Original Study Article
DOI: https://doi.org/10.17816/0321-4443-637367 EDN: ZQPJBL

Modeling and optimization of the consumer properties of mobile energy units in the agricultural industry

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ABSTRACT

BACKGROUND: This paper contains examples of the implementation of multi-criteria optimization in the justification of consumer properties of mobile energy units. The criteria include five main functional and operational indicators: productivity rate, energy rate by the relative reduction of total specific costs of mobile energy units, total costs of maintenance and repair, pressure on the soil and energy efficiency. The use of multi-criteria optimization can have a wide range of applications: in the design, development and operation of mobile energy units.

AIM: Modeling and optimization of consumer properties of mobile energy units of the agricultural industry using the example of a mobile energy unit of the drawbar category 1.4.

METHODS: Collection and analysis of scientific publications, scientific papers, and other sources of information on formation of the R&D for creation of intelligent transport and technical means, on key indicators of consumer properties of agricultural mobile energy units, as well as on improvement of methodological and software support for multi-criteria optimization calculations of efficiency of mobile energy units. In solving the task, methods of scientific generalization and statistical processing of available information and analytical materials from domestic and foreign sources were used.

RESULTS: As a result of the performed calculations, the following result points were selected by a decision-maker as the most preferable among the obtained Pareto points for the drawbar category 1.4 tractor:

1. Plowing — the productivity rate of 1.17 ha/h; the soil pressure of 145 kPa; the total costs of 149.2 thousand rubles; the energy rate of 35.0%, the energy efficiency of 19.7 kW·ha/h.
2. Sowing — the productivity rate of 2.87 ha/h; the soil pressure of 149.3 kPa; the total costs of 178.39 thousand rubles; the energy rate of 35.3%, the energy efficiency of 24.17 kW·ha/h.
3. Chemization — the productivity rate of 3.541 ha/h; the soil pressure of 177.513 kPa; the total costs of 124.408 thousand rubles; the energy rate of 22.8%, the energy efficiency of 32.10 kW·ha/h.

CONCLUSION: The analysis of the classification of functional operational and economic indicators of mobile energy units (consumer properties), as well as their expert assessment, helped to identify five main quality criteria: soil pressure ($q^{к}_{max}$), productivity rate (W), total repair and maintenance costs $(З_{p_i})$, energy rate by the relative reduction of total specific fuel and energy costs of mobile energy units, $(Э^{n}_{w})$, energy efficiency (E_c), for the modeling and optimization of which the software package for solving the multi-criteria optimization problems, allowing solving problems with more than 50 variable parameters and 20 quality criteria, was developed. For a full disclosure of the optimal consumer operational properties of mobile energy units of the drawbar category 1.4 and the three most important operations (plowing, sowing, chemization), were selected.

Keywords: multi-criteria optimization; consumer properties of mobile energy units; functional properties; quality criteria; variable parameters; making compromise decisions.

To cite this article:
Godzhaev TZ, Zubina VA. Modeling and optimization of the consumer properties of mobile energy units in the agricultural industry. *Tractors and Agricultural Machinery.* 2025;92(1):35–42. DOI: 10.17816/0321-4443-637367 EDN: ZQPJBL

Received: 23.10.2024 **Accepted:** 03.02.2025 **Published online:** 21.03.2025

Оригинальное исследование

DOI: https://doi.org/10.17816/0321-4443-637367 EDN: ZQPJBL

Моделирование и оптимизация потребительских свойств мобильных энергосредств АПК

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АННОТАЦИЯ

Обоснование. В данной статье отражены примеры реализации многокритериальной оптимизации (МКО) в обосновании потребительских свойств мобильных энергосредств. В качестве критериев взяты 5 основных функциональных и эксплуатационных характеристик: производительность, энергетическая оценка по относительному снижению полных удельных затрат мобильных энергосредств (МЭС), суммарные затраты на техническое обслуживание и ремонт (ТОР), давление на почву и энергоэффективность. Использование МКО может иметь широкий спектр применения: при создании, разработке и эксплуатации МЭС.

