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Farm Power and Machinery Distribution in Iran: Fuzzy Analytical Hierarchy Process (FAHP) and Weight Restriction Data Envelopment Analysis (WR-DEA) Models

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ABSTRACT

In Iran, allocating tractors and agricultural machinery to regions that have different characteristics has been a challenge. This study was carried out in order to develop an optimal and practical model for distribution of agricultural machinery throughout the country. Gini coefficient was used in order to investigate whether current status of tractor distribution is suitable. This coefficient confirmed that the current tractor power distribution is not appropriate since there were no relationships between Gini coefficient of distributed machinery power and crop production or farm area. Accordingly, two main techniques were applied to develop a suitable agricultural machinery distribution pattern; *i.e.* a Fuzzy Analytical Hierarchy Process (FAHP) and a Weight Restriction Data Envelopment analysis (WR-DEA) technique. A power distribution category was defined in order to show qualitatively how much machinery power should be sent to each province. The outputs of both FAHP and WR-DEA models showed that three and nine provinces need 'much more power' and 'more power', respectively, while four and three provinces need 'absolutely no more power' and are 'currently suitable', respectively. The sensitivity analysis revealed that none of the developed models was sensitive to the weights defined by a panel of experts. The similarity of the results obtained from both models implies that the provided agricultural machinery distribution pattern is reliable and can be used in the country.

Keywords: Agricultural economics, Agricultural machinery, Decision support systems, Gini coefficient.

INTRODUCTION

Agricultural Mechanization (AM) represents the use of various power sources in agriculture to run farm machines, tools, and equipment (Verma, 2012). Mechanization planning requires a quantitative assessment of a mechanization index and its impact on agricultural production (Singh, 2006; Olaoye and Rotimi, 2010). The Mechanization Level (ML) is an index that describes how much power is used per unit area to perform farm operations (see also section "3. Methods"). Although AM has made a significant contribution to agri-rural development worldwide, in some developing countries like Iran, mechanization has not had a noticeable share in agricultural development (Najafi and Torabi Dastgerduei, 2015; Mottaleb *et al*., 2016). Numerous attempts were made by the agricultural authorities during 1991-2010 in order to achieve a satisfying level of mechanization through five-year programs called 'Agricultural Mechanization Development Programs' (AMDPs)-(Ministry of Agriculture Jihad, AMDP, 2011). Although there have been four AMDPs so far, no outstanding progress has been achieved. Management in agriculture is important, especially for farm machines. When suitable

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agricultural machinery is not available on the farms, many farm operations may be completed with delays, which in turn would reduce crops yields and farmers' incomes (Zarafshani *et al*., 2017). An evaluation showed that a lack of practical plans for the development of AM is a major problem in Iran’s agricultural sector (Rasooli Sharabiani and Ranjbar, 2008). Currently, the focus is on the promotion of ML in the country’s agriculture from a ‘mechanization development’ point of view. Yet, machinery allocations are mainly based on the provinces’ demands for agricultural machinery or the total farm areas, since there are no suitable policies to distribute farm machines. Unfortunately, the demands in some provinces are due to non-real demand rather than the real status of farming systems. Furthermore, agricultural machinery distribution based on the total farm area addresses only one factor or criterion, while other aspects, such as climate, soil fertility, and yield, are neglected. There should be reasonable relationship between farming capacity (*i.e.* farming area and crop production) and available tractor power in each province. Therefore, the main question is how farm machines should be distributed throughout the country? With this in mind, the two main objectives of this study were to: (1) Explore whether current situation of tractor power distribution is appropriate? and (2) Introduce an optimal agricultural machinery distribution pattern. To meet the first objective, Gini coefficient was calculated to show how power is equally distributed throughout the country. For the second objective, Fuzzy Analytical Hierarchy Process (FAHP) and Weight Restriction Data Envelopment Analysis (WR-DEA) models were applied.

Theoretical background

Gini coefficient

The Gini coefficient is a popular inequality measure system that can be applied to the distribution of income, consumption, or any other size variable defined over a population of statistical units (Fusco *et al*., 2010). This coefficient is between 0 and 1. When the coefficient is 0 it means absolute equality and when it is 1 it means absolute inequality (Foster and Wolfson, 2010). With regard to making the best decisions for ML promotion in Iran, there are no satisfactory plans to distribute agricultural machinery throughout the country. The main focus was to increase the average Mechanization Level (ML) in the country and to send tractor power to each of the provinces suitably. In order to validate this claim, the Gini coefficient was employed to show to what extent tractor power is distributed equally/fairly throughout the country. It was expected that the value of Gini coefficient is almost equal for ML and to other agricultural factors such as crop area and crop yield of each province. If not, it can be concluded that tractor power distribution, *i.e.* ML, is not suitable and is not in accordance with other factors.

Why use Multi-Criteria Decision Making, fuzzy AHP (FAHP) and weight restriction DEA (WR-DEA)?

The Multi-Criteria Decision Making (MCDM), including Multi-Attribute Decision Making (MADM) and Multi-Objective Decision Making (MODM), is a well-known branch of operations research models that deal with decision problems when several decision criteria exist (Tzeng *et al*., 2007). One of the well-known MADM techniques is an analytical hierarchy process (AHP), which uses hierarchic structures, matrices and linear algebra in order to formalize decision processes (Saaty, 1980).

