RESEARCH ARTICLE

International Journal of Agriculture, Environment and Food Sciences 2024; 8(1): 25-43
DOI: https://doi.org/10.31015/jaefs.2024.1.4

Safety of agricultural machinery and tractor maintenance planning with fuzzy logic and MCDM for agricultural productivity

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Abstract
Productivity is one of the most important measures used to determine the growth and development level of countries or sectors. A wide variety of projects have been planned and implemented to increase agricultural productivity. The productivity to be obtained in agriculture; Soil conditions, climate, seeds, fertilizer, pesticides, labor and agricultural mechanization directly affect it. Agricultural mechanization is the realization of agricultural activities by using energy together with agricultural tools and machines. Agricultural mechanization; It is an important agricultural production technology that helps increase agricultural productivity. Due to the inadequate maintenance planning of agricultural machinery, agricultural machinery cannot be utilized at the desired level in agricultural production. Most agricultural equipment is subject to frequent changes in speed and direction of movement while operating. Damage that can be seen on a single machine; It also causes other machines to malfunction. During the year, especially in the months when agricultural activity is high, excessive working tempo can cause tractors to malfunction. The breakdown of tractors causes disruptions in agricultural activities. In addition, the breakdown of tractors increases the repair costs. Since there is no tractor maintenance planning, farmers face interruptions in agricultural activities due to tractor malfunction. However, tractor malfunctions may cause cost and economic losses. For these reasons, there is a need for appropriate maintenance planning of agricultural machinery in order to continue agricultural activities without disruption. Maintenance planning; It consists of a set of preventive activities to improve the reliability and availability of any system. The main purpose of this study is to determine and rank the importance level weights of the criteria that are important for agricultural machinery maintenance planning using the fuzzy AHP method. Fuzzy AHP method, which provides ease of application, was preferred in determining the Criterion Weights. The research proposes a framework to determine the weights of appropriate criteria for care planning selection through a combined approach of fuzzy multi-criteria decision making involving relevant stakeholders. On the basis of the prioritization of criteria of tractor maintenance planning (TMP), it was found from the ranking that checking for all fluid levels (TMP1) ranked first. This respectively is followed by checking for general conditions (TMP4), checking for tires and wheels (TMP2) and checking for batteries (TMP3). With the results of the study, a guide was created for farmers and other stakeholders, as well as decision makers, to help plan the maintenance of machines in better working conditions. It is also thought that this study will be encouraging for other studies.

Keywords: Agricultural Marketing, Agricultural Productivity, Agricultural Mechanization, MCDM, fuzzy AHP

Citation: Atli, H.F. (2024). Safety of agricultural machinery and tractor maintenance planning with fuzzy logic and MCDM for agricultural productivity. International Journal of Agriculture, Environment and Food Sciences, 8(1), 25-43

Received: *October 31, 2023*
Accepted: *February 7, 2024*
Published Online: *March 25, 2024*

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Available online at
https://dergipark.org.tr/jaefs
https://jaefs.com/

INTRODUCTION

Productivity is one of the most important measures used to determine the growth and development level of countries or sectors. Economic growth and development can be achieved by including idle resources into production and directing currently used resources to more productive areas (Bayramoglu, 2010). This also represents an increase in productivity. Productivity; It can be defined as the ratio between the amount of goods and services produced and the inputs used to produce this amount of goods and services. A wide variety of projects have been planned and implemented to increase agricultural productivity. Moreover, academic research on these subjects supports this (Table 1). The productivity to be obtained in agriculture; Soil conditions, climate, seeds, fertilizer, pesticides, labor and agricultural mechanization directly affect it. It is a fact that especially with the introduction of tractors into field work, it provides great convenience to farmers in every aspect (Dogan, 2012). The agricultural sector is negatively affected by global market instability, economic crisis, animal diseases and climate changes in recent years (Ozguven et al., 2010). However, structural problems in the agricultural sector cause in inproductivity. In order to carry out agricultural activities in an optimum way and to obtain a good crop as a result, it is inevitable to use some inputs (Isik et al., 2003). Productivity increase is possible by using inputs (fertilizer, pesticides, seeds) in harmony with each other (Ozguven et al., 2010).

Agricultural mechanization is the realization of agricultural activities by using energy together with agricultural tools and machines. Agricultural mechanization; It is an important agricultural production technology that helps increase agricultural productivity. According to the Food and Agriculture Organization of the United Nations (FAO, 2023), sustainable mechanization contributes to the sustainable development of the food and agriculture sector; It takes into account technological, economic, social, environmental and cultural dimensions. The use of machinery in agriculture, unlike other agricultural technology applications, indirectly affects the increase in productivity; It enables the application of new production methods in rural areas (Ozguven et al., 2010). Technological developments in agriculture have increased the importance of mechanization and enabled more productivity per unit area in agricultural production (Altuntas, 2016). Agricultural mechanization in agricultural enterprises is implemented at different levels depending on the technical and economic structure of the enterprise (Zeren et al., 1995). The level of agricultural mechanization must be planned correctly in order to meet the rapidly increasing demand for agricultural crops, increase the current production level and increase productivity. The level of mechanization may have different values in each agricultural enterprise, depending on the technical and economic structure of the enterprise (Kocturk and Avcioglu, 2007). Planning the level of agricultural mechanization; This can be achieved by increasing the diversity of the tractor and agricultural equipment-machinery park and making it more effective (Altuntas and Demirtola, 2004). Due to the inadequate maintenance planning of agricultural machinery, agricultural machinery cannot be utilized at the desired level in agricultural production. Agricultural mechanization can achieve its goal with the availability of appropriate and sufficient equipment for the tractor, which is the main power source in agriculture (Altuntas and Demirtola, 2004). The use of agricultural mechanization increases the productivity of the workforce and the productivity of the use of other resources (Oguz et al., 2017). As a result of unplanned mechanization, the balance between agriculture and industry may be disrupted to the detriment of agriculture and may lead to an increase in unemployment in rural areas (Ozguven et al., 2010). Increasing agricultural mechanization can only be achieved by correct agricultural mechanization planning (Toga, 2006).