Цель работы — моделирование и оптимизация потребительских свойств мобильных энергосредств АПК на примере МЭС тягового класса 1,4.

Материалы и методы. Сбор и анализ научных публикаций, научных статей и других источников информации по разработке НИОКР по созданию интеллектуальных транспортно-технических средств, по ключевым показателям потребительских свойств МЭС сельскохозяйственного назначения, а также совершенствованию методического и программного обеспечения многокритериальных оптимизационных расчётов эффективности МЭС. При решении поставленной задачи использовались методы научного обобщения и статистической обработки имеющихся информационных и аналитических материалов по отечественным и зарубежным источникам.

Результаты. Таким образом, в результате полученных расчётов наиболее предпочтительным среди полученных Паретовских точек при работе трактора класса 1,4 по мнению лица, принимающего решение (ЛПР) были выбраны следующие:

1. Пахота — производительность 1,17 га/ч; давление на почву 145 кПа; суммарные затраты 149,2 тыс. рублей; энергетическая оценка 35,0 %, энергоэффективность 19,7 кВт·га/ч.
2. Посев — производительность 2,87 га/ч; давление на почву 149,3 кПа; суммарные затраты 178,39 тыс. рублей; энергетическая оценка 35,3%, энергоэффективность 24,17 кВт·га/ч.
3. Химизация — производительность 3,541 га/ч; давление на почву 177,513 кПа; суммарные затраты 124,408 тыс. рублей; энергетическая оценка 22,8%, энергоэффективность 32,10 кВт·га/ч.

Заключение. Анализ классификации функциональных эксплуатационных и экономических характеристик МЭС (потребительских свойств), а также их экспертной оценки позволили выявить 5 основных критериев качества: давление на почву $\left(q^{к}_{\max}\right)$, производительность $\left(W\right)$, суммарные затраты на ТОР $\left(З_{p_i}\right)$, энергетическая оценка по относительному снижению полных удельных топливно-энергетических затрат МЭС, $\left(Э^{n}_{w}\right)$, энергоэффективность $\left(E_c\right)$, для моделирования и оптимизации которых был разработан программный комплекс решения задачи МКО, позволяющий решать задачи с более 50 варьируемыми параметрами и 20 критериями качества. Для полноты представления об оптимальных потребительских эксплуатационных свойствах мобильных энергосредств были выбраны МЭС тягового класса 1,4 и наиболее важные три операции: пахота, посев, химизация.

Ключевые слова: многокритериальная оптимизация; потребительские свойства мобильных энергосредств; функциональные свойства; критерии качества; варьируемые параметры; принятие компромиссных решений.

Как цитировать:
Годжаев Т.З., Зубина В.А. Моделирование и оптимизация потребительских свойств мобильных энергосредств АПК // Тракторы и сельхозмашины. 2025. Т. 92, № 1. С. 35–42. DOI: 10.17816/0321-4443-637367 EDN: ZQPJBL

Рукопись получена: 23.10.2024 **Рукопись одобрена:** 03.02.2025 **Опубликована online:** 21.03.2025

INTRODUCTION

Agricultural industry development requires innovative production equipment and technology that ensure high performance of agricultural operations. Among those equipment and technology widely used in the agricultural industry are mobile power units (MPUs). They couple with various agricultural implements both hauled and mounted. According to Resolution No. 740 of the Russian Federation On Determining Functional Performance (Consumer Properties) and Performance of Agricultural Machinery and Equipment, agriculture requires machinery and equipment with high functional performance, including MPUs (tractors). State-of-the-art agricultural MPUs used in agriculture are sophisticated devices consisting of many parts and assemblies and performing various crop production, livestock farming, gardening, and other operations. They have multiple performance, technology, and environmental properties. At the stage of MPU design and operation, functional performance specifications of consumer properties require optimization. Such specifications are numerous and the optimization problem has multiple criteria.