By using the AHP, decisions can be made with regard to more than one effective factor that considers all features. Accordingly, the AHP is a decision-aided method that decomposes a complex multi-factor problem into a hierarchy when each level is composed of specific elements (Tiwari *et al*., 1999). The pair-wise comparisons in the AHP analysis are accomplished by experts and it is essential to consider that the AHP cannot handle uncertainties in the comparisons. To solve this

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problem, a Fuzzy AHP (FAHP) method has been proposed in the study that uses fuzzy functions in the AHP comparisons. The fuzzy set theory was introduced by Zadeh (1965) in order to deal with uncertainty due to imprecision and vagueness (Sadatinejad *et al*., 2010).

Some provinces that hold high political authority often have higher ML despite lower yields, while other provinces receive farm machines based on only one criterion (total farming area). Consequently, such an unbalanced distribution has led to high and low MLs, respectively, in some provinces with more infertile and fertile lands. As a solution, the FAHP was employed in this study in order to find the proper ranks of the provinces to receive farm machines with respect to five agricultural factors (see section 3.2). The given ranks is called the 'National Agricultural Machinery Distribution Pattern' (NAMDP) in this study.

Data Envelopment Analysis (DEA) is a nonparametric approach to assess the productivity and efficiency of some organizational units that are called Decision Making Units (DMUs). The differences between each of the conventional DEA models are their used Production Possibility Sets (PPSs), which are sets of all possible DMUs that their outputs can produce by consuming their inputs (Fukuyama and Mirdehghan, 2012; Ji *et al*., 2015). In DEA, the PPS is constructed based on various postulates; *i.e.* observations, convexity, free disposability, Constant Returns to Scale (CRS), Variable Returns to Scale (VRS), etc. A research field has been established with Weight Restrictions (WR) in DEA (Mirdehghan *et al*., 2015; Podinovski, 2016). The models proposed in this field reduce the flexibility of the DMUs' weights of the inputs and outputs. An agricultural machinery power distribution pattern was developed once more by WR-DEA models to make sure that the model given by FAHP was suitable for the country. To our knowledge, this is the first study in which FAHP and WR-DEA models have been applied in order to decide how to adjust agricultural machinery power distribution.

MATERIALS AND METHODS

FAHP Model

The FAHP was applied in order to determine the priority of the provinces for receiving agricultural machinery. The ranks of the provinces could be considered as a guide for how agricultural decision makers determine which provinces should receive farm machines first. Therefore, the ranking, as the main objective of this study, stays in the first level or main goal in the FAHP model (Figure 1). Given Iran's 30 provinces, the number of alternatives was considered to be 30. In the NAMDP, five agricultural factors; *i.e.* 'irrigated farms area', 'rain-fed farms area', 'crop yield in irrigated farms', 'crop yield in rain-fed farms' and 'level of mechanization' were put on a hierarchical structure: cultivated area, yield and mechanization as three criteria, and yields and areas under irrigated and rainfed conditions as four sub-criteria (Figure 1).

Goal: **"Ranking the provinces to receive agricultural machinery"**

Criteria:
C1: Cultivated Area (CA);
C2: Yield (Y),
C3: Mechanization Level (ML).
Sub-criteria:
SC1: Irrigated Farms Area (IFA);
SC 2: Rain-fed Farms Area (RFA);
SC 3: Crop Yield in Irrigated Farms (CY-IF),
SC 4: Crop Yield in Rain-fed Farms (CY-RF).

Since cereal production is of primary importance in Iran, the decision process was made with respect to both total crops and cereal crops production, separately. The data from the farming year 2013-2014 (Ministry of Agriculture Jihad (Jihad-e-Keshavarzi), 2014) was used in the study (Table 1). To introduce the NAMDP, some other agricultural factors; *i.e.* 'topography', 'soil

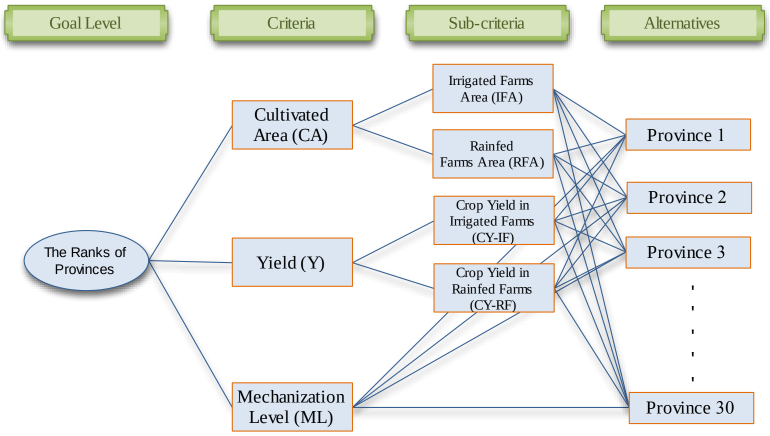

Figure 1. AHP decision tree to determine the rank of the provinces.