Most agricultural equipment is subject to frequent changes in speed and direction of movement while operating. In addition, the operating conditions of these devices; It also varies greatly due to agricultural activity and environmental factors. Due to all these factors, agricultural machinery is exposed to various loads and causes damages (Mishra and Satapathy, 2023). Damage that can be seen on a single machine; It also causes other machines to malfunction. In the studies, maintenance planning problems have been discussed from different angles in different sectors (Barabady and Kumar, 2008; Gu and Huang, 2010; Bose et al., 2012; Jurca, 2012; Poozesh et al., 2012; Lynch et al., 2013; Khodabakhshian, 2013; Afsharnia et al., 2014; Amini Khoshalan et al., 2015; Najafi et al., 2015; Obinna and Oluka, 2016; Wolfert et al., 2017; Rybacki and Grześ, 2018; Da Silva et al., 2019).

The tractor, which is the most important form of mechanization in agriculture, is an important tool for agricultural statistics. However, the agricultural development function of a country is evaluated by the presence and abundance of tractors (Dogan, 2012). Tractors are very important for agricultural activities. With developing technology, more modern and more functional tractors; It contributes to agricultural work with a wide variety of functions (Dogan, 2012). During the year, especially in the months when agricultural activity is high, excessive working tempo can cause tractors to malfunction. The breakdown of tractors causes disruptions in agricultural activities. Disruptions in agricultural activities; It may cause inefficient use of labor and losses in production (Mishra and Satapathy, 2023). In addition, the breakdown of tractors increases the repair costs. Especially in developing countries; Lack of adequate preventive maintenance planning increases the problem of tractor malfunctions due to spare parts shortage and similar reasons. Since there is no tractor maintenance planning, farmers face interruptions in agricultural activities due to tractor malfunction. However, tractor malfunctions may cause cost and economic losses. For these reasons, there is a need for appropriate maintenance planning of agricultural machinery so that agricultural activities can be continued without disruption (Mishra and Satapathy, 2023). Maintenance planning; It consists of a set of preventive activities to improve the reliability and availability of any system. Studies on the analysis of machine malfunctions have focused mostly on maintenance, malfunction risks, malfunction probabilities and malfunction detection (Table 1). In many studies where uncertainty is taken into account, MCDM methods are applied to solve different problems (Atlı, 2024). Although many studies have been conducted in which uncertainty is taken into account using MCDM methods, the number of studies applied to agricultural sectors is quite limited. The studies are mostly in the agricultural supply chain; strategies, supplier selection, location selection, strategy selection and planning (Kaviani et al., 2020; Lau et al., 2020; Rani et al., 2020; Ozkan et al., 2020; Durczak et al., 2020; Mugiyo et al., 2021; Ronaghi and Mosakhani, 2022; Yazdani et al., 2022).

When the studies are examined, it is seen that different techniques and criteria are applied as evaluation tools. Generally, expert opinion is needed to evaluate the current situation in order to decide which criteria among the proposed criteria will be the most appropriate. The selection of evaluation criteria is the most important part of the care planning evaluation. In this study, it was first aimed to determine the criteria that could be effective in maintenance planning. For this purpose, the criteria frequently used in the literature for the selection of maintenance planning were examined in a meeting environment with experts who have experience in maintenance planning, and the criteria that were thought to be the most important for the sector were evaluated. In this study, the criteria considered to be the most important were applied, adapted from the study of Mishra and Satapathy (2023). Criteria and sub-criteria are shown in (Figure 4).

This research contributes to the literature in the following ways: It is the first study in which the maintenance planning of agricultural machinery is applied with fuzzy AHP for agricultural productivity in the agricultural sector. However, there are modeling studies that examine the maintenance planning selection problem on a sector-by-sector basis using classical MCDM methods. The criteria were adapted from the study of Mishra and Satapathy (2023) in order to make a general evaluation of maintenance planning in the agricultural sector, taking into account the opinions of decision makers. Fuzzy AHP method, which provides ease of application, was preferred in determining the Criterion Weights. The research proposes a framework to determine the weights of appropriate criteria for care planning selection through a combined approach of fuzzy multi-criteria decision making involving relevant stakeholders.

The main purpose of this study is to determine and rank the importance level weights of the criteria that are important for agricultural machinery maintenance planning using the fuzzy AHP method. Fuzzy AHP method, which provides ease of application, was preferred in determining the Criterion Weights. The research proposes a framework to determine the weights of appropriate criteria for care planning selection through a combined approach of fuzzy multi-criteria decision making involving relevant stakeholders. In this study, first of all, a comprehensive analysis of the literature in the field was made. A wide variety of elements have been identified and classified related to the basic elements of agricultural productivity, agricultural mechanization, maintenance planning and agricultural machinery safety. Then, the method and application are given. Finally, the results of the study are summarized.