MATERIALS AND METHODS

Collection and analysis of scientific works, research papers, and other references on the R&Ds of intelligent vehicles and machinery; key indicators of consumer properties of agricultural MPUs, and improvement of guidelines and software for multi-criteria optimization calculations of MPU performance. Methods of scientific generalization and statistical processing of available information and analytical Russian and foreign references were used to solve the problem.

RESULTS AND DISCUSSION

We analyzed consumer properties of agricultural MPUs and built a classification of specifications, i.e. quality criteria of MPUs (Fig. 1).

When solving problems with a single-criterion statement, a single vector and a single objective function are usually produced. Depending on the problem statement, by minimizing or maximizing the objective function data, we find the best value of a specific objective function. However, due to certain limitations of single-criteria optimization

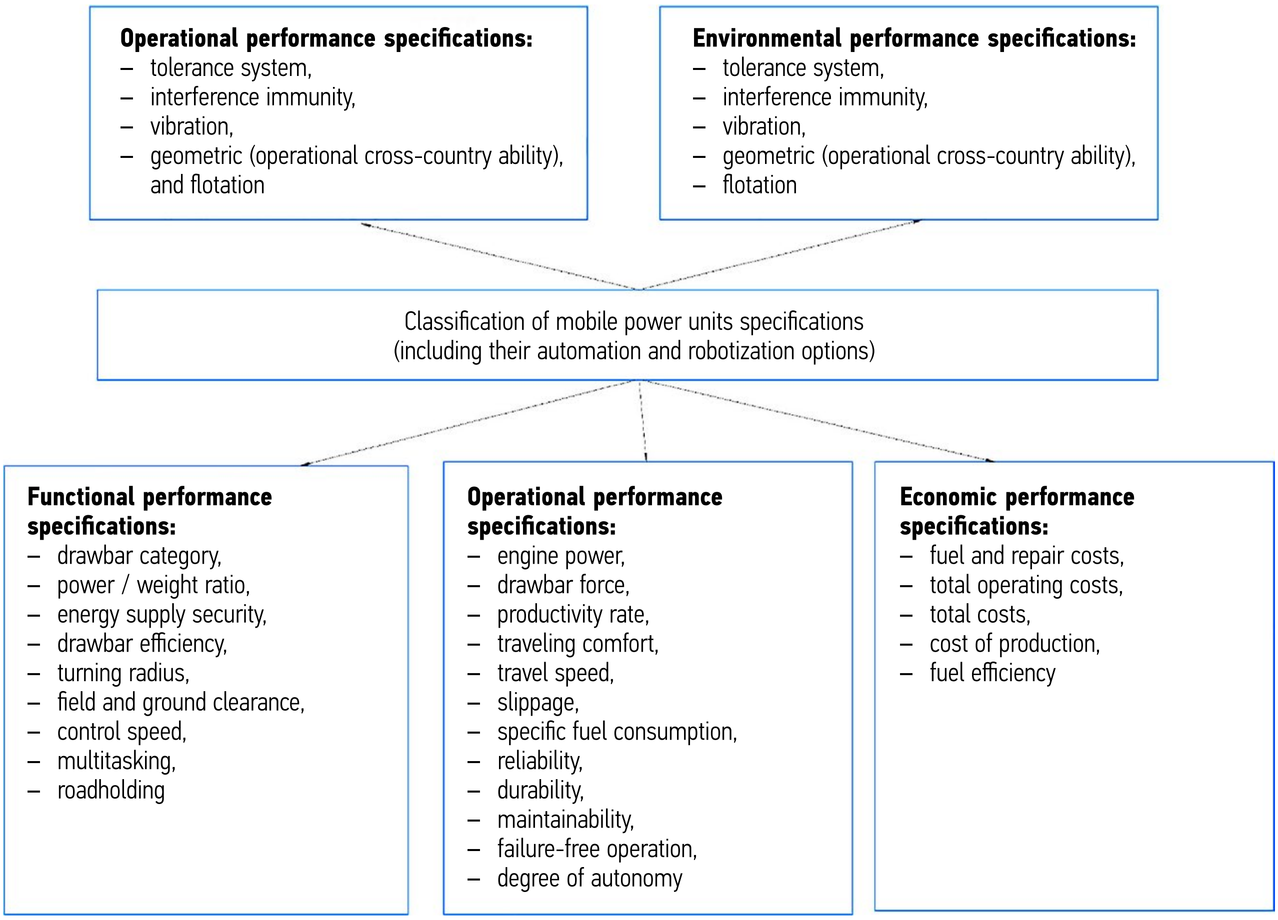

Fig. 1. Classification of properties that are quality criteria of a mobile energy unit.
Рис. 1. Классификация характеристик — критериев качества МЭС.

methods, recent years have seen a trend toward development and design of multi-criteria optimization (MCO) methods and tools. MCO is typically reduced to the search for Pareto–optimal sets of quality criteria that characterize the optimized object. Pareto–optimal sets are points (object variants) with values that cannot be improved simultaneously without degradation of at least one of them in the totality of all criteria [1–3].

