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ALGORITHM FOR CALCULATING THE NORMATIVE AREA OF AN INDUSTRIAL ENTERPRISE LAND PLOT

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Abstract. In the article, the problem of finding justified approaches aimed at achieving sustainable development of urban land use is presented. In Ukraine, as in many post-Soviet countries of Eastern Europe, the transition to market relations has led to a change in production technologies, a reduction in the capacity or the termination of the functioning of industrial enterprises within settlements, but the parameters of land use remained unchanged. However, today, most of the especially large cities face the problem of lack of available land for its normal development. There are trends in the reduction of green zones and building compaction, etc.
Based on the results of the established sizes of normative land plots, tax regulation of land use it is proposed to levy a tax in a fivefold amount for a portion of the land plots granted to enterprises, institutions and organizations (except agricultural land) exceeding the standards of land allotment. In the case of the excess of establishing territory for enterprises, institutions and organizations and refusal to pay increased tax, it is possible to optimize the land use by means of an equivalent exchange.
Based on the results of the conducted studies it was established that when determining the area of a land plot for an industrial enterprise, the main technical characteristic is its capacity. Modelling is carried out on the basis of data on typical sizes of land plots and enterprise capacities.
It is established that a linear regression reliably approximates the dependence of the area on the capacity of the enterprise according to calculations. A detailed analysis shows that for low-capacity enterprises their area will be more reliably determined by non- linear dependence.

Keywords: modeling, linear approximation, least squares method, correlation dependence, regression equation, mean square error.

Introduction

In modern conditions, the problem of finding justified approaches aimed at achieving sustainable development of urban land use becomes extremely urgent. In Ukraine, as in many post-Soviet countries of Eastern Europe, the transition to market relations has led to a change in production technologies, a reduction in the capacity or the termination of the functioning of industrial enterprises within settlements, but the parameters of land use remained unchanged. However, today, most of the especially large cities face the problem of lack of available land for its normal development. There are trends in the reduction of green zones and building compaction, etc.

Thus, a promising direction is the spatial ordering of urban areas by rationalizing the land use of industrial enterprises. The optimization of urban space by redistributing land is proposed in (De Moor, 2015; Drees, 2002; Giovarelli & Bledsoe, 2001). Thus there is a need to develop an approach that would allow to determine the excess land area of existing industrial enterprise.

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1. Materials and methods

Modeling the optimal ratio between the capacity of enterprise and its production facilities in determining the excess area

The definition of the normative area of industrial enterprise land plot is proposed to perform in the following order:

1. Selection of initial data, namely information on enterprises that use their territories rationally and efficiently and for their intended purpose and have project documentation produced in accordance with the requirements of the current legislation and contains a technical justification for the required area of the land plot;
2. Finding a mathematical model for determining the area of industrial enterprise land plot;
3. Accuracy assessment of the results.

Based on the results of the established sizes of normative land plots, tax regulation of land use it is proposed to levy a tax in a fivefold amount for a portion of the land plots granted to enterprises, institutions and organizations (except agricultural land) exceeding the standards of land allotment. In the case of the excess of establishing territory for enterprises, institutions and organizations and refusal to pay increased tax, it is possible to optimize the land use by means of an equivalent exchange (Malashevskyi & Bugaienko, 2016).

Table 1. Typical sizes of land plots of Ukrainian bakery enterprises

Capacity of the enterprise, tons/day	The land plot area, m^2
135	18 000
100	17 000
65	16 000
45	10 000
30	9000
20	7000
10–3	5000–3000

2. Linear approximation of the optimal ratio between the capacity of an enterprise and its production areas

Based on the results of the conducted studies it was established that when determining the area of a land plot for an industrial enterprise, the main technical characteristic is its capacity (Malashevskyi & Melnyk, 2016). Modeling is carried out on the basis of data on typical sizes of land plots and enterprise capacities. In this case, the objects of the food industry are considered due to lack of the need for further justification for the size of the warehouses area for storage of raw materials and finished products (Table 1) (Malashevskyi & Gorpinich, 2014).