MATERIALS AND METHODS

The main purpose of this study is to determine and rank the importance level weights of the criteria that are important for agricultural machinery maintenance planning using the fuzzy AHP method. With the results of the study, a guide was created for decision makers, farmers and other stakeholders to help plan the maintenance of machines in better working conditions. It is also thought that this study will be encouraging for other studies. For agricultural machinery maintenance planning, decision makers have the task of identifying potential criteria that will complement that decision-making process. The MCDM flowchart for agricultural machinery maintenance planning is shown in (Figure 1).

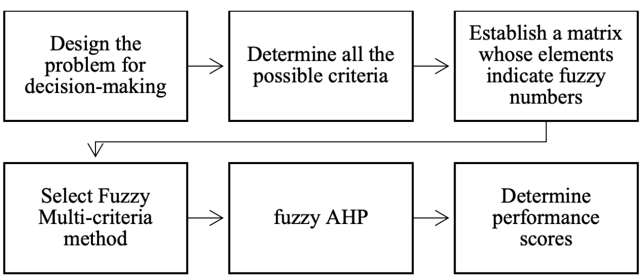

Figure 1. MCDM flowchart for agricultural machinery maintenance planning.

Table 1. Agricultural mechanization and agricultural productivity literature.

Autor	Research Purpose
Irz et al., 2001; Olesen and Bindi, 2002; Ruttan, 2002; Gollin et al., 2002; Wiebe, 2003; Thirtle et al., 2003; Goldsmith et al., 2004; Robertson and Swinton, 2005; Coelli and Rao, 2005; Lee, 2005; Dale and Polasky, 2007; Molden et al., 2007; Li et al., 2007; Restuccia et al., 2008; Mittal and Tripathi, 2009; Mittal et al., 2010; Molden et al., 2010; Alston et al., 2010; O'Donnell, 2010; Gornall et al., 2010; Gollin, 2010; Burney et al., 2010; McMillan and Rodrik, 2011; Connor et al., 2011; Peterman et al., 2011; Chand et al., 2011; Davis et al., 2012; Savci, 2012; Lobell and Gourdji, 2012; Cassidy et al., 2013; Reimers and Klasen, 2013; Lagakos and Waugh, 2013; Kurukulasuriya and Rosenthal, 2013; Teklewold et al., 2013; Adamopoulos and Restuccia, 2014; Gollin et al., 2014; Alston and Pardey, 2014; Kilic et al., 2015; Emerick et al., 2016; Bustos et al., 2016; Lawry et al., 2017; Adamopoulos and Restuccia, 2020; Ortiz-Bobea et al., 2021.	Agricultural productivity
Martin and Olmstead, 1985; Binswanger, 1986; Pingali et al., 1987; Clarke, 2000; Pingali, 2007; Kocturk and Avcioglu, 2007; Asoegwu and Asoegwu, 2007; Ozguven et al., 2010; Houmy et al., 2013; Houssou et al., 2013; Akinbamowo, 2013; Yang et al., 2013; Takeshima et al., 2013; Benin, 2015; Iqbal, 2015; Biggs and Justice, 2015; Amare and Endalew, 2016; Luo et al., 2016; Diao et al., 2016; Sims and Kienzle, 2017; Li et al., 2018; Mrema et al., 2018; Emami et al., 2018; Aryal et al., 2019; Jiang et al., 2020; Van Loon et al., 2020; Takeshima et al., 2020; Daum and Birner, 2020; Belton et al., 2021; Qian et al., 2022.	Agricultural mechanization
Paman et al., 2010; Fathollahzadeh et al., 2010; Rohani et al., 2011; Mousazadeh et al., 2011; Spinelli et al., 2011; Moorehead et al., 2012; Vernon and Meier, 2012; Lips and Burose, 2012; Khodabakhshian, 2013; Lorencowicz and Uziak, 2015; Baudron et al., 2015; Takeshima et al., 2015; Pickett et al., 2015; Redreev, 2016; Mantoam et al., 2016; Redreev et al., 2017; Myalo et al., 2018; Galiev et al., 2018; Redreev et al., 2018; Gupta et al., 2019; Hrytsaienko et al., 2019; Myalo et al., 2019; Redreev et al., 2020; Galiev et al., 2020; Elhaki and Shojaei, 2020; de Araujo Zanella et al., 2020; Daum et al., 2021.	Tractor maintenance

Selection of the best maintenance alternative in maintenance planning of machines, selection of the most appropriate multi-criteria decision-making (MCDM) model to evaluate each alternative according to a set of criteria; It is a multi-criteria decision making problem. In the methodology section, fuzzy numbers and fuzzy AHP used in the study and its application steps are given. Additionally, the scales used to convert numbers into fuzzy ones are presented. In this study, the importance levels and weights of the evaluation criteria were measured by the fuzzy AHP method. Accordingly, the rankings of the main criteria and sub-criteria were obtained.