Table 1. Criteria and sub-criteria data to use in AHP model based on total crops and cereals productions in 2012-2013. (Ministry of Jihad-e-Keshavarzi, Department of Agronomy, 2014).[a]

	Attribute (Total crops production)					Attribute (Cereals production)				
Alternative (Province)	IFA (%)	DFA (%)	CY-IF (%)	CY-DF (%)	ML (hp ha^{-1})	IFA (%)	DFA (%)	CY-IF (%)	CY-DF (%)	ML (hp ha^{-1})
1- Khuzestan	10.88	4.81	16.35	3.04	0.62	12.76	6.19	12.74	5.87	0.62
2- Fars	11.98	4.43	10.92	3.08	0.64	15.83	4.45	18.84	10.61	0.64
3- Khorasan Razavi	10.09	5.72	9.37	2.91	0.59	9.49	3.13	9.99	3.45	0.59
4- Esfahan	4.91	0.52	6.86	0.41	0.79	4.31	0.57	5.49	0.42	0.79
5- Kerman	5.02	0.01	5.83	0.01	0.63	2.09	0.00	2.64	0.00	0.63
6- Tehran	2.84	0.02	5.66	0.01	0.80	2.68	0.03	3.05	0.03	0.80
7- East Azarbaijan	4.03	7.65	3.86	7.30	0.71	2.96	7.46	2.59	6.59	0.71
8- Hamadan	3.73	6.16	4.13	4.84	0.70	3.34	6.85	3.20	6.65	0.70
9- West Azarbaijan	4.67	6.13	3.88	5.68	0.60	3.13	5.74	2.45	6.03	0.60
10- Golestan	4.90	5.52	2.67	11.07	0.78	5.28	5.39	4.03	10.13	0.78
11- Mazandaran	3.46	2.54	2.09	14.69	1.35	5.03	1.53	5.65	3.35	1.35
12- Ardabil	3.33	7.02	2.98	5.80	0.75	2.55	6.55	2.30	5.34	0.75
13- Qazvin	2.49	2.06	3.30	1.03	0.42	2.77	1.92	3.06	1.81	0.42
14- Kermanshah	2.63	9.20	2.20	9.19	0.62	3.69	9.37	3.82	11.14	0.62
15- Lorestan	2.93	8.10	1.90	6.49	0.52	2.93	7.72	2.07	7.47	0.52
16- Sistan-baluchestan	2.40	0.05	2.44	0.20	0.60	1.79	0.00	0.80	0.20	0.60
17- Kordestan	1.60	9.35	1.30	7.42	0.57	1.06	10.18	1.13	2.82	0.57
18- Markazi	2.78	2.46	1.95	1.52	0.84	2.60	2.89	2.21	2.81	0.84
19- Zanjan	1.69	5.38	1.30	4.57	0.62	0.76	5.24	0.71	5.83	0.62
20- Hormozgan	1.07	0.05	1.65	0.04	0.80	0.49	0.00	0.61	0.00	0.80
21- North Khorasan	1.89	2.80	1.16	2.61	0.70	2.10	2.91	1.51	0.75	0.70
22- Gilan	3.07	0.58	1.24	1.33	0.58	4.71	0.38	4.99	0.49	0.58
23- Chaharmahal-Bakhtiari	1.27	0.85	1.28	0.80	0.26	1.08	1.12	1.01	1.54	0.26
24- Semnan	1.30	0.26	1.32	0.19	0.83	1.11	0.22	0.98	0.28	0.83
25- Ilam	0.95	2.70	0.84	2.37	0.47	1.17	3.01	1.05	3.14	0.47
26- Yazd	0.90	0.01	1.04	0.00	0.58	0.84	0.00	0.80	0.00	0.58
27- Bushehr	0.67	2.61	0.81	1.29	0.22	0.56	3.46	0.42	1.03	0.22
28- South Khorasan	0.90	0.83	0.74	0.36	0.42	1.01	0.52	0.56	0.10	0.42
29- Kohgiluyeh-Boyer-Ahmad	0.79	2.17	0.43	1.74	0.64	1.04	3.15	0.98	2.11	0.64
30- Qom	0.83	0.01	0.50	0.01	0.89	0.84	0.02	0.82	0.01	0.89
Gini coefficient	0.422	0.502	0.489	0.571	0.160	0.476	0.509	0.522	0.552	0.16

[a] IFA: Irrigated Farms Area; RFA: Rain-fed Farms Area; CY-IF: Crop Yield in Irrigated Farms, CY-RF: Crop Yield in Rain-fed Farms.

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types' (texture and structure) and 'weather conditions' in irrigated and rain-fed farms should have also been used. The main obstacle to producing such a model was that the related data have not yet been made available for all of the provinces. However, the amount of yield in each province intrinsically show the differences between soil types, topography, and weather conditions.

Most of the agricultural experts who contribute to the AM planning in the country were asked to take part in the study. In total, 19 experts participated in the study and were asked to make the pair-wise comparisons between the criteria and sub-criteria using a triangular fuzzy number. Triangular fuzzy number was chosen since it is simpler to define in comparison with other fuzzy numbers such as trapezoidal (Azadi *et al*., 2009). Matrix 1, for instance, shows that 'Y' is more important than 'ML' by fuzzy number 6,7, and 8 according to the experts` opinion. There may be some inconsistencies between two by two comparisons. To avoid inconsistent comparisons, Saaty (1980) suggested that the value of inconsistency should be lower than 0.1.

Matrix. An example of criteria pair-wise comparisons for this study.

Factor	CA	Y	ML
CA: Cultivated Area	1,1,1	1/5,1/3,1/2	4,5,6
Y: Yield	---	1,1,1	6,7,8
ML: Mechanization Level	---	---	1,1,1

A qualitative power distribution managerial category was defined in order to clarify how much power should be sent to each province as (Figure 2):

1- More than 10 ranks displacement from current rank: Much More Power (MMP) or Absolutely No More Power (ANMP)

2- 5 to 10 ranks displacement from current rank: More Power (MP) or No More Power (NMP)

3- Lower than 5 ranks displacement from current rank: Currently Suitable (CS).

As the last step, a sensitivity analysis was implemented in order to find the sensitivity of the provinces' ranks to the weights of the criteria and sub-criteria.

