Machine-building Enterprise Fuzzy Model as the Interrelated Factor Complex System

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Abstract. The article considers the features of the modern machine-building complex of Bryansk region. The authors have developed a component classifier of an industrial enterprise internal environment; have formed the machine-building enterprise fuzzy model describing its internal environment factor relationship. The main result of the model made was forming a confidence interval that describes the mutual influence degree of the internal environment factors of a machine-building enterprise.

1. Introduction
The engineering sector is a major industry of Bryansk region; therefore, providing conditions for the effective functioning of a machine-building enterprise is an important direction of industrial management [12, 13, 16].

The purpose of this article is to create the machine-building enterprise model based on fuzzy logic which could take into account the enterprise internal component interaction [1, 8, 10, 18]. The evaluation of this influence can help to shape management decisions that improve the overall business efficiency.

2. The modern state of the Bryansk region engineering complex
Bryansk region is an industrial and agricultural region in Central Russia with a high share of manufacturing and innovative development potential. At present stage of economic development, the industrial production in Bryansk region has almost the fifth part of the gross regional product. The industrial complex of Bryansk region includes about 300 large and medium-sized enterprises, and more than 11 thousand small ones [3, 4].

The portion of the manufacturing sector in 2014 amounted to about 90% of the shipped production regional volume, the amount of which is about 120 million rubles in current prices [11, 16]. The processing industry is represented by machine-building, military-industrial complex, metallurgical production, building material production, woodworking, electrical equipment manufacture, light industry, food and processing industry and other manufacturing types. The key position in the production segment of Bryansk region is that the socio-economic system belongs to mechanical engineering.
2.1. Basic machine-building enterprises of Bryansk region

In table 1, there is a list of major machine-building enterprises of Bryansk region indicating industrial output.

| Machine-building enterprise                        | Produced goods                                                                                                                                 |
|---------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|
| CJSC Management company "Bryansk machine-building plant" | Mainline and shunting locomotives, carriages and platforms of different modifications, diesel locomotive and diesel engine overhaul, spare parts for railway transportation, mill products, gearboxes for travelling the underground escalators |
| OJSC "Mobile crane plant Klintsovskiy"            | Truck cranes 16, 20, 25 tons on chassis MAZ, KAMAZ, Ural                                                                                     |
| OJSC "Bryansk Arsenal"                            | Graders, pavers, milling roads for cold milling of asphalt pavement, trailers, spare parts for road machines                                    |
| LLC "Bryansk automobile plant"                     | Multi-chassis for dual-use                                                                                                                   |
| CJSC JV "Bryansk-Selmash"                         | Self-propelled combine harvesters "PALESSE" with a capacity of 7, 8 and 12 kg/s, forage harvesters and complexes with a capacity of 235 to 450 HP |
| OJSC "Irmash"                                     | Tracked and wheeled asphalt pavers, motor graders of grades 100 and 180, complex road machines with three interchangeable sets of equipment, machine for patching by the jet-injection method, paving rollers, trench and bucket chain excavators |
| OJSC "Novozybkovskiy machine-building plant"      | Electrothermal equipment, electrical welding equipment, wagons and accessories for the carriages                                             |
| LLC "Zhukovskiy motovelozavod"                    | Motorcycles, tricycles, bicycles, snowmobiles                                                                                                 |

Most of Bryansk region machine-building complex enterprises indicate that the economic sanctions imposed on Russia by the US and the EU have not affected its economic activities. In some cases, the retaliatory protective measures from the Russian side have helped to increase the production volume. However, the management of some enterprises is anxious about the significant risk increase associated with the imported equipment and component supply [12, 15]. If the situation gets worse, there is a chance of having difficulties with both purchasing modern machine tools and spare parts in other countries and raising credits to finance the activity.

