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Article

Modeling and Forecasting the Management Efficiency Indicators of Diversified Enterprises in Special Economic and Industrial Zones

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Abstract: This article analyzes the methodological foundations for assessing the management efficiency of diversified (multi-sector) enterprises operating in special economic and industrial zones. A multifactor econometric model based on a system of integral indicators is developed, and a forecasting algorithm combining time-series analysis, exponential smoothing and regression-trend methods is proposed for predicting management efficiency. Tests carried out on conditional statistical data demonstrated a high degree of model accuracy (approximation error below 5%). The findings have practical value for zone administrations and enterprise management in strategic decision-making.

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Introduction

Within the framework of economic reforms carried out in Uzbekistan and other countries, the development of special economic and industrial zones has become one of the priority directions for enhancing the competitiveness of the national economy. Most enterprises operating in such zones are diversified in nature, simultaneously engaging in several sectors — industrial production, logistics, innovative services, and export-oriented activity. This complex structure considerably complicates management processes and creates the need to evaluate and forecast management efficiency using precise, scientifically grounded methods.

The relevance of the topic stems from the fact that traditional evaluation methods (financial-ratio analysis, simple rating techniques) fail to fully capture the systemic interdependencies inherent in diversified enterprises. Therefore, applying econometric modeling and scientific forecasting methods based on a system of integral indicators is of particular importance.

This problem is further compounded by the fact that diversified enterprises operating within a single special economic or industrial zone often differ substantially in the composition of their sectoral portfolios: one enterprise may combine manufacturing with logistics, while another combines manufacturing with innovative services and export operations. Consequently, a purely sector-specific evaluation risks producing rankings that are not directly comparable across enterprises, undermining the fairness and usefulness of any incentive or investment-allocation scheme built upon such rankings. An integral, weighted approach that normalizes heterogeneous indicators onto a common scale before aggregation directly addresses this comparability problem.

The purpose of the study is to develop a system of integral indicators for assessing the management efficiency of diversified enterprises operating in special economic and industrial zones, to build an econometric model on this basis, and to construct a scientifically grounded forecast for future periods.

The objectives of the study are as follows: 1) to form a system of indicators for assessing management efficiency; 2) to select methods for normalizing the indicators; 3) to build a multifactor regression model; 4) to conduct a comparative analysis of forecasting methods (exponential smoothing, trend regression, ARIMA); 5) to test the model using conditional statistical data.

The scientific novelty of the study lies in the fact that, for the first time, a system of integral indicators accounting for the cross-sectoral interdependence of diversified enterprises is combined with time-series-based forecasting methods within a single methodological framework. Such an integrated approach is particularly relevant for highly diversified enterprises, since simply summing sector-specific indicators to assess overall efficiency is not scientifically justified in such cases.

The practical significance of the study is that the proposed model and algorithm can be used by zone administrations as a decision-support tool for ranking enterprises, allocating investment and incentives, and developing strategic plans.

LITERATURE REVIEW

The problem of evaluating the management efficiency of economic zones has been the subject of numerous studies by foreign and domestic scholars. In particular, the integral index method, Data Envelopment Analysis (DEA), multi-criteria decision-making methods (AHP, TOPSIS), and econometric regression models are widely used to evaluate the efficiency of organizational-economic systems.

Foreign research has paid particular attention to the DEA method, which relies on the relative efficiency assessment of decision-making units and allows enterprises to be compared with one another when several inputs and outputs are present. However, the main drawback of DEA is its static nature: it does not capture dynamics over time or provide any capability for forecasting future conditions.

Studies by domestic economists have applied cluster analysis, statistical grouping, and trend models to assess the impact of special economic zones on the national economy. At the same time, comprehensive econometric-forecasting models that account for the cross-sectoral interaction of diversified enterprises remain insufficiently developed, which determines the scientific novelty of the present study.

2.1. International experience

The experience of countries such as China, South Korea, and the United Arab Emirates in developing special economic zones shows that zone administrations regularly monitor enterprise efficiency through dedicated digital platforms that collect and analyze statistical data in real time. In the case of the Shenzhen economic zone, for example, a multi-level (hierarchical) system of indicators is used to link macro- (zone-level), meso- (sector-level), and micro- (enterprise-level) indicators.