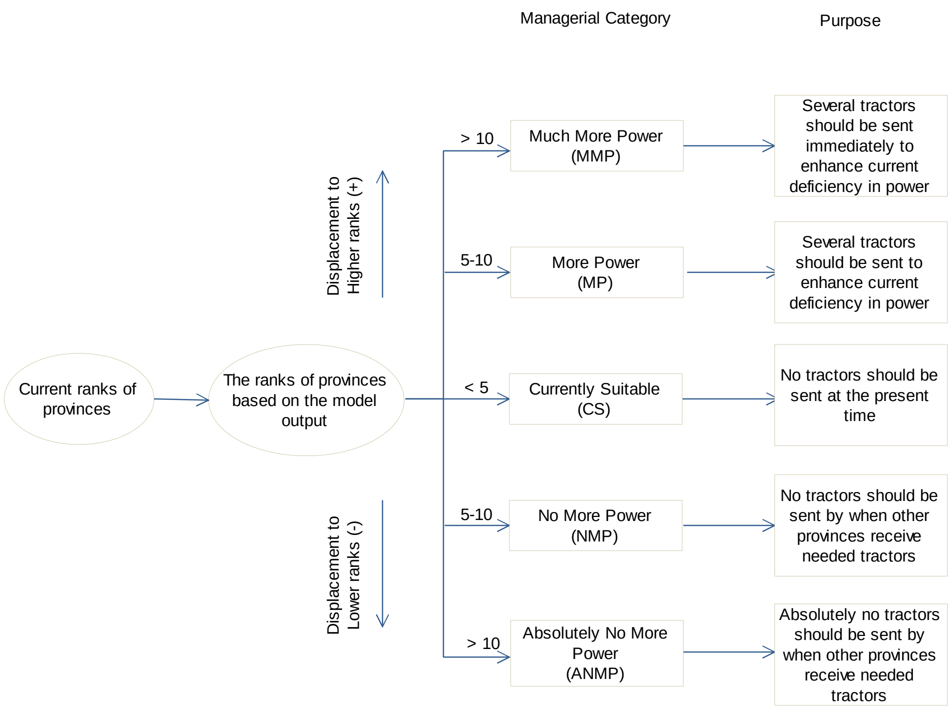

Figure 2. The managerial category of agricultural machinery power distribution based on the model result.

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WR-DEA Model

To obtain the ranks of the provinces in regard to some inputs and outputs, the WR-DEA model was used. The DEA model was employed using four inputs and two outputs. According to available data (Table 1), the inputs were ML IFA^{-1}, ML RFA^{-1}, ML CY-IF^{-1} and ML CY-RF^{-1}. The inputs ML IFA^{-1} and ML RFA^{-1} present the amount of machinery power consumption per percentage of area and the inputs ML CY-IF^{-1} and ML CY-RF^{-1} show the amount of machinery power consumption per percentage of crop production. The outputs were CY-IF and CY-RF. The WR-DEA model, which was used to assess the constructed DMUs with four inputs and two outputs, was proposed by Podinovski (2016) as follow equation. Where, n, m and s are the numbers of DMUs, inputs and outputs, respectively. x_{ij} and y_{rj} are the ith input and rth output of DMU$_j$, respectively. Moreover, $\underline{u}_r, \overline{u}_r, \underline{v}_i$ *and* $\overline{v}_i$ are the lower and upper bounds of the weights of the inputs and outputs, respectively. In the WR-DEA model, the sensitivity of the provinces' ranks to two factors was assessed; *i.e.* (1) The sensitivity to weights of inputs and outputs, and (2) The sensitivity to reduction in number of provinces. The sensitivity of the provinces' ranks to the weights of inputs and outputs were also investigated to ensure that the result is not sensitive to the experts' personal opinions.

RESULTS AND DISCUSSION

As discussed earlier, the main objectives of the four previous AMDPs in Iran (between 1991 and 2010) were to increase the number of farm machines (tractor, combine harvester, tiller, mower, and so on) and, consequently, the promotion of the average ML. In spite of these long-term efforts, no significant progress has been observed in the ML. Table 2 shows the number of predicted and provided farm machines in the first three AMDPs (Ministry of Jihad-e-Keshavarzi, AMDC, 2011). Farming systems and the capacity of farms in each province were completely ignored in the previous AMDPs. Also, no pattern was predicted in the AMDPs to show how farm machines should be distributed in the country to increase the total level of mechanization. The farming system is discussed in the next section. Furthermore, a categorical model; *i.e.* 'National Agricultural Machinery Distribution Pattern (NAMDP)' is introduced in sections 3.2. and 3.3 to clarify how provinces should receive machinery power to enhance the ML corresponding to their needs.

Farming Systems and Agricultural Machinery Distribution Pattern

Agricultural conditions such as soil fertility and type (texture and structure), topography, weather, Irrigated and Rain-fed Farming Areas (IFA and RFA), Crop

$$
\begin{aligned}
&Max \quad \sum_{r=1}^{s} u_r y_{ro} \\
&s.t. \quad \sum_{i=1}^{m} v_i x_{io} = 1 \\
&\qquad \sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} + u_0 \le 0 \qquad j = 1,2,\dots,n \\
&\qquad \underline{u}_r p \le u_r \le \overline{u}_r p, \quad \underline{v}_i q \le v_i \le \overline{v}_i q \quad i = 1,2,\dots,m, \;\; r = 1,2,\dots,s \\
&\qquad p, q > 0
\end{aligned}
$$