To determine the dependence of the land plot area (y – variable) on the capacity (x – regressor) of the industrial enterprise, it is proposed to use the linear regression model:

$$y = k_1 + k_2 x. \tag{1}$$

To determine its parameters using the method of least squares, we use the following formulas:

$$k_2 = \frac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)\left(y_i - \bar{y}\right)}{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}; \tag{2}$$

$$k_1 = \bar{y} - k_2 \bar{x}, \tag{3}$$

where $\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$ – is the selective average factor (enterprise capacity); $\bar{y} = \frac{\sum_{i=1`}^{n} y_i}{n}$ – is the selective average of the indicator (the area of the land plot); x_i, y_i $i = 1, 2, \ldots, n$ – are the current values of the factor and indicator, respectively; n – is the number of observations (sample size).

The initial data and the results of intermediate calculations are presented in Table 2.

Table 2. Estimation of linear regression parameters by least squares

No	1	2	3	4	5	6	7	8	Σ	Mean
X_i	135	100	65	45	30	20	10	3	308	51
Y_i	18 000	17 000	16 000	10 000	9000	7000	5000	3000	68 000	10 625
$X_i - X_{mean}$	84	49	14	–6	–21	–31	–41	–48	0	
$Y_i - Y_{mean}$	7375	6375	5375	–625	–1625	–3625	–5625	–7625	0	
$(X_i - X_{mean})*(Y_i - Y_{mean})$	619 500	312 375	75 250	3750	34 125	112 375	230 625	366 000	1 754 000	
$(X_i - X_{mean})^2$	7056	2401	196	36	441	961	1681	2304	15 076	

Then, in accordance with the k_1 and k_2 defined by formulas (2) and (3) we obtain a linear regression model (1):

$$y^* = 4691.463 + 116.344x.$$

In order to assess the reliability of the correlation dependence between the capacity of the enterprise and its area, we perform the following calculations. Let's define the mean squared errors (Table 3):

$$\left.\begin{aligned} m_x &= \sqrt{\frac{[\upsilon_x^2]}{n-1}} \\ m_y &= \sqrt{\frac{[\upsilon_y^2]}{n-1}} \end{aligned}\right\}.$$

As a result, we obtain:

$$\left.\begin{aligned} m_x &= \sqrt{\frac{15\,076}{7}} = 46.408 \\ m_y &= \sqrt{\frac{229\,875\,000}{7}} = 5730.557 \end{aligned}\right\}.$$

The empirical correlation coefficient will be:

$$r_{xy} = \frac{[\upsilon_x \upsilon_y]}{(n-1)m_x m_y};$$

$$r_{xy} = \frac{1754000}{7 \times 46.408 \times 5730.557} = 0.94.$$

The mean square error of the correlation coefficient is:

$$m_r = \frac{1 - r_{xy}^2}{\sqrt{n}};$$

$$m_r = \frac{1 - 0.94^2}{\sqrt{8}} = 0.040.$$

The presence of correlation dependence is determined by $r \geq t \cdot m_t$. With a confidence probability of p = 0.95 from the tables of the Student's distribution for n–1 = 7, we get:

$$0.77 > 2.36 \times 0.040$$

or

$$0.77 > 0.094.$$

To determine the functional relation between x and y we calculate the regression coefficient as follows:

$$\rho_{y/x} = r_{xy}\frac{m_y}{m_x};$$

$$\rho_{y/x} = 0.94\frac{5730.557}{46.408} = 116.344.$$

Root-mean-square error of the regression coefficient:

$$m_{\rho_{y/x}} = m_r\frac{m_y}{m_x};$$

$$m_{\rho_{y/x}} = 0.040\frac{5730.557}{46.408} = 4.901.$$

According to preliminary calculations, it is determined that the existing correlation dependence r = 0.94 ≈ 1.0, is approximated by straight-line function. Since the data are taken from the normative documents obtained from the results of experimental evaluations or from the available areas of existing industrial enterprises, they can be attributed to the technical measurements characterized by confidence at p = 0.90. The regression coefficient by probabilistic analysis is sufficiently reliable at the assumed confidence level of p = 0.90, since

$$\rho_{y/x} \geq t_\beta m_{\rho_{y/x}};$$

$$116.344 > 9.313,$$

where t_β = 1.90 are determined from tables of the Student's distribution with confidence probability p = 0.90 and n–1 = 7.