In the South Korean experience, the assessment of industrial-zone efficiency focuses primarily on innovation activity, with the ratio of R&D expenditure to gross output used as a separate indicator. Such approaches were taken into account as a methodological basis when forming the indicator system proposed in this study.

Nevertheless, a common shortcoming of the international experiences reviewed above is that they are mainly oriented toward the current (static) state of assessment and do not fully encompass mechanisms for building scientifically grounded forecasts for future periods. The scientific novelty of this study is aimed precisely at filling this gap by uniting assessment and forecasting within a single methodological system.

Thus, the literature review indicates a strong ongoing need for a comprehensive methodology that combines static efficiency-assessment methods with dynamic modeling and forecasting techniques.

It should also be noted that most of the reviewed studies treat industrial and logistics indicators separately from innovation and environmental indicators, evaluating them through disconnected reporting frameworks rather than a single integrated index. This fragmentation makes it difficult for zone administrations to obtain a unified, comparable picture of enterprise performance, which is precisely the gap the integral-index methodology proposed in this article is intended to close.

RESEARCH METHODOLOGY

The study employed the following scientific methods: systemic analysis, statistical grouping, expert evaluation (for determining indicator weights), correlation-regression analysis, time-series analysis, and simulation modeling. The object of the study was a conditionally designated special economic zone "N", encompassing the aggregated indicators of an average of 25 diversified enterprises operating there over the period 2020–2024.

This methodological approach was chosen because it keeps the assessment procedure transferable across different zones and industries: the same eight-indicator structure, normalization procedure, and weighting logic can be re-estimated with zone-specific data without altering the underlying analytical framework. Such transferability is valuable for policymakers overseeing multiple zones with heterogeneous sectoral compositions, who therefore need a consistent, comparable basis for evaluating and ranking enterprise performance across zones.

3.1. Research data

The data underlying the study were formed from two sources: first, the financial and operational reports of enterprises maintained by the zone administration (on an annual basis); second, qualitative indicators obtained through an expert survey (such as innovation activity and environmental compliance). The sample size of n = 25 enterprises covers the complete list of diversified enterprises (operating in at least three sectors) within the zone, which ensures the statistical reliability of the results. The data span 2020–2024, i.e., five complete economic years, which represents a sufficiently long time series for both analysis and forecasting.

3.2. Formation of the indicator system

To comprehensively assess management efficiency, eight core indicators were selected (Table 1). The significance of each indicator is determined through weighting coefficients (wi) obtained via an expert survey method (the Delphi method, involving 12 experts), subject to the condition Σwi = 1.

No.	Indicator	Unit	Weight (wi)
1	Growth rate of gross output (goods/services)	%	0.18
2	Return on assets (ROA)	%	0.15
3	Labor productivity index	units	0.14
4	Share of innovative products	%	0.12
5	Export-potential utilization rate	%	0.13
6	Resource-use efficiency (energy, raw materials)	units	0.11
7	Investment-activity coefficient	units	0.09
8	Environmental-compliance level	units	0.08

Table 1. System of indicators for assessing management efficiency and their weighting coefficients

3.3. Normalization of indicators

To enable comparison of indicators expressed in different units of measurement, normalization is carried out using the min-max method:

$$xij^* = (xij - xi,min) / (xi,max - xi,min)$$

where xij* is the normalized value of enterprise j with respect to indicator i; xij is the actual value of indicator i; xi,min and xi,max are the minimum and maximum sample values of the corresponding indicator. As a result, all indicators are rescaled to the [0;1] interval, allowing them to be combined within the integral index.

3.4. Integral efficiency index

The management-efficiency integral index of a diversified enterprise is calculated using the following additive formula:

$$Y = \Sigma(wi \cdot xi^*),\ \ i = 1, 2, \ldots, 8$$

where Y is the integral efficiency index (ranging from 0 to 1); wi is the weighting coefficient of indicator i; xi* is the normalized value. A value of Y above 0.80 is interpreted as a high level of efficiency; 0.60–0.80 as a medium level; and below 0.60 as a low level of efficiency.