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production from Irrigated and Rain-fed Farming Areas (CY-IF and CY-RF), farming systems, the number of farm holdings in each farming system, and average farm size are different in each province. Generally, northern, western and some parts of eastern Iran are mountainous. However, annual precipitation is higher in the northern and western areas, compared to the eastern and southern areas (Iran Meteorological Organization, 2015). Therefore, farming systems in those parts of the country, especially for wheat production, are rain-fed. In other words, the irrigated and rain-fed farms are not spread equally all over the country; this, in turn, leads to uneven crop yield in the provinces of the country. In the former AMDPs, the agricultural policy was to achieve a higher level of mechanization throughout the country. In other words, tractors were distributed throughout the provinces equally. To approve this claim, the Gini coefficient was calculated. This coefficient is 0.16 for ML, which shows that the distribution of tractors is almost equal within the country (Table 1). The coefficient for other factors, *i.e.* IFA, RFA, CY-IF and CY-RF are around 0.5, which indicates that these factors are not equally spread all over the country, *i.e.* crop yield and farming conditions vary between the provinces. Thus, it is clear that power distribution does not correspond to the farming area and crop production.

Thus, not having a suitable agricultural machinery distribution pattern and disregarding agricultural conditions result in high MLs in some provinces with low output. The data included in Table 1, for instance, clearly show that the ML of some provinces, such as Qom, Markazi and Semnan, are not reasonable with regard to the IFA, RFA, CY-IF and CY-RF. As a result of high ML in such provinces with low potential agricultural conditions (inadequate fertile soil, available water, and the like), it is understandable why some studies concluded that agricultural machinery power in Iran cannot contribute to the crop yield as much as other inputs like fertilizers or chemicals (Tabatabaeefar and Omid, 2005; Amjadi and Chizari, 2006). To improve the situation, a suitable agricultural machinery distribution pattern that considers a wide range of valid data on agricultural conditions in each province is needed.

NAMDP Using FAHP Model

The ranks of provinces

As discussed, five agricultural factors were considered in an FAHP model, which consists of three criteria and four sub-criteria. According to the experts' pair-wise comparisons, the weights of the criteria 'CA', 'Y' and 'ML' were 0.240, 0.550, 0.210, and the weights of sub-criteria 'IFA', 'RFA', 'CY-IF' and 'CY-RF' were, 0.667, 0.333, 0.778 and 0.222, respectively. Inconsistency values for all of the judgments were less than 0.01, representing the suitability of all the judgments (Saaty, 1980). According to the Ministry of Agriculture (Ministry of Jihad-e-Keshavarzi, 2014), the mean yield in irrigated farms is three to four times higher than rain-fed farms. Our experts believed that there would be much higher losses in fertile farms with higher yields than infertile farms when sufficient farm machines are not available. Accordingly, higher weights were given to these three factors; *i.e.* 'Y', 'IFA' and 'CY-IF'. Table 3 shows the ranks of the provinces for receiving agricultural machinery power with regard to the total crops and cereal crop production based on the FAHP model. The top three provinces that urgently need to receive agricultural machinery are Khuzestan, Fars and Khorasan Razavi, respectively. It seems that the status of ML in these provinces has been neglected since their displacements to new ranks are as large as 11-18 ranks.

Since the displacement of each province would be confusing, the categorical model given in Figure 2 was defined to show the importance of sending/not sending tractors to provinces. The new ranks of Khuzestan, Fars and Khorasan Razavi are placed from one to three and displaced more than 10 provinces to

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Table 2. Agricultural machinery status according to three AMDPs in Iran. (Ministry of Jihad-e-Agriculture, AMDC, 2009).

Machine type	First AMDP (1991-1995)			Second AMDP (1996-2000)			Third AMDP (2001-2005)		
	Predicted NO	Distributed NO	Fulfilled (Percent)	Predicted NO	Distributed NO	Fulfilled (Percent)	Predicted NO	Distributed NO	Fulfilled (Percent)
Tractor	107596	45992	42.75	203707	20892	10.3	143600	69833	48.6
Combine harvester	-----	2878	-----	7800	983	12.6	12740	2523	19.8
tiller	6140	20183	32.86	59860	10515	17.6	72035	7225	11.6
Mower	-----	1501	-----	24170	816	3.4	16286	1214	7.5

Table 3. Rank of provinces to receive mechanical power sources based on the FAHP model.

Alternative (Province)	Rank based on current ML	Based on total crops production		Based on cereals production		Power distribution managerial category[a]	
		Weight	Rank	Weight	Rank	(Based on total crops production)	(Based on cereal production)
1- Khuzestan	16	0.089	1	0.08	2	MMP	MMP
2- Fars	13	0.072	2	0.107	1	MMP	MMP
3- Khorasan Razavi	21	0.066	3	0.061	3	MMP	MMP
4- East Azarbaijan	10	0.043	4	0.038	8	MP	CS
5- West Azarbaijan	19	0.042	5	0.036	9	MMP	MP
6- Golestan	8	0.042	6	0.047	5	CS	CS
7- Kermanshah	17	0.04	7	0.052	4	MP	MMP
8- Esfahan	7	0.039	8	0.031	15	CS	NMP
9- Hamadan	11	0.039	9	0.04	7	CS	CS
10- Lorestan	25	0.037	10	0.041	6	MMP	MMP
11- Kerman	15	0.036	11	0.02	21	CS	NMP
12- Ardabil	9	0.036	12	0.033	12	CS	CS
13- Mazandaran	1	0.035	13	0.035	10	ANMP	NMP
14- Kordestan	24	0.035	14	0.03	17	MP	MP
15- Bushehr	30	0.034	15	0.035	11	MMP	MMP
16- Qazvin	27	0.032	16	0.032	14	MMP	MMP
17- Tehran	5	0.03	17	0.02	22	ANMP	ANMP
18- Chaharmahal-Bakhtiari	29	0.03	18	0.031	16	MMP	MMP
19- Zanjan	18	0.027	19	0.027	18	CS	CS
20- Sistan-baluchestan	20	0.022	20	0.015	26	CS	NMP
21- Markazi	3	0.022	21	0.024	20	ANMP	ANMP
22- Ilam	26	0.022	22	0.025	19	CS	MP
23- North Khorasan	12	0.021	23	0.02	23	ANMP	ANMP
24- Gilan	22	0.021	24	0.033	13	CS	MP
25- South Khorasan	28	0.019	25	0.018	25	CS	CS
26- Kohgiluyeh-Boyer-Ahmad	14	0.016	26	0.02	24	ANMP	NMP
27- Yazd	23	0.015	27	0.014	27	CS	CS
28- Hormozgan	6	0.014	28	0.01	29	ANMP	ANMP
29- Semnan	4	0.014	29	0.012	28	ANMP	ANMP
30- Qom	2	0.009	30	0.01	30	ANMP	ANMP