Based on the analysis of the classification of functional, operational, and economic performance specifications of MPUs (consumer properties) and their expert review, we developed a multi-criteria problem of substantiating the performance of MPUs. As a result, the MCO problem statement includes the following 5 quality criteria: soil pressure $\left(q^{\kappa}_{\max}\right)$, productivity $\left(W\right)$, total repair and maintenance costs $\left(З_{p_i}\right)$, energy rate based on the relative reduction of the total specific fuel and energy costs of the MPUs $\left(Э^n_w\right)$, and energy efficiency $\left(E_c\right)$. The problem is stated as follows:

$$\left(\begin{array}{l} q^{\kappa}_{\max} = F_1\left(x_1, x_2, \ldots, x_n\right) \\ W = F_2\left(x_1, x_2, \ldots, x_j\right) \\ Э^n_w = F_3\left(x_1, x_2, \ldots, x_i\right) \\ З_{p_i} = F_4\left(x_1, x_2, \ldots, x_k\right) \\ E_c = F_5\left(x_1, x_2, \ldots, x_m\right) \end{array}\right) \Rightarrow \text{opt.}\left(\text{Pareto set}\right) \quad (1)$$

where F_1–F_5 are quality criteria; x_1, x_2,..., x_n, x_i, x_j, x_k, x_m are variable parameters.

Mathematical models of the above criteria include numerous variable parameters related to the operational features of the MPUs, i.e. drawbar force, implement effective width, operational speed, shift time, specific fuel consumption of the MPU, etc.

Procedural flow chart of the algorithm used to solve the MCO problem of MPU specifications is shown in Fig. 2.

