtain

$$\frac{b_n}{b_1} = (1+q)^{n-1} \quad (12)$$

or

$$\sqrt[n-1]{\frac{b_n}{b_1}} = 1+q \quad (13)$$

From this equation, for a given parameter  $q$ , the number of elements of the series is determined as

$$n = \frac{\ln \left| \frac{b_n}{b_1} \right|}{\ln |1+q|} + 1 \quad (14)$$

From this expression (14) it follows that as the ratio  $b_n/b_1$  increases, the number of elements in the parametric series increases, whereas with an increase in the increment  $q$  of conditional entropy, the number decreases.

Analyzing relations (10) - (14), we can see that the dimensional series with a constant increment of conditional entropy transforms from the arithmetic series (4) - (7) into a geometric series with a constant ratio

$$z = 1+q \quad (15)$$

To illustrate the effectiveness of the proposed method for constructing dimensional series, let us consider the model range of wheeled tractors produced by "Fendt" [3; 4]. Table 1 presents the values of the maximum effective engine power for each element of the model range. In total, the series includes 19 elements (differing by maximum effective engine power).

Table 1

"Fendt" tractor model range

Model	$N_{emax}$ , kW	$\Delta N_e = \Delta b_i$ , kW	Series member number
231Gt	26	4	$b_1$
Farmer 240S	30	3	$b_2$
F345GTM	33	4	$b_3$
Farmer 250SF	37	7	$b_4$
Farmer 260SA	44	2	$b_5$
Farmer 305LSA	46	2	$b_6$
F365 GTA	48	4	$b_7$
Farmer 306LSA	52	3	$b_8$
Farmer 275SA	55	4	$b_9$
F380GT	59	1	$b_{10}$
Farmer 308LSA	60	6	$b_{11}$
Farmer 309LSA	66	4	$b_{12}$
Farmer 310LSA	70	4	$b_{13}$
F390GTA	74	9	$b_{14}$
Farmer 312LSA	85	7	$b_{15}$
Favorit 611 LSA	92	15	$b_{16}$
Favorit 612 LSA	107	14	$b_{17}$
Favorit 614 LSA	121	15	$b_{18}$
Favorit 615 LSA	136	-	$b_n$

For the “Fendt” tractor model range presented in Table 1  $b_1 = 26 \text{ kW}$  and  $b_n = 136 \text{ kW}$ . To determine the number of series elements  $n$ , we use the increment of the conditional entropy of the series based on the difference between the main parameters of the series elements  $b_1$  and  $b_2$ . This value is equal to  $q = 0.1538$ . Using formula (14), we determine the number of elements in the geometric series, which is  $n = 11.56$  (accepted as  $n = 12$ ). According to the formula (derived from equation (13))

$$q = \exp \left( \frac{\ln \left| \frac{b_n}{b_1} \right|}{n-1} \right) - 1 \quad (16)$$

for the specified value  $n = 12$ , the refined value of the parameter is  $q = 0.1478$ .

## Results and discussion

Table 2 presents the model series constructed with a constant value of the conditional entropy of the main standardization parameter – the maximum effective engine power. This series represents a geometric progression. Such an approach is proposed for the first time for the ranking of agricultural machinery.

Thus, it can be concluded that the use of conditional entropy in constructing model series of tractors and self-propelled chassis makes it possible to reduce the number of series elements. The principle of equal increments of the conditional entropy of the standardization parameter (in this case, the maximum effective engine power) enables the transformation of the model series from an arithmetic progression into a geometric progression. A comparison of the “Fendt” tractor model range data presented in Tables 1 and 2 illustrates a reduction in the number of series elements from 19 to 12, which represents a decrease of 36.8%.

As noted, reducing the tractor model range is advantageous not only for manufacturers but also for equipment users. Farmers benefit from having a smaller number of tractor models which engine power covers the majority of agricultural operations. The proposed method for calculating model series of tractors and self-propelled chassis using a geometric progression creates an opportunity to optimize equipment acquisition and reduce the costs associated with fleet renewal.

Table 2

**Proposed tractor model range**

Parameter	Tractor model number											
	1	2	3	4	5	6	7	8	9	10	11	12
$N_{e_{max}}$ , kW	26	30	34	39	45	52	59	68	78	90	103	136
$\Delta N_e = \Delta b_i$ , kW	4	4	5	6	7	7	9	10	12	13	33	-

## Conclusions

1. The proposed method for constructing model series of automobiles, tractors, and self-propelled chassis using a constant increase in the conditional entropy of the main standardization parameter makes it possible to reduce the number of elements in the series.
2. Calculations performed using the example of the model range of “Fendt” tractors showed that applying the proposed method allows the number of elements in the series (differing by maximum engine power) to be reduced from 19 to 12. This reduction amounts to 36.8%.

## Author contributions

Conceptualization and preparation of the initial manuscript draft – Mikhail Podrigalo, review and validation – Nikolay Artiimov, formal analysis and editing – Vladimir Krasnokutsky, methodology and investigation – Mikhail Podrigalo, Nikolay Artiimov, Vitalii Shein, Vladimir Krasnokutsky, software and data processing – Vitalii Shein.

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