3. Machine-building enterprise as a system of interrelated factors

We will introduce the notion of a machine-building enterprise as a system consisting of the internal environment factor plurality and determine the study object as the machine-building enterprise fuzzy model [6, 9]:

\[ W = <\{P_{hs}, M_{hs}, F_{hs}, K_{hs}, Y_{hs}\}, Z> \]  

where \( W \) is the internal environment factors of the machine-building enterprise; \( P_{hs} \) is the s-th factor of the h-th "Production" factors subgroup; \( M_{hs} \) is the s-th factor of the h-th "Marketing" factor subgroup; \( F_{hs} \) is the s-th factor of the h-th "Finances" factor subgroup; \( K_{hs} \) is the s-th factor of the h-th "Staff" factor subgroup; \( Y_{hs} \) is the s-th factor of the h-th "Organization of General management" factor subgroup of the machine-building enterprise internal environment; \( Z \) is the mutual relation of \( W \) factors of the enterprise internal environment.

3.1. Classification of the internal environment factors of a machine-building enterprise

Table 2 shows a fragment of the factor classification for the machine-building enterprise internal environment.

| Table 2. A fragment of the factor classification of the machine-building enterprise internal environment |
| Internal environment factors of the first order, $W$ | Internal environment factors of the second order, $W_h$ | Internal environment factors of the third order (private factors of the internal environment), $W_{hs}$ |
|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|
| **Code of factor $W_h$** | **Linguistic value of factor, $W_h$** | **Code of factor $W_{hs}$** | **Linguistic value of factor, $W_{hs}$** |
| Production, $P$ | Work organization of the main production | $P_{11}$ Organizing production processes (planning the output on the range and upgradeability degree; regulating the production process, its volume, structure and rhythm) | $P_{12}$ Organizing production control (analysis and improvement of production management systems; participation in planning production development, working out production management rational structures) |
| Marketing, $M$ | Commodity-focused marketing | $M_{11}$ Distribution system organization | $M_{12}$ Product distribution organisation |
| Finance, $F$ | Financial planning | $F_{11}$ Financial planning and budgeting enterprise | $F_{12}$ Planning the level of production costs |
| | | $F_{12}$ Planning the level of production costs | $K_{12}$ Organizing recruitment and staff selection |

The document offers a breakdown of factors $W$ of the internal environment, represented as set $\{P_{hs}, M_{hs}, F_{hs}, K_{hs}, Y_{hs}\}$, for more private indices of the second and third order. The breakdown of factors $W$ of the internal environment, represented as set $\{P_{hs}, M_{hs}, F_{hs}, K_{hs}, Y_{hs}\}$, will allow later to define clearly their mutual impact.

To determine the mutual influence of a $Z$ factor on $W$ factors of the enterprise internal environment, it is required to determine the influence of the strength and direction. For this purpose, the work introduces the concept of $Z$ as vector $\bar{Z}$ describing the interaction of factors $W$ of the company internal environment:

$$Z = (Z; z), \quad (2)$$

where $Z$ is the force of factor mutual impact of the enterprise internal environment, defined as a linguistic variable; $z$ is the direction of factor influence of the enterprise internal environment.

### 3.2. Fuzzy model of the machine-building enterprise external environment

Due to changes in the business environment, special attention should be paid to the interaction between the regional social economic system of the region and the so-called external environment, which is understood as a set of external influences and relations between them:

$$F = \{F_{ijk} : i, j, k \in N, 1 \leq i \leq 5\} \quad (4)$$

where $F$ is factor of some predicted environment, including:

- $F_1$ are political factors;
- $F_2$ are economic factors;
- $F_3$ are scientifically technological factors;
- $F_4$ are social demographic factors;
- $F_5$ are natural geographical factors;
- $V$ is the communications set, coupling $F_{ijk}$ with each other.
Quality estimation of $V$ (factors communications of the little forecast environment - $F_{ijk}$) and $O$ (constituents communications of the regional social economic system - $S_{mn}$) can be conducted by forming the special evaluation questionnaires. Then they are based on expert estimation theory.

3.3. The machine-building enterprise fuzzy model

In describing the enterprise internal environment, $Z$ qualitative assessment is used, that is the mutual influence of $W$ factors of the enterprise internal environment. Despite the fact that we can intuitively choose strongest relationship $\gamma$ of factors $W$ of the enterprise internal environment, their qualitative assessment is quite difficult to evaluate by the exact numeric parameter. For the mathematical description of $Z$ and operations with $Z$ factors, L Zadeh’s concepts of a fuzzy set theory and fuzzy logic are used.