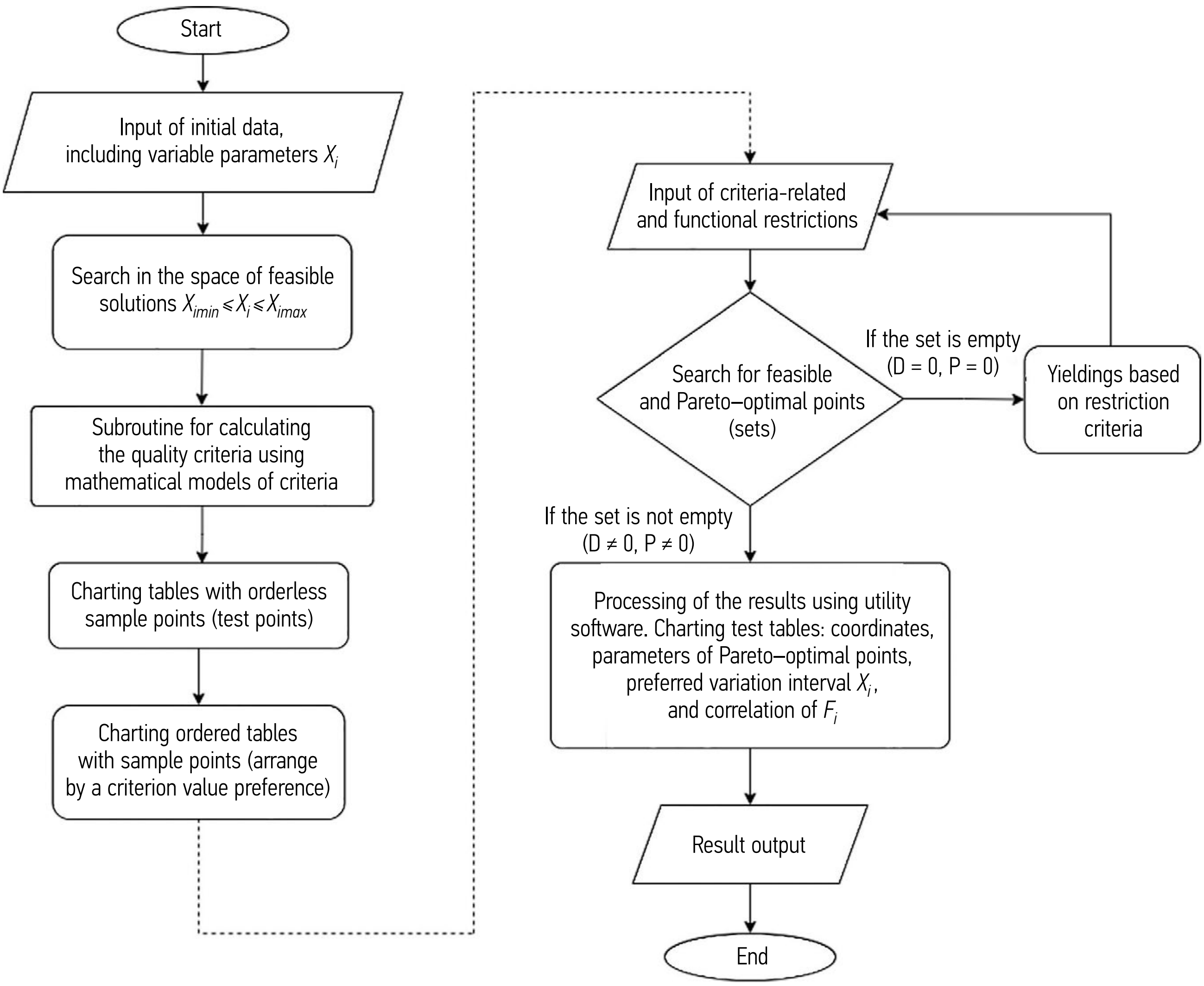

Fig. 2. The block diagram of the multi-criteria optimization of the properties of a mobile energy unit.
Рис. 2. Блок-схема алгоритма многокритериальной оптимизации (МКО) характеристик мобильных энергосредств (МЭС).