[*] MMP: Much More Power; MP: More Power; CS: Currently Suitable; NMP: No More Power; ANMP: Absolutely No More Power.

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new ranks, which represented that these provinces need 'Much More Power (MMP)' to reach a suitable ML. Although the ranks of these three provinces were from one to three, some other provinces with current low ML (*i.e.*, Qazvin, Lorestan, Bushehr and West Azarbaijan) should not be underestimated since a large displacement (> 10) was also needed in their current ranks according to the FAHP results. Taking this into account, these provinces were put also into category MMP in order to reach a higher ML.

Five high ML provinces (*i.e.*, Qom, Markazi, Semnan, Hormozgan and North Khorasan) should be at much lower ranks and go to the ranks 30, 21, 29, 28 and 23 from 2, 3, 4, 6 and 12, respectively. Although these provinces have currently high ML, they include only nearly 9 and 7.2% of the total CA and Y, respectively. These provinces should receive 'Absolutely No More Power (ANMP)' until other provinces gain higher levels of machinery power. Some provinces like Esfahan, Kerman and Hamadan have received suitable agricultural machinery power since their current ML ranks and FAHP results are similar and, therefore, no great displacement is needed. Hence, the ML statuses of these provinces are 'Currently Suitable (CS)'. All in all, according to the results, the ML of 11 provinces are 'currently suitable' and the ranks of the other 19 should be displaced to improve the ML all over the country with regard to total crop production. The aforementioned results were also based on the provinces' ranks with respect to the total crop production. Consequently, the NAMDP may be slightly changed, as cereal production is more important than the total crop production. For instance, Esfahan, Kerman and Sistan-Baluchestan need 'no more power' regarding cereal production (last column in Table 3).

Sensitivity analysis

Sensitivity analysis is used to investigate the sensitivity of the alternatives to changes in the priorities of the criteria and sub-criteria. In other words, it shows to what extent the ranks of alternatives (provinces) are sensitive to the allocated weights of the criteria and sub-criteria from the pair-wise comparisons. For instance, the sensitivity analysis of the provinces' ranks to the criterion 'Y' regarding the total crops production is shown in Figure 3. As discussed, the experts' pair-wise comparisons resulted in the weight of 'Y' as 0.550, which in turn indicated that the first three ranked provinces are Khuzestan, Fars, and Khorasan Razavi, respectively. If the weight of 'Y' was lower than 0.240 and

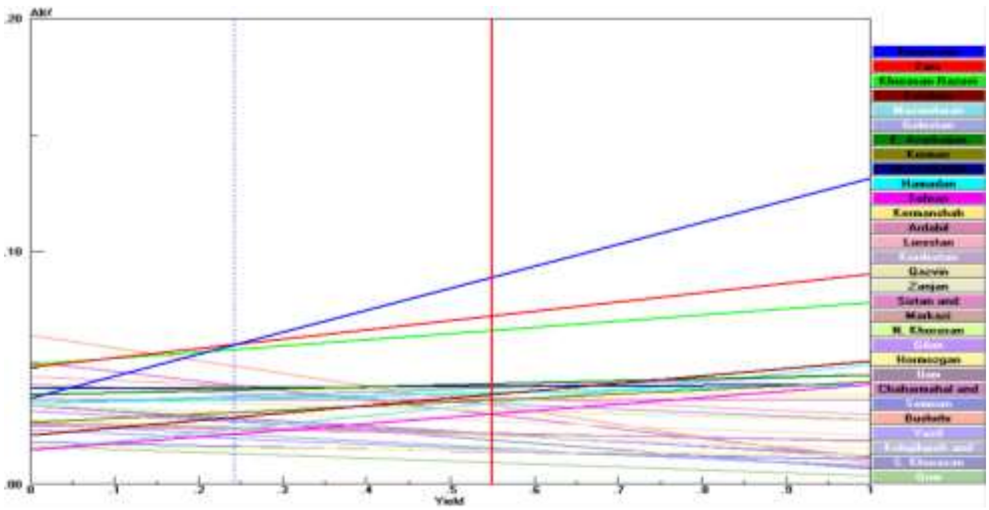

Figure 3. Sensitivity analysis of provinces' ranks to criterion 'Yield'.