Fuzzy Logic and Fuzzy Numbers

Fuzzy logic is a logic structure formed by the article "fuzzy sets and systems" published by Zadeh (1965) and the article "fuzzy logic and approximate reasoning" by Zadeh (1975). Fuzzy sets, basic operations, concepts and properties are given in this article. According to Zadeh (2015: 4), one of the main contributions of fuzzy logic is to provide a basis for progress from binarization to gradation, from binary to pluralism, from black and white to shades of grey. Fuzzy logic theory offers a number of methods and rules that take into account the uncertainty, indecision and imprecision in verbal expressions and express them numerically. According to Sergi (2021), such imprecise linguistic terms, which are quite suitable for the human mindset, are used in people's decision-making mechanism in the face of an event or situation.

The basis of fuzzy logic is based on fuzzy sets and subsets. In the fuzzy set, each object has a degree of membership. A fuzzy set is a set of objects with a continuous degree of membership (Ertugrul, 2007: 175). The fuzzy set characterizes each object with a membership function with a membership degree varying between 0 and 1 (Zadeh, 1965: 338). There are membership functions in different forms that define fuzzy sets analytically and represent their membership degrees, and the most commonly used among the various forms of fuzzy membership functions are triangular, trapezoidal, Gaussian and generalized bell curve membership functions (Sergi, 2021: 56). In this study, triangular fuzzy numbers were used. To create the decision matrix, linguistic expressions were transformed into triangular fuzzy number form.

Triangular fuzzy numbers were created to maximize the accuracy of the evaluations in uncertain evaluations when making decisions (Arslankaya and Göraltay, 2019:56). Parameters expressed as (*l, m, u*) show the smallest possible value, the most probable value and the largest possible value, respectively (Ertugrul, 2007). Equation (1) is given in (Hudec, 2016), and the graph drawn for the function is given in (Figure 2). The membership function of the triangular fuzzy number is defined as follows (Equation 1):

$$\mu_{\tilde{A}}(x) = \begin{Bmatrix} 0, & if\ x \leq l \\ \frac{x-l}{m-l}, & if\ l \leq x \leq m \\ \frac{u-x}{u-m}, & if\ m \leq x \leq u \\ 0, & if\ u \leq x \end{Bmatrix} \quad (1)$$

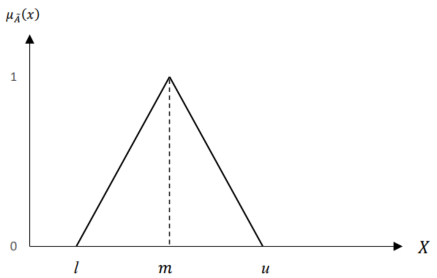

Figure 2. Triangle Membership Function.

Calculation of criterion weights with the fuzzy AHP method

Analytic Hierarchy Process (AHP) was first proposed by Myers and Alpert (1968). Analytic Hierarchy Process (AHP) is a multi-criteria decision-making method based on pairwise comparison developed by Thomas L. Saaty (1977 and 1982) for the solution of complex measurement and decision-making problems involving a large number of criteria and alternatives. Method; It offers a hierarchical structure that expresses the connection between the purpose of the problem, its criteria and alternatives. The AHP approach is used effectively in the decision-making process in many real-life problems (Ustalı and Tosun, 2019). Since it is not sufficient to evaluate situations of uncertainty and imprecision (Deng, 1999); The AHP method was combined with fuzzy logic and the fuzzy AHP approach started to be used as a new method. There are many studies based on B-AHP techniques in the literature (Chan and Kumar, 2007; Subramanian and Ramanathan, 2012; Xu and Liao, 2013; Ghadikolaei and Esbouei, 2014; Keršulienė and Turskis, 2014a, 2014b; Nguyen et al., 2015; Turskis et al., 2015; Mavi, 2015; Zavadskas et al., 2015; Shafiee, 2015; Prakash and Barua, 2016; RazaviToosi and Samani, 2016; Wang et al., 2016; Kubler et al., 2016; Soberi and Ahmad, 2016; Nguyen et al., 2016; Emrouznejad and Marra, 2017; Turskis et al., 2019; Liu et al., 2020; Wang et al., 2021; Fu et al., 2021; Bakır and Atalık, 2021; Atlı, 2022).

In the structure of the AHP method; First of all, there is the decision maker, this decision maker has a goal/target set and has many alternatives to choose or rank. Of course, the criteria to be used in evaluating these alternatives and the weights of these criteria should be determined. As a result, a "decision matrix" should be created using these values and implemented (Eren, 2021). There are many fuzzy AHP application methods in the literature. In this study, the B-AHP application method, which is more practical and easier to apply, was used. The application steps of the B-AHP approach are as follows (Soberi and Ahmad, 2016; Atlı, 2022):

Creating the Hierarchical Structure

The hierarchy consists of different levels that allow decision makers to view their problems from a comprehensive framework, ranging from the purpose of the problem to a set of various criteria and alternatives. A hierarchical model was created containing the research problem, 4 main criteria and 16 subcriteria. The hierarchy created for the research problem is shown in (Figure 3).