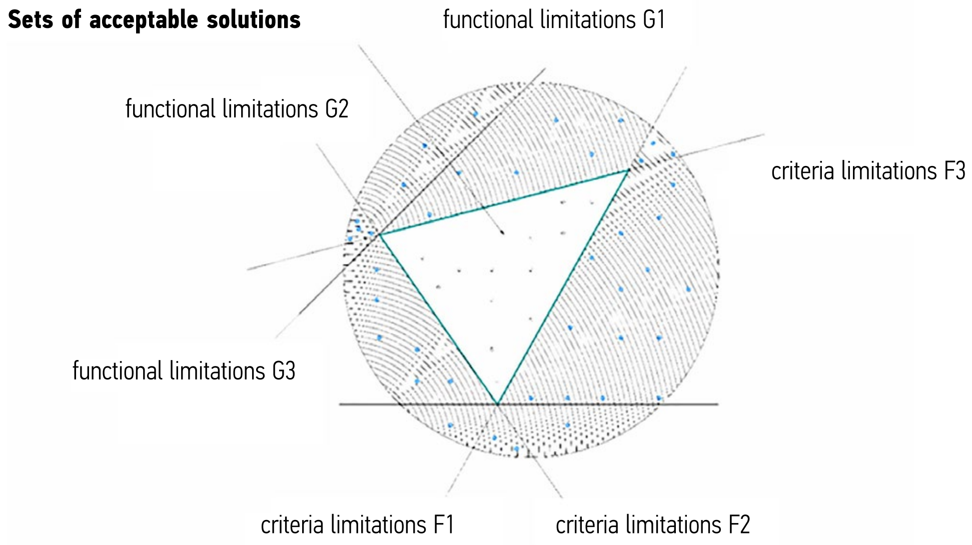

Fig. 3. Selection of the set of acceptable solutions.
Рис. 3. Иллюстрация выбора множества допустимых решений.

Table 1. Initial data of the variables for a mobile energy unit of the drawbar category 1.4 (basic tractor is the MTZ-82.1, the alternative tractor is the Belarus-1025)*

Таблица 1. Исходные данные варьируемых параметров по МЭС тягового класса 1,4 (базовый трактор- МТЗ-82.1, аналог «Беларус-1025»)*

Variable parameters	Plowing	Sowing	Chemicalization (pesticides application)
$B_{\text{р}}$ — Implement effective width, m	1,05–1,4	2,1–5,4	10,08–24
β — Effective width utilization ratio	0,8–1,0	0,8–0,95	0,8–0,95
$V_{\text{р}}$ — Implement operational speed, km/h	8–10	10–15	6–12
$T_{\text{см}}$ — Standard shift hours, h	8	8	8
τ — Shift hours utilization ratio	0,8–0,85	0,7–0,8	0,7–0,8
$Э^{б}_{\text{тр}}$ — Tractor energy consumption, mJ/h	110–140	107–140	110–130
$Э^{б}_{\text{топ}}$ — Energy consumption of fuel for the base-case scenario and ratios,* mJ/h	880–910	880–1000	850–950
a is the ratio of structural masses of a new and base-case tractors	0,8–0,9	0,8–0,9	0,8–0,9
b is the ratio of the new specific fuel consumption to the base-case MPU	0,75–0,9	0,71–0,8	0,75–0,85
c is the ratio of the replacement new and base-case MPU productivity based on the range of operations	1,2–1,28	1,1–1,27	1,2–1,28
$n_{\text{м}}$ is the number of machines or implements mounted on the MPU (supplied with the device), pcs	1	1	1
$Б_{\text{м}_j}$ is the price of j-th device (excl. VAT), RUB	2 500 000–3 500 000	2 700 000–3 600 000	2 750 000–3 800 000
$\mu_{\text{дв}}$ is the engine efficiency	0,38–0,4	0,38–0,4	0,38–0,4
$P_{\text{дв}}$ is the engine power, kW	50–75	50–75	50–75
$\mu_{\text{кпд тр.}}$ is the tractor propulsion efficiency	0,65–0,75	0,65–0,75	0,65–0,75
W is the productivity rate, ha/h	0,54–1,12	1,01–2,84	2,90–8,52
m is the MPU weight (for drawbar category 1.4), kg	4000–4200	4700–5000	4100–4600

*The data are sourced from the Concept System of Machines and Technology for Comprehensive Motorization and Automation of Agricultural Industry up to 2020 developed by the Federal Scientific Agroengineering Center VIM of the RUSSIAN AGRICULTURAL ACADEMY (Volume 1, Plant Growing. Moscow, 2012). When compiling the initial data, it was assumed that the following machine sets would be used: plows PLN-3-35, PLN-4-35U; seeders SZ-3,6A, SZP-3,6A, SZT-3,6A, and sprayers OSH-3000, OPSH-15-03, OP-2000-01.