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0.140, Fars and Bushehr would have risen to the first and second ranks, respectively. As there is almost as much difference between these weights and the existing weights to swap the ranks of the provinces, it can be concluded that the ranks of the alternatives are not sensitive to 'Y'.

Applying the same procedure, if the weight of criterion 'CA' was higher than 0.820, the rank of Fars would be swapped for the one of Khuzestan (Figure 4). In other words, there is no sensitivity among the three top provinces ranks' to 'CA' due to the long distance between the weights of 0.820 and 0.240. Sensitivity analysis can be applied to each criterion and sub-criterion. Our findings show that there was no sensitivity among alternatives to the weights of criteria and sub-criteria, especially for the top three provinces. However, some provinces that are close in rank would be more sensitive to the weights of the criteria and sub-criteria. In addition, the result of weight restriction DEA would be close to the result of the FAHP model to ensure that a minimum amount of sensitivity to the experts' opinions existed.

NAMDP using WR-DEA Model

The results of the WR-DEA model are summarized in Table 4. The ranks of the provinces were very similar to the ranks of provinces obtained by the FAHP model. Again, the three top provinces that need to receive urgent agricultural machinery power were Khuzestan, Fars, and Khorasan Razavi. Although the ranks of some provinces were changed around one to three ranks, no change was observed, especially for the provinces ranked the first five and the last five, for both total and cereal crop production statuses. In addition, no change was observed in the introduced categorical distribution pattern for this model compared to FAHP model. Since the results are completely similar to the FAHP model, the discussion about the ranks are also similar to Section 3.2.1 and not repeated here. The sensitivity analysis of the provinces' ranks was investigated twice in WR-DEA models, *i.e.* the sensitivity to weights and sensitivity to reduction in the number of provinces.

The results indicated that the ranks of the provinces had no sensitivity to changes in weights of 1.2 to 2.8 for inputs/outputs. In other words, if the current weight is changed by 1.2 to 2.8, the rank of a province will change. Due to this high gap between the current weights and the given weights in the sensitivity analysis, it was concluded that no sensitivity currently exists. The sensitivity of the provinces' ranks to the number of provinces was investigated three times; *i.e.* 1) for provinces numbered one to ten, and 2)

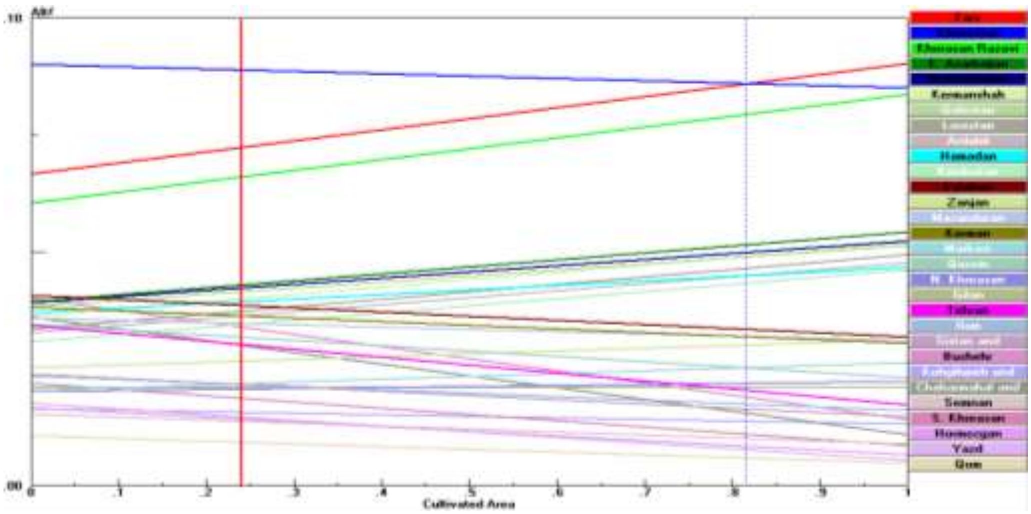

Figure 4. Sensitivity analysis of provinces' ranks to criterion 'Cultivated Area'.

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Table 4. The ranks of Iran provinces to receive mechanical power sources based on the WR-DEA model.

Alternative (Province)	Rank based on current ML	Based on total crops production		Based on cereals production		Power distribution managerial category *	
		Weight	Rank	Weight	Rank	(Based on total crops production)	(Based on cereal production)
1- Khuzestan	16	1	1	0.5309	2	MMP	MMP
2- Fars	13	0.4434	2	1	1	MMP	MMP
3- KhorasanRazavi	21	0.3568	3	0.2811	3	MMP	MMP
4- East Azarbaijan	10	0.0783	4	0.0506	8	MP	CS
5- West Azarbaijan	19	0.0712	5	0.0487	9	MMP	MP
6- Golestan	8	0.1334	6	0.099	5	CS	CS
7- Hamadan	11	0.0716	7	0.0627	6	CS	CS
8- Esfahan	7	0.0882	8	0.0141	17	CS	NMP
9- Kermanshah	17	0.1189	9	0.1177	4	MP	MMP
10- Ardabil	9	0.0622	10	0.0511	7	CS	CS
11- Kerman	15	0.0439	11	0.0041	23	CS	NMP
12- Lorestan	25	0.0406	12	0.0327	12	MMP	MMP
13- Mazandaran	1	0.0377	13	0.0462	10	ANMP	NMP
14- Kordestan	24	0.0302	14	0.02	16	MP	MP
15- Qazvin	27	0.0224	15	0.0455	11	MMP	MMP
16- Bushehr	27	0.0214	16	0.0278	14	MMP	MMP
17- Zanjan	18	0.0172	17	0.0082	21	CS	CS
18- Chaharmahal-Bakhtiari	29	0.0164	18	0.0237	15	MMP	MMP
19- Tehran	5	0.0122	19	0.0124	18	ANMP	ANMP
20- Sistan-baluchestan	20	0.012	20	0.0017	26	CS	NMP
21- Ilam	26	0.0096	21	0.0082	20	CS	MP
22- Markazi	3	0.0076	22	0.0107	19	ANMP	ANMP
23- North Khorasan	12	0.0075	23	0.0067	22	ANMP	ANMP
24- Gilan	22	0.007	24	0.032	13	CS	MP
25- South Khorasan	28	0.006	25	0.0021	25	CS	CS
26- Kohgiluyeh-Boyer-Ahmad	14	0.0048	26	0.0035	24	ANMP	NMP
27- Yazd	23	0.0041	27	0.0014	27	CS	CS
28- Hormozgan	6	0.0033	28	0.001	29	ANMP	ANMP
29- Semnan	4	0.0014	29	0.0011	28	ANMP	ANMP
30- Qom	2	0.0006	30	0.0001	30	ANMP	ANMP