The regression equation is determined by the formula:

$$y_з^* = \bar{y} - \rho_{y/x}(x_i - \bar{x})$$

or

$$y_i^* = 10\,625 + 116.344(x_i - 51),$$

i.e.

$$y_i^* = 4691.463 + 116.344x_i. \quad (4)$$

Table 3. Correlation

X	y	υ_x	υ_y	$\upsilon_x\,\upsilon_y$	υ_x^2	υ_y^2
3	3000	–48	–7625	366 000	2304	58 140 625
10	5000	–41	–5625	230 625	1681	31 640 625
20	7000	–31	–3625	112 375	961	13 140 625
30	9000	–21	–1625	34 125	441	2 640 625
45	10 000	–6	–625	3750	36	390 625
65	16 000	14	5375	75 250	196	28 890 625
100	17 000	49	6375	312 375	2401	40 640 625
135	18 000	84	7375	619 500	7056	54 390 625
				1 754 000	15 076	229 875 000

Table 4. Estimation of the linear approximation accuracy

No.	x	Y	y^*	υ_{y^*}	$\upsilon_{y^*}^2$	y^*_{min}	y^*_{max}
1	3	3000	5040.5	–2040.5	4 163 619.1	509.0	9572.0
2	10	5000	5854.9	–854.9	730 857.1	1323.4	10 386.4
3	20	7000	7018.3	–18.3	336.4	2486.9	11 549.8
4	30	9000	8181.8	818.2	669 485.6	3650.3	12 713.2
5	45	10 000	9926.9	73.1	5338.2	5395.5	14 458.4
6	65	16 000	12 253.8	3746.2	14 033 909.5	7722.3	16 785.3
7	100	17 000	16 325.8	674.2	454 479.5	11 794.4	20 857.3
8	135	18 000	20 397.9	–2397.9	5 749 847.9	15 866.4	24 929.4
Σ				0.0	25 807 873.4		

By regression Eq. (4), we calculate the value of the function, depending on the value of the enterprise capacity (Table 4).

Let's plot the regression dependence graph (Figure 1).

To estimate the accuracy of the approximation, let's determine the deviations of the calculated ordinates (Table 4):

$$\upsilon_{y^*} = y - y^*$$

and

$$[\upsilon_{y^*}^2] = 25\ 807\ 873.$$

Root-mean-square error of the regression:

$$m_y = \sqrt{\frac{[\upsilon_{\rho y/x}^2]}{n-1}};$$

$$m_y = \sqrt{\frac{25\ 807\ 873}{7}} = 1920.11.$$

Extreme admissible deviation is defined as follows:

$$\Delta^*_{\rho y/x} = \pm t_\beta m_{\rho_{y/x}}$$

or

$$\Delta^*_{\rho y/x} = |2.36 \times 1920.11| = |4531.47|.$$

Thus

$$y^*_{i\,\min} = y^*_i - 4531.47;$$

$$y^*_{i\,\max} = y^*_i + 4531.47.$$

According to Table 4 the maximum error of approximation is $\upsilon_{y^*} = +3746.2$.