Table 2. Summary table of values of the Pareto-optimal points for a mobile energy unit of the drawbar category 1.4 at selected technological operations

Таблица 2. Сводная таблица значений Парето-оптимальных точек для МЭС тягового класса 1,4 на выбранных технологических операциях

Quality criteria	Plowing		Sowing		Chemicalization	
	Point	Criterion value	Point	Criterion value	Point	Criterion value
F1 — Soil pressure, kPa	69 245 363 387 599	163,639 139,924 145,012 151,082 127,984	15 39 51	149,327 165,623 152,707	11 129 287	162,877 177,513 122,941
F2 — Productivity rate, ha/h	69 245 363 387 599	0,633 1,214 1,171 1,571 1,588	15 39 51	2,872 3,391 2,966	11 129 287	3,463 3,541 3,689
F3 — Energy rate based on the relative reduction of the total specific MPU costs, %	69 245 363 387 599	25,094 28,381 35,036 25,098 33,693	15 39 51	35,342 22,051 30,203	11 129 287	21,962 22,806 19,552
F4 — Total repair and maintenance costs, '000 RUB	69 245 363 387 599	149,331 149,743 149,216 179,461 224,861	15 39 51	178,386 188,332 202,011	11 129 287	207,562 124,408 125,089
F5 — Energy efficiency, kWh/ha	69 245 363 387 599	42,788 23,867 19,713 17,084 15,296	15 39 51	24,173 18,510 12,706	11 129 287	37,195 32,101 29,637

In addition, when building and finding the optimal set for the problem, the following tasks were solved: preparation of initial data, preparation of the algorithm, calculation of the quality criteria value, charting of the tests table, introduction of criteria and functional restrictions, development of admissible sets, and obtaining Pareto sets.

Selection of admissible solutions with the introduced criteria restrictions is shown in Fig. 3.

Thus, the analytical decision maker dialog system allows us, with 1,000–1,500 points at the initial stage, to eventually obtain one or two Pareto points that are not inferior to each other in terms of the criteria set.

Similar problems for tractors of drawbar category 1.4 were solved for 3 specific processes (plowing, sowing, chemicalization), where multi-criteria optimization was used to substantiate the effective consumer properties of mobile power units. A similar algorithm may be applied both at the stage of design, development, and production of the MPUs and at the stage of MPU operation during creation of the vehicle and tractor fleet. Interviews with existing authors and analysis of the references allowed us to conclude that we can use up to five quality criteria. According to the mathematical models of the quality criteria used, the initial data for the MPUs of drawbar category 1.4 were generated for all 3 processes (Table 1) [1–7].

Optimization calculations are shown in the summary tables of Pareto–optimal points for MPUs when performing Plowing, Sowing, and Chemicalization processes shown in Table 2 [1–7].

Thus, according to the decision maker and based on resulting calculations, the below points have been selected as the most preferable among the obtained Pareto points when operating a category 1.4 tractor:

1. Plowing: productivity rate is 1.17 ha/h; soil pressure: 145 kPa; total costs: RUB 149,200; energy rate: 35.0%, energy efficiency: 19.7 kW*ha/h.
2. Sowing: productivity rate is 2.87 ha/h; soil pressure: 149.3 kPa; total costs: RUB 178,390; energy rate: 35.3%, energy efficiency: 24.17 kW*ha/h.
3. Chemicalization: productivity rate is 3.541 ha/h; soil pressure: 177.513 kPa; total costs: RUB 124,408; energy rate: 22.8%, energy efficiency: 32.10 kW*ha/h.

CONCLUSION

Today, due to the fact that the diversity of operational, functional, and production performance specifications of equipment has greatly increased, it has become necessary to solve optimization problems of MPU consumer properties using a multi-criteria statement at the stage of the MPU design and operation.

To simulate and optimize consumer properties of the MPU, the agricultural sector has developed a software package to solve the MCO problem allowing to solve problems with more than 50 variable parameters and 20 quality criteria.

The analysis of the classification of functional, operational and economic performance specifications of the MPU (consumer properties) and their expert review resulted in identifying 5 main quality criteria, including soil pressure $\left(q^{\kappa}_{\max}\right)$, productivity rate $\left(W\right)$, total repair and maintenance costs $\left(З_{p_i}\right)$, energy rate based on the relative reduction of the total specific fuel and energy costs of the MPU $\left(Э^{n}_{w}\right)$, and energy efficiency $\left(E_c\right)$.