Pairwise comparison matrices between criteria

After the hierarchical structure is created, binary comparison matrices are created in line with the opinions of the decision makers (Equation 2). In cases where there is more than one decision maker, the pairwise comparison matrices created by the decision makers are converted into a combined pairwise comparison matrix.

$$\tilde{A}=\begin{bmatrix}1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n}\\ \tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2n}\\ \vdots & \vdots & \ddots & \vdots\\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & 1\end{bmatrix}=\begin{bmatrix}1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n}\\ 1/\tilde{a}_{12} & 1 & \cdots & \tilde{a}_{2n}\\ \vdots & \vdots & \ddots & \vdots\\ 1/\tilde{a}_{1n} & 1/\tilde{a}_{2n} & \cdots & 1\end{bmatrix}$$

$$\tilde{a}_{ij}=\begin{cases}\tilde{1},\tilde{3},\tilde{5},\tilde{7},\tilde{9} & \text{Criterion } i \text{ is more important than criterion } j\\ 1, & i=j\\ \tilde{1}^{-1},\tilde{3}^{-1},\tilde{5}^{-1},\tilde{7}^{-1},\tilde{9}^{-1} & \text{Criterion } i \text{ is less important than criterion } j\end{cases} \quad (2)$$

Fuzzy triangular scales are used to determine the priorities of criteria in the hierarchy, reflecting the relative importance among other criteria (Soberi and Ahmad, 2016). When decision makers evaluate criteria, they are compared using linguistic terms as shown in (Table 2).

Table 2. Linguistic terms and the corresponding triangular fuzzy scale.

Linguistic terms	Fuzzy Triangular Scale	Triangular Fuzzy Correspondence Scale	Saaty scale
Equally important (Eq. Imp.)	(1,1,1)	(1,1,1)	1
Weakly important (W. Imp.)	(1,3,5)	(1/5,1/3,1/1)	3
Fairly important (F. Imp.)	(3,5,7)	(1/7,1/5,1/3)	5
Strongly important (S. Imp.)	(5,7,9)	(1/9,1/7,1/5)	7
Absolutely important (A. Imp.)	(7,9,9)	(1/9,1/9,1/7)	9

Sources: Chang (1996); Atlı (2022).

Pairwise comparisons between all criteria are made by decision makers. Pairwise comparisons made by decision makers are combined by taking the geometric mean of the collected data suggested by Saaty and a common opinion is obtained. The reason why the geometric mean is preferred to the arithmetic mean method is that it satisfies the rule that symmetric elements in the comparison matrix must be inverse of each other (Omurbek and Tunca, 2013). The pairwise comparison data of each criterion in the triangular fuzzy scale in (Table 2) are then synthesized into matrix contribution form.

Normalized relative weights of criteria

In creating the dual pairwise comparison matrix, fuzzy geometric means and fuzzy weights of each criterion are determined by using the geometric mean method of Buckley (1985). In this step, the $\tilde{r}_i$ fuzzy comparison value is found using Equation (3). Then, the geometric mean of the fuzzy comparison value is taken.

$$\tilde{r}_i=\left(\prod_{j=1}^{n}\tilde{d}_{ij}\right)^{1/n} \quad (3)$$

The geometric means of fuzzy values is then converted to relative fuzzy of weight by multiplying them with the total of reverse fuzzy geometric means in increasing order by using Equation (4).

$$\tilde{w}_i=\tilde{r}_i\otimes[\tilde{r}_1\oplus\ldots\oplus\tilde{r}_i\oplus\ldots\tilde{r}_n]^{-1} \quad (4)$$

Finally, the relative non-fuzzy weight of each criteria is calculated by averaging the fuzzy numbers for each criteria. The normalized weights of each criteria, is calculated by dividing the each value of relative fuzzy weight with the total of all criteria's value.

RESULTS AND DISCUSSION

Calculation of criterion weights with the fuzzy AHP method

Creating the Hierarchical Structure

A hierarchical model has been created that allows decision makers to enter their problems from a comprehensive framework and includes the purpose of the problem, 4 main criteria and 16 subcriteria. The hierarchy created for the research problem is shown in (Figure 3).

Pairwise comparison matrices between criteria

To create the pairwise comparison matrix, nine experts were interviewed to compare the criteria using the B-AHP method. Experts were asked to make pairwise comparisons of the criteria according to the B-AHP scale (Chang, 1996; Atlı, 2022) shown in (Table 2). Pairwise comparisons between all criteria were made by decision makers. A common opinion was obtained by combining the pairwise comparisons made by the ground transmitters by taking the geometric mean of the collected data suggested by Saaty. The pairwise comparison data of each criterion relative to each other on a triangular scale from (Table 2) were then synthesized into matrix contribution form.

Data on performance values of the criteria were received from decision makers. The evaluations of decision makers were transformed into triangular fuzzy numbers through linguistic variables and the combined values are given in (Tables 3, 4, 5, 6, 7).

Normalized relative weights of criteria

In creating the dual pairwise comparison matrix, fuzzy geometric means and fuzzy weights of each criterion were determined by using the geometric mean method of Buckley (1985). In this step, the fuzzy comparison value was found using Equation (3) (Tables 8, 9, 10, 11, 12). Then, the geometric mean of the fuzzy comparison value was taken.