[a] MMP: Much More Power; MP: More Power; CS: Currently Suitable; NMP: No More Power, ANMP: Absolutely No More Power.

for provinces numbered 11 to 20, and for provinces numbered 21 to 30. These separate investigations also confirmed previous results since only one displacement was observed within each ten ranks of the provinces. Accordingly, the given model is highly reliable and has no sensitivity to both the weights of inputs/outputs and the number of provinces.

CONCLUSIONS

Iranian decision makers face a challenge in the distribution of agricultural machinery power in the country with a reasonable pattern, based on some relationships between the given machinery and other agricultural characteristics such as crop yield and cultivated area. This study has introduced a management tool for National Agricultural Machinery Distribution Pattern (NAMDP) to optimize distribution of farm machines all over Iran. The results of the proposed models, namely, FAHP and WR-DEA are more realistic than other studies in which agricultural machinery distribution was estimated based on only one factor. For instance, the Ghadiryanfar *et al.* (2009) study showed that the maximum number of tractors should be given to Hormozgan, Tehran, Kerman, Bushehr, Mazandaran, Kohgiluyeh-Boyer-Ahmad and Kordestan based on the current demand for agricultural machinery. Besides FAHP, the provinces ranks were investigated by WR-DEA, including inputs and outputs, in order to ensure that the results of FAHP are reliable enough. The contribution of experts to decisions for such patterns would lead to a more realistic distribution of power, which, in turn, increases the acceptance of the results by decision makers. The investigation on the exact amount of power (hp ha^{-1}) that should be sent to each province remains for future studies, keeping in mind that agricultural machinery operations should be completed with minimum delay. Notably, to improve ML, a wide range of local agricultural data should be used. Although five agricultural factors were employed in this study in order to introduce NAMDP, other relevant measurements of local agricultural conditions (e.g. ‘average farm size’, ‘number of farmers’, ‘topography’, ‘soil types’ and ‘weather conditions’) are necessary to improve the proposed pattern and which could be recommended for future studies. The combination of the GIS and FAHP is suggested in order to design a spatially explicit agricultural machinery distribution pattern. Furthermore, the described methodology can be applied in other fields of management to help decision makers for distribution of the desired objects.

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الگوی توزیع توان ماشین الات مزارع در ایران: مدل‌های تحلیل فرآیند سلسله مراتبی فازی (FAHP) و تحلیل فراگیر داده‌ها با محدودیت وزنی (WR-DEA)

ا. هوشیار، ح. آزادی و س.م. میردهقان

چکیده

اختصاص تراکتور و ماشین‌های کشاورزی به مناطقی با خصوصیات متفاوت در کشور ایران همواره یک چالش بوده است. این پژوهش با هدف توسعه یک مدل بهینه برای توزیع ماشین‌های کشاورزی در سراسر کشور انجام شد. ضریب جینی برای ارزیابی اینکه آیا توزیع کنونی تراکتور در کشور درست است یا خیر مورد استفاده قرار گرفت. این ضریب نشان داد که وضعیت کنونی توزیع تراکتور نامناسب است زیرا هیچ همبستگی بین ضریب جینی با توان ماشینی توزیع شده یا سطح مزارع وجود ندارد. بنابراین دو روش برای توسعه الگوی مناسب توزیع ماشین‌های کشاورزی استفاده شد: تحلیل فرآیند

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سلسله مراتبی فازی (FAHP) و تحلیل فراگیر داده‌ها با محدودیت وزنی (WR-DEA). یک طبقه‌بندی کمی برای نشان دادن اینکه چقدر توان ماشینی باید به هر استان فرستاده شود تعریف گردید. خروجی هر دو مدل FAHP و WR-DEA نشان داد که ۳ و ۹ استان به ترتیب " به توان بسیار بیشتر" و "توان بیشتر" نیاز دارند، در حالی که ۴ استان "مطلقاً به هیچ توان اضافی" نیاز ندارند و ۳ استان در "حال حاضر مناسب" هستند. آنالیز حساسیت نشان داد که هیچ کدام از مدل‌های توسعه داده شده به وزن‌های تعریف شده توسط گروه متخصصان حساس نبودند. شباهت نتایج حاصل شده از دو مدل تأکید می‌کند که الگوی توزیع ماشین‌های کشاورزی قابل اعتماد بوده و می‌تواند در کشور مورد استفاده قرار گیرد.

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