Thus, for complete understanding of the optimal operational consumer properties of mobile power units, we selected MPUs of drawbar category 1.4 and the three most important operations (plowing, sowing, and chemicalization).

This method allows argumentation at the stage of approval and setting the optimal functional MPU parameters and at the design stage; at the stage of the equipment operation, it is possible to select machines with the specifications selected by the decision maker, including for selecting the coupling capability of implements or when creating a vehicle and tractor fleet as a whole.

ADDITIONAL INFORMATION

Author contributions. T.Z. Godzhaev — development of the mathematical models of economic quality criteria of mobile energy units, optimization models and building of the block diagram of the algorithm; V.A. Zubina — problem statement, development of the mathematical models of functional properties of mobile energy units, formation of a list of variables, preparation of the introduction and conclusions; conducting optimization calculations. All authors made a substantial contribution to the conception of the work, acquisition, analysis, interpretation of data for the work, drafting and revising the work, final approval of the version to be published and agree to be accountable for all aspects of the work.

Disclosure of interests. The authors declare the absence of obvious and potential conflicts of interest.

Funding sources. This study was not supported by any external sources of funding.

ДОПОЛНИТЕЛЬНАЯ ИНФОРМАЦИЯ

Вклад авторов. Т.З. Годжаев — разработка математических моделей экономических критериев качества МЭС, оптимизационных моделей и построение блок-схемы алгоритма; В.А Зубина — постановка задачи, разработка математических моделей функциональных характеристик МЭС, формирование перечня варьируемых параметров, подготовка введения и выводов; а также проведение оптимизационных расчётов. Авторы подтверждают соответствие своего авторства международным критериям *ICMJE* (авторы внесли существенный вклад в разработку концепции, проведение исследования и подготовку статьи, прочли и одобрили финальную версию перед публикацией).

Раскрытие интересов. Авторы декларируют отсутствие явных и потенциальных конфликтов интересов, связанных с публикацией настоящей статьи.

Источники финансирования. Авторы заявляют об отсутствии внешнего финансирования при проведении исследования.

СПИСОК ЛИТЕРАТУРЫ | REFERENCES

1. Godzhaev TZ. Justification of the efficiency of modern agricultural mobile energy vehicles using multi-criteria optimization methods [dissertation] Moscow; 2024 (In Russ.)

2. Zubina VA, Godzhaev TZ, Malakhov IS. Carrying out multi-criteria optimization calculations to increase the efficiency of the fleet of mobile energy vehicles. *Tractors and agricultural machinery.* 2024;91.(2):217–227. (In Russ.) doi: 10.17816/0321-4443-629124 EDN: SXTDCZ

3. *The system of machines and technologies for the comprehensive mechanization and automation of agricultural production for the period up to 2020,Plant Growing.* Moscow; 2012;1. (In Russ.)

4. Statnikov RB, Astashov VK, Matusov IB, et al. *MOVI 1.4 software package. User's Manual.* Moscow; 2009. (In Russ.)

5. Godzhaev TZ, Zubina VA, Malakhov IS. Justification of the functional characteristics of agricultural mobile energy vehicles in a multi-criteria formulation // *Tractors and agricultural machinery.* 2022;89(6):411–420. (In Russ.) doi: 10.17816/0321-4443-121325 EDN: XTFDEB

6. Zubina VA, Godzhaev TZ, Malakhov IS. Development of optimization mathematical models for making compromise decisions on the efficiency of the agricultural machinery fleet. *Tractors and agricultural machinery.* 2023;90(6):523–529. (In Russ.) doi: 10.17816/0321-4443-569403 EDN: KZHOIX

7. Sobol IM, Statnikov RB. *Selection of optimal parameters in problems with many.* Moscow: Nauka; 1981. (In Russ.)

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