Then, the geometric means of the fuzzy values were converted to relative weight blur by multiplying them with the sum of the inverse fuzzy geometric means in increasing order using Equation (4) (Table 13). Finally, the relative non-fuzzy weight of each criteria was calculated by averaging the fuzzy numbers for each criteria. The normalized weights of each criteria, were calculated by dividing the each value of relative fuzzy weight with the total of all criteria's value (Table 14, 15). The ranking of criteria and subcriteria according to their global weights with fuzzy AHP is shown in (Table 16). On the basis of the prioritization of criteria of tractor maintenance planning (TMP), it was found from the ranking that checking for all fluid levels (TMP1) ranked first. This respectively is followed by checking for general conditions (TMP4), checking for tires and wheels (TMP2) and checking for batteries (TMP3). Identifying all errors and error mechanisms of a system; It is an analysis to evaluate the effects of each potential error on system security and performance and to classify each error according to its criticality (Cekel and Acar, 2023). The points that should be included in tractor maintenance planning should be determined according to the critical functions of the vehicle that affect its mission. Cekel and Acar (2023) made failure modes and criticality analyzes by choosing the engine subsystem as the subsystems that are mostly handled in periodic maintenance applications of the tractor. However, with good tractor maintenance planning, risks and accidents can be prevented by foreseeing error possibilities. If tractor maintenance planning is not implemented, it increases risks and accidents. For example; Reasons such as the failure of the brake system to function due to neglect of the tractor and the brakes not working when the brakes are applied frequently have been effective in the risk of accidents (Erdal, 2005; Yildirim and Altuntas, 2015).

Table 3. Combined comparison matrix (Main criteria).

CRI	TMP1			TMP2			TMP3			TMP4		
TMP1	1,000	1,000	1,000	2,485	3,195	3,475	3,637	6,031	7,770	2,432	3,482	5,196
TMP2	0,288	0,313	0,402	1,000	1,000	1,000	4,787	6,853	8,452	0,192	0,270	0,378
TMP3	0,129	0,166	0,275	0,118	0,146	0,209	1,000	1,000	1,000	0,129	0,166	0,275
TMP4	0,192	0,287	0,411	2,646	3,708	5,196	3,637	6,031	7,770	1,000	1,000	1,000

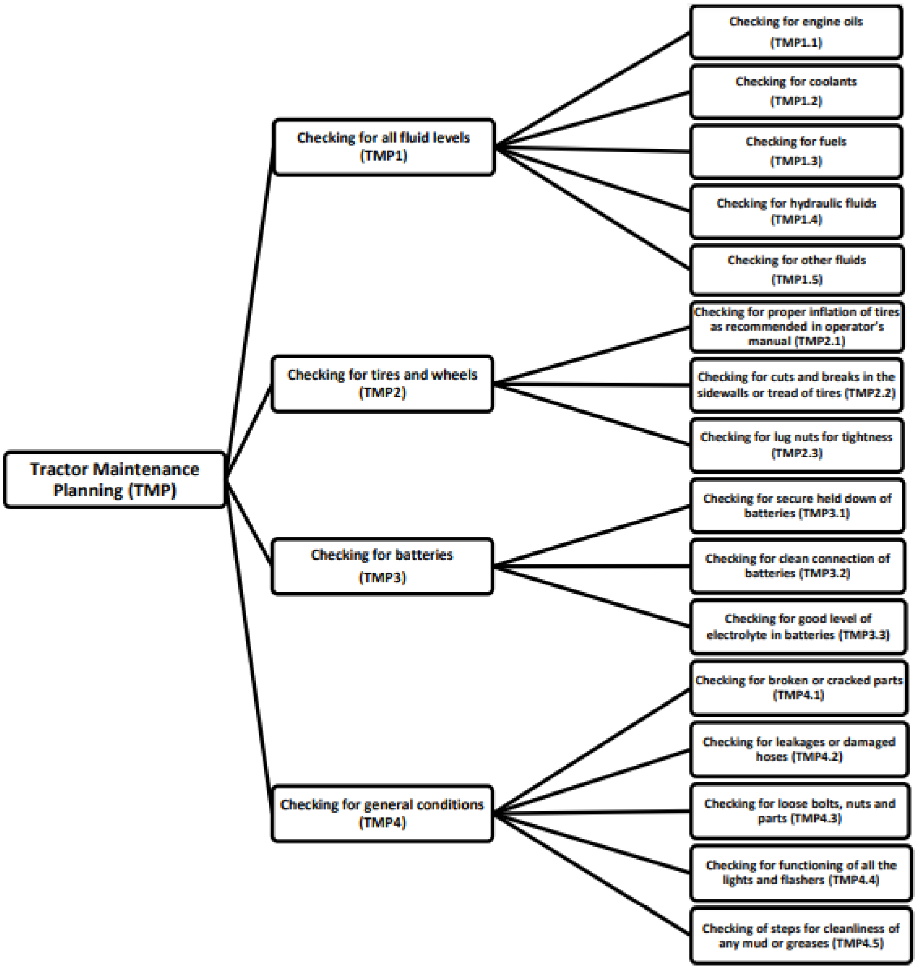

Figure 3. Hierarchical model.

Table 4. Combined comparison matrix (TMP1 subcriteria).

CRI	TMP1.1			TMP1.2			TMP1.3			TMP1.4			TMP1.5		
TMP1.1	1,000	1,000	1,000	3,956	6,422	7,770	4,787	6,853	8,452	3,956	6,422	7,770	3,637	6,031	7,770
TMP1.2	0,129	0,156	0,253	1,000	1,000	1,000	3,201	5,544	7,297	1,769	3,000	4,486	0,577	0,880	1,210
TMP1.3	0,118	0,146	0,209	0,137	0,180	0,312	1,000	1,000	1,000	0,386	0,508	0,809	0,137	0,180	0,312
TMP1.4	0,129	0,156	0,253	0,223	0,333	0,565	1,236	1,968	2,590	1,000	1,000	1,000	0,333	0,467	0,615
TMP1.5	0,129	0,166	0,275	0,827	1,136	1,732	3,201	5,544	7,297	1,627	2,141	3,000	1,000	1,000	1,000

Table 5. Combined comparison matrix (TMP2 subcriteria).