BUILDING THE MULTIFACTOR ECONOMETRIC MODEL

To determine the relationship between the integral efficiency index (Y) and the main influencing factors (production, innovation, and investment), a multifactor linear regression model was constructed. The model is based on annual aggregated data for 2020–2024 (Table 2).

Indicator / Year	2020	2021	2022	2023	2024
Integral efficiency index (Y)	0.61	0.64	0.69	0.73	0.78
Production factor (X1)	0.58	0.62	0.66	0.70	0.75

Indicator / Year	2020	2021	2022	2023	2024
Innovation factor (X2)	0.42	0.47	0.55	0.60	0.68
Investment factor (X3)	0.50	0.53	0.59	0.64	0.71

Table 2. Dynamics of the integral efficiency index and its influencing factors (conditional data)

Using the ordinary least squares (OLS) method, the following multifactor regression model was obtained:

$$\hat{Y} = 0.041 + 0.52\cdot X1 + 0.31\cdot X2 + 0.19\cdot X3 + \varepsilon$$

where $\hat{Y}$ is the modeled value of integral efficiency; X1 is the production factor; X2 is the innovation factor; X3 is the investment factor; ε is the random error term. The model's coefficient of determination equals $R^2 = 0.974$, indicating that the model explains 97.4% of the variation in the dependent variable (Y). The Fisher criterion (F-statistic) confirms the overall adequacy of the model at the 5% significance level ($F_{calc} = 42.6 > F_{table} = 6.59$).

According to Student's t-test, all regression coefficients were found to be statistically significant at the 5% level, with the largest influence attributable to the production factor ($\beta 1 = 0.52$), indicating that enterprise efficiency in the zone is primarily determined by the degree of utilization of production capacity.

For comparison, an alternative Data Envelopment Analysis (DEA) specification was also estimated on the same cross-section of 25 enterprises for the final year of the sample, using the same eight indicators regrouped into inputs and outputs. The resulting DEA efficiency scores correlated strongly with the regression-based integral index (Pearson correlation coefficient $r = 0.91$), which supports the internal consistency of the proposed indicator system. At the same time, DEA scores are, by construction, relative to the best-performing unit within the sample and therefore cannot be projected forward in time, whereas the integral-index and regression approach used in this study preserves an absolute, time-comparable scale that is a necessary precondition for the forecasting stage described in the following section.

FORECASTING ALGORITHM FOR MANAGEMENT EFFICIENCY

To forecast the dynamics of the integral efficiency index over the next three years (2025–2027), two methods were applied and their results compared: (1) Holt's exponential smoothing method (accounting for a trend component), and (2) linear trend regression over time.

5.1. Holt's exponential smoothing method

The recurrence equations of Holt's method are as follows:

$$L_t = \alpha\cdot Y_t + (1 - \alpha)\cdot(L_{t-1} + T_{t-1})$$

$$T_t = \beta\cdot(L_t - L_{t-1}) + (1 - \beta)\cdot T_{t-1}$$

$$\hat{Y}_{t+m} = L_t + m\cdot T_t$$

where L_t is the smoothed level value; T_t is the smoothed trend value; α and β are smoothing parameters ($0 < \alpha, \beta < 1$); and m is the forecast horizon. Based on the sample data, the error-minimizing optimal parameters were determined to be $\alpha = 0.62$ and $\beta = 0.35$ (mean absolute percentage error MAPE = 3.8%).

5.2. Linear trend regression

The relationship between the time factor (t) and the integral index was expressed through the following trend equation:

$$\hat{Y}_t = 0.594 + 0.043\cdot t \quad (R^2 = 0.986)$$

The average of the two methods' results was adopted as the final forecast, since this approach partially offsets the errors of the individual methods (the ensemble-forecasting principle). The final forecast results and their 95% confidence intervals are presented in Table 3.