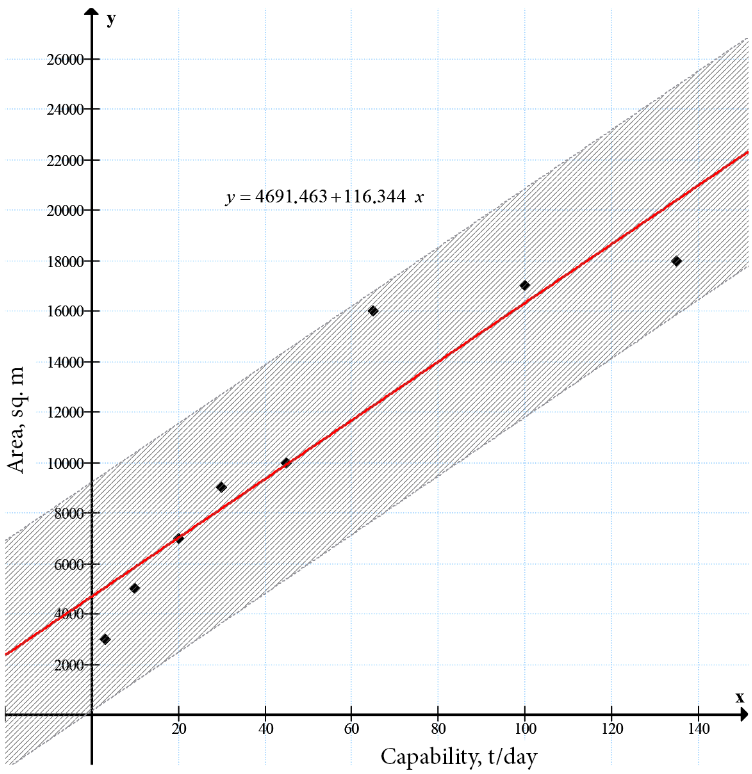

Figure 1. Graph of linear regression dependence

Since $\upsilon_y < \Delta_{\rho_{y/x}}$ $(+3746.2 < 4531.47)$, then the linear approximation of dependence of the area on the capacity of the enterprise is reliable. This is confirmed by the graph (Figure 1). By the extreme deviation $\pm\Delta^*_{\rho_{y/x}}$ let's construct the field of possible deviations of the areas depending on the capacity of enterprises according to Table 4 (Figure 1).

By calculations results, the equations of a straight line with the confidence intervals are obtained, from which it is possible to reasonably calculate the over-standard area of an industrial enterprise for further taxation or use for other more important problems of the local community.

It is established that a linear regression reliably approximates the dependence of the area on the capacity of the enterprise according to calculations. A detailed analysis of the graph (Figure 1) shows that for low-capacity enterprises their area will be more reliably determined by non- linear dependence.

3. Parabolic approximation of the optimal ratio between the capacity of the enterprise and its production areas

Let's calculate the correlation dependence of the n-th degree polynomial by the Chebyshev method. Let's assume the model of parabolic relation between the variables x and y express it as follows:

$$y = k_1 + k_2 x + k_3 x^2 + k_4 x^3 + \ldots + k_n x^{n-1}, \quad (5)$$

where n – is the exponent of the terms number in the expansion of the function, which is equal to the number of required parameters k in the presence of reliable approximation.

The solution to the problem is to optimally determine the number of parameters k of function (5) for $[p\upsilon^2] = \min$.

At the first stage, it is advisable to determine the approximate values of the parameters k_i^0. According to Table 2 we get:

$$\left.\begin{aligned} k_2^0 &= \frac{(y_n - y_1)}{(x_n - x_1)} = \frac{1.5}{13.2} = +0.114 \\ k_1^0 &= y_0 - k_2^0 x_0 = 0.971 - 0.114 \times 4.400 = +0.470 \\ k_3^0 &= \frac{(y_0 - k_1^0 - k_2^0 x_0)}{x_0^2} = \\ &\frac{(0.971 - 0.470 - 0.114 \times 4.400)}{4.400^2} = -0.00005 \end{aligned}\right\},$$

where $x_0 = [x]/n$; $y_0 = [y]/n$; n – is the number of objects on which the dependency is defined.

The parametric correction equation for a parabola of the n-th degree is determined by the formula:

$$\upsilon_э = \tau_1 + x_i \tau_2 + x_i^2 \tau_3 + x_i^3 K_4 + \ldots + x_i^{n-1} K_n + l_i,$$

where $\tau_i = k_i - k_i^0$.