CRI	TMP2.1			TMP2.2			TMP2.3		
TMP2.1	1,000	1,000	1,000	1,495	2,010	3,000	0,223	0,270	0,411
TMP2.2	0,333	0,497	0,669	1,000	1,000	1,000	0,863	1,236	1,592
TMP2.3	2,432	3,708	4,486	0,628	0,809	1,158	1,000	1,000	1,000

Table 6. Combined comparison matrix (TMP3 subcriteria).

CRI	TMP3.1			TMP3.2			TMP3.3		
TMP3.1	1,000	1,000	1,000	0,223	0,333	0,565	2,646	5,196	6,708
TMP3.2	1,769	3,000	4,486	1,000	1,000	1,000	0,939	1,316	1,592
TMP3.3	0,149	0,192	0,378	0,628	0,760	1,065	1,000	1,000	1,000

Table 7. Combined comparison matrix (TMP4 subcriteria).

CRI	TMP1.1			TMP1.2			TMP1.3			TMP1.4			TMP1.5		
TMP4.1	1,000	1,000	1,000	0,577	0,669	0,809	1,236	1,495	1,732	1,236	1,592	1,884	1,627	2,381	3,065
TMP4.2	1,236	1,495	1,732	1,000	1,000	1,000	1,236	1,592	1,884	1,236	1,495	1,732	3,482	5,904	7,297
TMP4.3	0,577	0,669	0,809	0,531	0,628	0,809	1,000	1,000	1,000	2,432	3,708	4,486	1,236	2,096	2,817
TMP4.4	0,531	0,628	0,809	0,577	0,669	0,809	0,223	0,270	0,411	1,000	1,000	1,000	0,827	1,210	1,884
TMP4.5	0,326	0,420	0,615	0,137	0,169	0,287	0,355	0,477	0,809	0,531	0,827	1,210	1,000	1,000	1,000

Table 8. Geometric means of fuzzy comparison values (Main criteria).

CRITERIA			
TMP1	2,165	2,862	3,442
TMP2	0,718	0,872	1,065
TMP3	0,210	0,252	0,354
TMP4	1,167	1,592	2,018
Total	4,260	5,578	6,879
P (-1)	0,235	0,179	0,145
INCR	0,145	0,179	0,235

Table 9. Geometric means of fuzzy comparison values (TMP1 subcriteria).

CRITERIA			
TMP1.1	3,070	4,429	5,244
TMP1.2	0,841	1,179	1,585
TMP1.3	0,244	0,300	0,440
TMP1.4	0,412	0,544	0,744
TMP1.5	0,889	1,175	1,598
Total	5,454	7,627	9,611
P (-1)	0,183	0,131	0,104
INCR	0,104	0,131	0,183

Table 10. Geometric means of fuzzy comparison values (TMP2 subcriteria).

CRITERIA			
TMP2.1	0,693	0,815	1,072
TMP2.2	0,660	0,850	1,021
TMP2.3	1,152	1,442	1,732
Total	2,505	3,108	3,826
P (-1)	0,399	0,322	0,261
INCR	0,261	0,322	0,399

Table 11. Geometric means of fuzzy comparison values (TMP3 subcriteria).

CRITERIA			
TMP3.1	0,839	1,201	1,559
TMP3.2	1,184	1,581	1,926
TMP3.3	0,454	0,527	0,738
Total	2,477	3,308	4,224
P (-1)	0,404	0,302	0,237
INCR	0,237	0,302	0,404

Table 12. Geometric means of fuzzy comparison values (TMP4 subcriteria).

CRITERIA			
TMP4.1	1,075	1,305	1,519
TMP4.2	1,457	1,839	2,104
TMP4.3	0,984	1,267	1,526
TMP4.4	0,563	0,672	0,873
TMP4.5	0,385	0,489	0,704
Total	4,463	5,572	6,726
P (-1)	0,224	0,179	0,149
INCR	0,149	0,179	0,224

Table 13. Relative fuzzy weight of each criteria.

CRITERIA				
TMP1		0,315	0,513	0,808
	TMP1.1	0,319	0,581	0,961
	TMP1.2	0,088	0,155	0,291
	TMP1.3	0,025	0,039	0,081
	TMP1.4	0,043	0,071	0,136
	TMP1.5	0,092	0,154	0,293
TMP2		0,104	0,156	0,250
	TMP2.1	0,181	0,262	0,428
	TMP2.2	0,173	0,274	0,408
	TMP2.3	0,301	0,464	0,691
TMP3		0,031	0,045	0,083
	TMP3.1	0,199	0,363	0,629
	TMP3.2	0,280	0,478	0,777
	TMP3.3	0,108	0,159	0,298
TMP4		0,170	0,285	0,474
	TMP4.1	0,160	0,234	0,340
	TMP4.2	0,217	0,330	0,471
	TMP4.3	0,146	0,227	0,342
	TMP4.4	0,084	0,121	0,196
	TMP4.5	0,057	0,088	0,158

Table 14. Averaged and normalized relative weight of criteria.