Let us determine the power of $Z$ influence for each estimated $W$ factor in the form of linguistic terms: "almost have no effect", "weak influence", "moderate influence", "strong influence". The terms determining $Z$, that is the mutual influence of factors, can be formalized as following linguistic variable $LV_{W \leftrightarrow W}$:

$$LV_{W \leftrightarrow W} = \langle W, T_q, X_q, M_q \rangle,$$

where $W$ is the factor of the internal environment, represented by set $W=\{P_{hs}, M_{hs}, F_{hs}, K_{hs}, Y_{hs}\}$; $T_q$ is the set of values $LV_{W \leftrightarrow W}$, representing terms: $T_q=\{"almost have no effect", "weak influence", "moderate influence", "strong influence"\}$; $X_q$ is the area of the internal environment factor definition $W$; $M_q$ is the semantic rule for the assignment of fuzzy subsets of set $X_q$, which membership functions are presented in Figure. 1.

![Figure 1](image_url)  

**Figure 1.** A graph of membership functions in fuzzy sets, which formalizes the terms of the linguistic variable "$W$".

Set $A_1$ corresponds to the term "almost have no effect", set $A_2$ - to the term "weak influence", set $A_3$ - to the term "moderate influence", set $A_4$ - to the term "strong influence". Fuzzy subsets are defined by fuzzy numbers of a $T$-$R$ type, such as "approximately 0.33", "approximately 0.66", "approximately 1".

For the calculation of membership function $\mu_A$ of fuzzy set $A_q$, there has been proposed the following model, represented in the general form:

$$\mu_A = \begin{cases} 0, & \text{if } X < b_1; \\ \frac{X - b_1}{b_2 - b_1}, & \text{if } b_1 \leq X \leq b_2; \\ 1, & \text{if } b_2 < X \leq b_3; \\ \frac{X - b_3}{b_3 - b_2}, & \text{if } b_3 < X \leq b_3; \\ 0, & \text{if } X > b_3, \end{cases}$$

where $b_1, b_2, b_3$ are the abscissa of fuzzy number $T$-$R$ of the type that defines fuzzy set $A_q$.

Taking $\mu = 0.8$, let us determine the mutual influence of $Z$ factors of the $W$ machine-building enterprise internal environment in the form of the following interval:

$$X_{\text{min}} = 0.8 \ b_1 + 0.2 \ b_3;$$
$$X_{\text{max}} = 0.2 \ b_2 - 1.2 \ b_3.$$
where $X_{\text{min}}$ is the lower limit of the degree of mutual influence of $Z$ factors of internal environment $W$; $X_{\text{max}}$ is the upper limit of the degree of mutual influence of $Z$ factors of internal environment $W$.

When the values of the membership function are $\mu = 0.8$, it can be argued that the force of the mutual influence of specific factors of the machine-building enterprise internal environment is in the interval $[X_{\text{min}}, X_{\text{max}}]$, calculated above. We should notice that in order to establish later a set of values of linguistic variable $\mathcal{M}^{\mathcal{E}_1,W}$, we should resort to the help of experts whose responses will be handled.

4. Results and discussion

Let us present the model of the information advising system with its input and output parameters (Figure 2). The input parameters of the enterprise ($W$) are changes in the environment ($F_{ijk}$).

Figure 2. The model of the information advising system, allowing making the managerial decisions at the enterprise.

The result parameters are administrative decisions providing an effective management at the enterprise different levels.

The created information advising system can be attributed to a class of the monitoring system and a subclass of the evaluated and diagnostic advising systems. The primary purpose of these systems is to watch some objects or processes and make some recommendations.

Therefore, monitoring the enterprise external environment can be done by the offered information advising system. It is based on permanent watching the factors of the external dynamic changing system, searching for the positive and negative tendencies in it.

5. Conclusions

Thus, the described fuzzy model of the factor interaction of the internal environment shows the possibilities of improving the machine-building enterprise management. There are identified strong linkages that could be taken into account when making management decisions by the enterprise management [14, 17, 18]. A formed mathematical apparatus of data processing will further develop the informational advising system that will automate the process of making management decisions and improve the management quality in general.

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