When calculating the coefficients of normal equations, it is convenient to reduce the value of x_i (Table 5) by the formula:

$$x_i = X_i \cdot 10^{-1}; \; y_i = Y_i \cdot 10^{-4}. \quad (6)$$

Let's define the system of normal equations from the recalculated coordinates of x_i:

$$\left.\begin{aligned} N_{11}\tau_1 + N_{12}\tau_2 + N_{13}\tau_3 + N_{14}k_4 + N_{15}k_5 + L_1 = 0 \\ N_{21}\tau_1 + N_{22}\tau_2 + N_{23}\tau_3 + N_{24}k_4 + N_{25}k_5 + L_2 = 0 \\ N_{31}\tau_1 + N_{32}\tau_2 + N_{33}\tau_3 + N_{34}k_4 + N_{35}k_5 + L_3 = 0 \\ N_{41}\tau_1 + N_{42}\tau_2 + N_{43}\tau_3 + N_{44}k_4 + N_{45}k_5 + L_4 = 0 \\ N_{51}\tau_1 + N_{52}\tau_2 + N_{53}\tau_3 + N_{54}k_4 + N_{55}k_5 + L_5 = 0 \end{aligned}\right\}, \quad (7)$$

where $N_{11} = n$; $N_{12} = [x]$; $N_{13} = [x^2]$; $N_{14} = [x^3]$; $N_{22} = [x^2]$; $N_{23} = [x^3]$; $N_{24} = [x^4]$; $N_{34} = [x^5]$; $N_{44} = [x^6]$; $L_1 = [l]$; $L_2 = [xl]$; $L_3 = [x^2 l]$; $L_4 = [x^3 l]$.

The free terms of the parametric equations of corrections l_i are calculated from:

$$l_i = k_1^0 + k_2^0 x_i + k_3^0 x_i^2 - y_i.$$

Table 5. Calculation of the normal equations coefficients

	x'	y	x^2	x^3	x^4	x^5	x^6	x^7	x^8
1	0.3	0.3	0.090	0.027	0.008	0.002	0.001	0.000	0.000
2	1	0.5	1.000	1.000	1.000	1.000	1.000	1.000	1.000
3	2	0.7	4.000	8.000	16.000	32.000	64.000	128.000	256.000
4	3	0.9	9.000	27.000	81.000	243.000	729.000	2187.000	6561.000
5	4.5	1.0	20.250	91.125	410.063	1845.281	8303.766	37 366.945	168 151.254
6	6.5	1.6	42.250	274.625	1785.063	11 602.906	75 418.891	490 222.789	3 186 448.129
7	10	1.7	100.000	1000.000	10 000.000	100 000.000	1 000 000.000	10 000 000.000	100 000 000.000
8	13.5	1.8	182.250	2460.375	33 215.063	448 403.344	6 053 445.141	81 721 509.398	1 103 240 376.879
Σ	40.8	8.5	358.840	3862.152	45 508.196	562 127.534	7 137 961.798	92 251 415.133	1206601794.262
Σ/n	5.829	1.214							

Using the data in Table 5 and 6, we obtain a system of normal equations:

$$\left.\begin{array}{l} 8\tau_1 + 40.8\tau_2 + 358.84\tau_3 + 3862.15k_4 + \\ 45\,508.20k_5 - 0.071 = 0 \\ 358.84\tau_2 + 3862.15\tau_3 + 45\,508.20k_4 + \\ 562\,127.53k_5 - 0.613 = 0 \\ 508.20\tau_3 + 562\,127.53k_4 + 7\,137\,961.80k_5 + \\ 13.889 = 137\,961.80k_4 + \\ 92\,251\,415.13k_5 + 341.644 = 0 \\ 1\,206\,601\,794.26k_5 + 5690.411 = 0 \end{array}\right\}.$$

At the first stage of approximation. we solve the normal equations for determining the parameters k_1, k_2, k_3. For this in the system of Eqs (7) we determine the coefficients $N_{11}, \ldots, N_{33}, L_1, L_2, L_3$. We solve the system of normal equations according to the Gaussian scheme and determine the corrections τ_1, τ_2, τ_3.