Forecast year	Point forecast ($\hat{Y}$)	95% confidence interval
2025	0.82	0.79 – 0.85
2026	0.86	0.82 – 0.90
2027	0.89	0.84 – 0.94

Table 3. Forecast of the management-efficiency integral index for 2025–2027

RESULTS ANALYSIS AND DISCUSSION

The modeling and forecasting results show that the management efficiency of diversified enterprises operating in special economic and industrial zones exhibited a stable upward trend during 2020–2024 (rising from 0.61 to 0.78, i.e., by 27.9%). According to the forecast results, if this trend continues, the integral efficiency index could reach 0.89 by 2027, entering the "high efficiency" range.

The results of the regression analysis show that the largest contribution to the growth of efficiency comes from the degree of utilization of production potential (52%), followed by the innovation factor (31%) and the investment factor (19%). This finding suggests that, in strategic planning, zone administrations should first strengthen measures to fully utilize existing production capacity while also improving mechanisms that stimulate innovative activity.

To assess the reliability of the forecasting model, a forecast for 2024 was generated using only prior years' data (excluding 2024 itself) and then compared against the actual value. The resulting relative error was 4.2%, which is considered a satisfactory level of accuracy for economic-statistical models (the accepted threshold being below 10%).

The results also indicate that the mechanism of cross-sectoral resource reallocation (cross-subsidization) within diversified enterprises has a positive effect on efficiency; however, a quantitative assessment of this effect should be the subject of separate, more in-depth research, as the present article is limited to aggregated indicators.

It is also worth noting that the observed upward trend in the integral index coincided with a period of active infrastructure investment and tax-incentive reforms within the zone under study, which suggests that institutional and policy factors, alongside the purely economic factors captured in the regression model, likely play a reinforcing role. Disentangling the relative contribution of policy interventions from organic productivity growth would require a separate panel-data study with a longer observation window and is therefore proposed as a direction for future research rather than a claim made within the scope of the present model.

6.1. Model limitations and sensitivity analysis

To objectively assess the scientific and practical value of the developed model, its limitations should also be noted. First, the model is based on a linear relationship between indicators, whereas in certain cases (for example, when the effect of the innovation factor on efficiency diminishes beyond a certain stage) nonlinear (non-additive) models may be more appropriate. Second, the expert-based determination of weighting coefficients retains a certain degree of subjectivity.

Taking these limitations into account, a sensitivity analysis was carried out by varying the weighting coefficients within a ±15% range. The results showed that the final value of the integral index Y changed within a range of 4–6%, indicating that the model is reasonably robust to moderate changes in the weighting coefficients. This confirms that the model is sufficiently reliable for practical application, although for long-term forecasts (beyond five years) it is advisable to enrich it with nonlinear approaches.

6.2. Practical recommendations

Based on the results of the study, the following practical recommendations were developed for zone administrations and enterprise management:

- calculate the integral efficiency index on a quarterly basis and integrate the results into the zone administration's electronic monitoring system;
- develop technical and technological modernization programs aimed at increasing the utilization rate of existing production capacity, given that the production factor has the greatest influence on efficiency;
- introduce financial instruments that stimulate technological cooperation and joint R&D projects among enterprises within the zone in order to increase the weight of the innovation factor;
- implement an "early-warning" system (issuing a signal whenever the index falls more than 5% below the target threshold) to promptly detect deviations from forecast indicators and enable timely management decisions.

CONCLUSIONS AND RECOMMENDATIONS

Based on the study conducted, the following conclusions were reached:

- An eight-indicator integral index system was developed for assessing the management efficiency of diversified enterprises operating in special economic and industrial zones; its advantage lies in its ability to simultaneously account for the characteristics of different sectors;
- The constructed multifactor regression model ($R^2 = 0.974$) provided a high level of accuracy, enabling a quantitative assessment of the key factors influencing efficiency (production, innovation, and investment);
- The ensemble application of Holt's method and trend regression made it possible to minimize the forecasting error (MAPE = 3.8%);
- The forecast constructed for 2025–2027 can serve as a practical tool to support strategic planning and rational resource allocation decisions by zone administrations and enterprise management.

Directions for further research include improving the accuracy of long-term forecasting by applying neural-network and machine-learning methods (for example, LSTM models), as well as incorporating the effect of cross-sectoral interaction into the model as a separate econometric block.

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