CRITERIA			Rank
TMP1	0,545	**0,506**	**1**
TMP2	0,170	**0,158**	**3**
TMP3	0,053	**0,049**	**4**
TMP4	0,310	**0,287**	**2**
TOTAL	0,481		

Table 15. Averaged and normalized relative weight of sub-criteria.

CRITERIA			
TMP1	TMP1.1	0,621	**0,559**
	TMP1.2	0,178	**0,160**
	TMP1.3	0,048	**0,044**
	TMP1.4	0,084	**0,075**
	TMP1.5	0,180	**0,162**
	TOTAL	1,110	
TMP2	TMP2.1	0,291	**0,274**
	TMP2.2	0,285	**0,268**
	TMP2.3	0,485	**0,458**
	TOTAL	1,061	
TMP3	TMP3.1	0,397	**0,362**
	TMP3.2	0,512	**0,467**
	TMP3.3	0,188	**0,172**
	TOTAL	1,097	
TMP4	TMP4.1	0,245	**0,232**
	TMP4.2	0,339	**0,321**
	TMP4.3	0,238	**0,226**
	TMP4.4	0,133	**0,126**
	TMP4.5	0,101	**0,095**
	TOTAL	1,057	

Table 16. Ranking of criteria and subcriteria according to their global weight.

Criteria and Sub-criteria	Global weights	Criteria ranking	Sub-criteria ranking
TMP1	0,506	1	
TMP1.1	0,283		1
TMP1.2	0,081		4
TMP1.3	0,022		14
TMP1.4	0,038		10
TMP1.5	0,082		3
TMP2	0,158	3	
TMP2.1	0,043		8
TMP2.2	0,042		9
TMP2.3	0,072		5
TMP3	0,049	4	
TMP3.1	0,018		15
TMP3.2	0,023		13
TMP3.3	0,008		16
TMP4	0,287	2	
TMP4.1	0,067		6
TMP4.2	0,092		2
TMP4.3	0,065		7
TMP4.4	0,036		11
TMP4.5	0,027		12

CONCLUSION

Tractors have a very important place in the agricultural mechanization system. Tractors, which constitute the basic power source for all tools and machines used in agriculture, are one of the indispensable tools of modern agriculture today. With the rapid change in technology, there has also been a rapid development in tractors. In order to increase the performance of agricultural machinery, especially tractors, choosing the right maintenance planning has become a necessity in developing and developed countries.

Due to deficiencies in the maintenance planning of agricultural machines used in agricultural activities, more expenses are required for maintenance and repair, especially for tractors. This negatively affects crop productivity in agriculture. To develop an optimal preventive tractor maintenance planning (TMP) for this purpose; It is very important in reducing maintenance costs and increasing machine performance. Fuzzy logic and multi-criteria decision making (MCDM) are useful for tractor maintenance planning (TMP) due to the nature of the agricultural sector, where there are many uncertainties.

For this purpose, choosing the right MCDM approach with fuzzy methods in an environment of uncertainty due to the nature of the agricultural sector; It has an important role in evaluating the problem according to a set of criteria. The study offers a different perspective to farmers and other stakeholders by using the fuzzy approach for tractor maintenance planning in the agricultural sector. On the basis of the prioritization of criteria of tractor maintenance planning (TMP), it was found from the ranking that checking for all fluid levels (TMP1) ranked first. This respectively is followed by checking for general conditions (TMP4), checking for tires and wheels (TMP2) and checking for batteries (TMP3). With the tractor maintenance planning (TMP) proposed in this study, the results of this study can have a positive impact on farmers to carry out their agricultural activities using tractors that operate smoothly. In addition to the experts and practitioners involved in this study, future research may also include farmers as decision makers to improve results, as various stakeholders may reveal different preferences. From a practical perspective; The application of a combined approach that integrates expert opinion and fuzzy multi-criteria decision making is a promising approach to overcome the problem of care planning characterized by multi-criteria, multi-stakeholders and uncertainty.

This research contributes to the literature in the following ways: It is the first study in which the maintenance planning of agricultural machinery is applied with fuzzy AHP for agricultural productivity in the agricultural sector. However, there are modeling studies that examine the maintenance planning selection problem on a sector-by-sector basis using classical MCDM methods. Fuzzy AHP method, which provides ease of application, was preferred in determining the Criterion Weights. The research proposes a framework to determine the weights of appropriate criteria for care planning selection through a combined approach of fuzzy multi-criteria decision making involving relevant stakeholders.

The results and analyzes of this study are based on literature that met our selection criteria. Some limitations should be noted. For example, we based our conceptual model on tractor maintenance planning and did not include other agricultural machines. Future studies should expand the number of studies on maintenance planning to other agricultural machinery. Research on different aspects of the effects of the efficiency of farm machinery on agricultural productivity is still emerging. Future research could also examine impacts on agricultural production and agricultural productivity, and possible changes in sustainable development and economic growth.

COMPLIANCE WITH ETHICAL STANDARDS

Peer-review

Externally peer-reviewed.

Conflict of interest

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Author contribution

The author read and approved the final manuscript. The author verifies that the Text, Figures, and Tables are original and that they have not been published before.

Ethics committee approval

Ethics committee approval is not required.

Funding

No financial support was received for this study.

Data availability

Not applicable.

Consent to participate

Not applicable.

Consent for publication

Not applicable.

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