To determine the number of approximation model parameters by the n-th degree parabola by the method of Chebyshev. the mean square errors mi and values $[\upsilon^2]_i$ are calculated by the formulas:

$$\left[\upsilon^2\right]_2 = \left[ll\right] - \frac{L_1}{N_{11}} L_1 - \frac{L_2^{(1)}}{N_{22}^{(1)}} L_2^{(1)};$$

$$\left[\upsilon^2\right]_3 = \left[\upsilon^2\right]_2 - \frac{L_3^{(2)}}{N_{33}^{(2)}} L_3^{(2)};$$

$$\left[\upsilon^2\right]_4 = \left[\upsilon^2\right]_3 - \frac{L_4^{(3)}}{N_{44}^{(3)}} L_4^{(3)};$$

$$m_i = \sqrt{\frac{[\upsilon^2]_i}{n-i}}.$$

As a result, the values: $[\upsilon^2]_2 = 0.260$, $m_2 = 0.208$, $[\upsilon^2]_3 = 0.053$, $m_3 = 0.117$, $[\upsilon^2]_4 = 0.052$, $m_4 = 0.114$, $[\upsilon^2]_5 = 0.048$, $m_3 = 0.127$ were obtained.

Since for certain values the inequality:

$$m_5 > m_4.$$

is satisfied, then the calculations were completed by determining the corrections of five parameters.

As a result, the values of the corrections: $\tau_3 = +0.026$; $\tau_2 = +0.031$; $\tau_1 = -0.175$; $k_4 = -0.004$, $k_5 = +0.0001$ are obtained.

Let's calculate the aligned values of the coefficients according to the following formula:

$$k_i = k_i^0 + \tau_i.$$

Let's get the values:

$k_1 = +0.470 - 0.175 = +0.295$;

$k_2 = +0.114 + 0.031 = +0.145$;

$k_3 = -0.00005 + 0.026 = +0.026$;

$k_4 = -0.004$;

$k_5 = +0.0001$.

According to (5) and (6) the equation of parabolic approximation (Figure 2) is:

$$y = 2952.969 + 144.917x + 2.604x^2 - 0.0405x^3 + 0.0001x^4.$$

In practical use of the model. an inequality:

$$y_i - tm_A \le y_i^* \le y_i + tm_A$$

is used.

Root-mean-square error of the approximation:

$$m_A = \sqrt{\frac{[\upsilon^2]}{n-1}}.$$

Then, according to the calculations given in Table 7 we obtain:

$$m_A = \sqrt{\frac{4\,811\,135.526}{7}} = 829.039.$$

The field of permissible deviations of the enterprise areas is shown in Figure 2. Since with a confidence $p = 0.9$ and $n–1 = 7$, in accordance with the Student's distribution $t_\beta = 1.90$, then

$$t_\beta m_\Delta = 1.90 \times 829.039 = 1575.173 \text{ m}^2.$$

Table 6. Calculation of coefficients l_i and L_i ($k_1^0 = +0.470$; $k_2^0 = +0.114$; $k_3^0 = -0.00005$)

n	k_1^0	$k_2^0 x_i$	$k_3^0 x_i^2$	$-y_i$	l_i	$l_i\, l_i$	xl	$X^2 l$	$x^3 l$	$X^4 l$
1	0.47	0.0342	0.000	–0.3	0.204	0.042	0.061	0.018	0.006	0.002
2	0.47	0.114	0.000	–0.5	0.084	0.007	0.084	0.084	0.084	0.084
3	0.47	0.228	0.000	–0.7	–0.002	0.000	–0.004	–0.007	–0.014	–0.029
4	0.47	0.342	0.000	–0.9	–0.088	0.008	–0.263	–0.788	–2.364	–7.092
5	0.47	0.513	0.001	–1.0	–0.016	0.000	–0.072	–0.324	–1.457	–6.556
6	0.47	0.741	0.002	–1.6	–0.387	0.150	–2.515	–16.346	–106.249	–690.618
7	0.47	1.14	0.005	–1.7	–0.085	0.007	–0.850	–8.500	–85.000	–850.000
8	0.47	1.539	0.009	–1.8	0.218	0.048	2.945	39.751	536.639	7244.620
Σ					–0.071	0.261	–0.613	13.889	341.644	5690.411

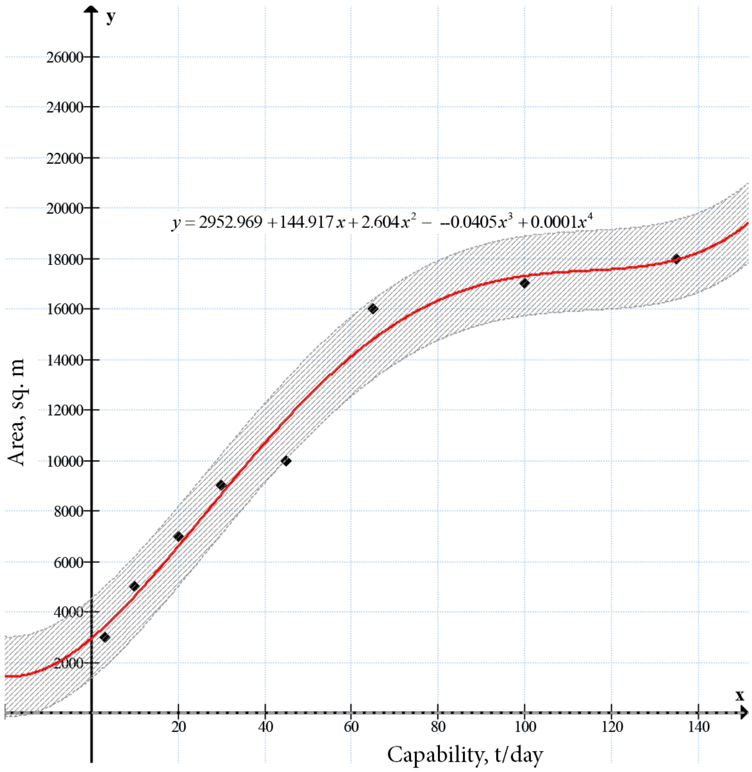

Figure 2. Graph of parabolic regression dependence

Table 7. Estimation of the approximation accuracy by the Chebyshev method

No.	X	K_1	K_2x	K_3x^2	k_4x^3	k_5x^4	y^*	υ_y^*	υ_y^{*2}
1	3	2952.969	434.751	23.436	−1.095	0.012	3410.073	−410.073	168 159.604
2	10	2952.969	1449.169	260.397	−40.544	1.437	4623.428	376.572	141 806.502
3	20	2952.969	2898.337	1041.587	−324.350	22.992	6591.536	408.464	166 843.197
4	30	2952.969	4347.506	2343.570	−1094.681	116.397	8665.762	334.238	111 715.006
5	45	2952.969	6521.258	5273.033	−3694.547	589.261	11 641.975	−1641.975	2 696 083.117
6	65	2952.969	9419.595	11 001.761	−11 134.321	2565.142	14 805.146	1194.854	1 427 675.293
7	100	2952.969	14 491.685	26 039.671	−40 543.727	14 370.038	17 310.637	−310.637	96 495.073
8	135	2952.969	19 563.775	47 457.300	−99 752.772	47 730.171	17 951.443	48.557	2357.735
Σ								0.000	4 811 135.526

Conclusions

Two models are proposed, which allow to determine the area of the land plot of an industrial enterprise, for which the norms of the land allotment, in fact, are exceeded.

The analysis of the mean square approximation errors of linear and parabolic model shows that the parabolic model more reliably determines the dependence of the area on the capacity of the enterprise and leads to a significant decrease in the field of permissible deviations of the area, which justifies the practical significance of the resulting parabolic model.

Author Contributions

Mykola Malashevskyi conceived the study and were responsible for the design and development of the data analysis. Natalia Kuzin and Maria Malanchuk were responsible for data collection and analysis. Elena Bugaenko and Alena Palamar were responsible for data interpretation.

Disclosure Statement

Authors have no competing financial, professional, or personal interests from other parties.

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