Logistics of raw materials supply for the ferroalloy industry

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Abstract
The problems of arranging traffic of material flows in the framework of micrologic system of the ferroalloy plant are studied in the paper. For the effective interaction of enterprises with the transport operators, the research task of the necessary car number for the delivery of raw materials and fuel should be fulfilled. The fulfillment of this task includes time scheduling of car stay on the house track of enterprise, which is the constituent part of the overall time of car cycle in the delivery route. On the basis of the statistical analysis and collinearity test of the initial parameters, the most

important of them were selected. The regression models were created and analyzed; the most adequate model with the minimum approximation error was selected. The suggested support system of decision making concerning determination of necessary cars number for delivery to the ferroalloy plant is based on the results of time scheduling of car stay on the house track with the help of the developed model.
Key words: LOGISTICS, FERROALLOY INDUSTRY, HOUSE TRACK, RAILWAY TRANSPORT, TRANSPORT OPERATOR, MATERIAL FLOW, INFORMATIONAL FLOW, THE INTENSITY OF UNLOADING, REGRESSION MODEL, MICROLOGIC SYSTEM

Introduction

The considerable quantity of agglomerate, ore, coal, limestone and other mineral resources pass to the ferroalloy plants every day. For delivery, the railway transport is used. The successful arrangement of material, informational and financial flows in the “suppliers - railway – ferroalloy plant – consumers” system is based on the logistic approach (Bauersoks & Kloss, 2001; Skovronek & Sariush-Vol’skiy, 2004); moreover, it is a part of social-economic stability of the particular area.

The effective interaction with transport operators is possible on the basis of determination of necessary car number for delivery of raw materials and fuel.

The part of overall time of car cycle in the delivery route is accounted for the raw materials supply, the part is accounted for movement and processing of the rail transport in the trunk railway stations, and part is accounted for the ferroalloy plants. The calculation of the last part is a very complex task.

The paper (Turpak and Grytsay, 2011) is devoted to the task of planning of the cars use. The investigations of dependence of time of the car stay on the house track of the metallurgical enterprise on the most important factors are conducted by the example of the metallurgical enterprise specializing in production of cast iron, steel and rolled ferrous products. The obtained regression model allows planning of the transport process and accordingly establishing of car cycle time in the delivery route and the necessary car number of the working track.

The absence of excessive number of cars cuts the costs for their servicing and increase the efficiency of their transporting.

For economic effect, the investigation must be integrated into the process model of functioning of the metallurgical enterprise logistic system (Hubenko, Derhausov & Nefodova, 2004; Parunakyan & Gusev, 2005).

Researches results

Statistical processing of output data

The length of cars stay in the metallurgical enterprise is determined by the temporal values of the cars delivery to the connecting station of railway trunks. It depends on the transport-technological process of cars treatment, technology of the materials handling and meteorological conditions. These processes depend on the goods properties and equipment of load points.

Depending on the goods type, the cars, which pass to the metallurgical plants, are divided into the following groups: container yard (CY), underground bunkers, limestone warehouse, inside storage of charging materials No 1 (CS ins.), outside storage of charging material No 1 (CS out.), charge workshop section No 2 (CWS 2), charge workshop section No 3 (CWS 3), charge workshop section No 4 (CWS 4).

The statistical data of the observations with different goods types to 8 load points in the period from November, 2011 to June, 2014 are presented in Table 1.

Table 1. The statistical data of the observations in the period from November, 2011 to June, 2014

No	Variable	Indexes	Range of values
1	Lay-over	y	11.41 – 24.56
2	CY	x_1	14 – 63
3	Undergr. bunkers	x_2	0 – 23
4	Limestone warehouse	x_3	0 – 53
5	CS 1 ins.	x_4	72 – 229
6	CS 1 out.	x_5	13 – 130
7	CWS 2	x_6	18 – 57

8	CWS 3	x_7	32 – 95
9	CWS 4	x_8	142 – 308
10	Agglomerate	x_9	104 – 241
11	Limestone	x_{10}	0 – 53
12	Coal	x_{11}	0 – 12
13	Electrode paste	x_{12}	1 – 9
14	Quartzite	x_{13}	37 – 128
15	Coke	x_{14}	33 – 220
16	Container	x_{15}	14 – 63
17	Ore	x_{16}	72 – 239
18	Shaving	x_{17}	1 – 16
19	Precipitation days	x_{18}	1 – 9
20	Number of days with t<0	x_{19}	0 – 10

Let us determine the main statistical characteristics: sample average, standard deviation of empirical distribution and coefficient of variations. The results of the main statistical characteristics of sample calculations are presented in Table 2.

Table 2. The main statistical characteristics

Variables and their characteristics		Property value	Variables and their characteristics		Property value	Variables and their characteristics		Property value
y	$\bar{y}$ σ v,%	15.216 3.193 20.986	x_7	$\bar{y}$ σ v,%	63.125 17.099 27.087	x_{14}	$\bar{y}$ σ v,%	126.917 44.602 35.142
x_1	$\bar{y}$ σ v,%	39.292 15.988 40.690	x_8	$\bar{y}$ σ v,%	216.375 39.906 18.443	x_{15}	$\bar{y}$ σ v,%	39.083 15.839 40.525
x_2	$\bar{y}$ σ v,%	5.125 6.110 119.3	x_9	$\bar{y}$ σ v,%	165.333 34.039 20.588	x_{16}	$\bar{y}$ σ v,%	147.542 42.358 28.709
x_3	$\bar{y}$ σ v,%	23.375 11.661 49.888	x_{10}	$\bar{y}$ σ v,%	23.292 11.782 50.586	x_{17}	$\bar{y}$ σ v,%	8.375 4.168 49.771
x_4	$\bar{y}$ σ v,%	136.792 34.554 25.261	x_{11}	$\bar{y}$ σ v,%	2.500 2.719 108.748	x_{18}	$\bar{y}$ σ v,%	4.667 2.036 43.627
x_5	$\bar{y}$ σ v,%	69.417 27.311 39.344	x_{12}	$\bar{y}$ σ v,%	4.958 1.922 38.762	x_{19}	$\bar{y}$ σ v,%	2.583 3.322 128.597
x_6	$\bar{y}$ σ v,%	37.458 10.726 28.634	x_{13}	$\bar{y}$ σ v,%	70.333 23.401 33.272			

The testing for normality of the investigated factors classification is carried out by criterion of U deviation range. According to (Lashchenykh, Kuzkin & Grytsay, 2011), the rejection lines of the criteria $U_1(\alpha) = 3.34$ i $U_2(\alpha) = 4.71$ are determined for $n = 24$ i $\alpha = 0.05$.

As $U_1(\alpha) = 3.34 < U = 4.118 < U_2(\alpha) = 4.71$, we can conclude that the final value satisfies the standard distributive law.

In order to determine the presence of anomalous values, let us put the statistical data in the order of increasing.

For the purpose of significance test of the suspect experimental data, let us use the Chauvenet criterion. According to this criterion, the element x_i with the volume n is an outlier if the probability of its deviation from the average values is no more than $1 / (12 \cdot n)$. We obtain the calculations for all sample units. The results of calculations are presented in Table 3.

The outliers are changed into the average values of corresponding characteristics for the further analysis.

Table 3. The results of outlier detection in the sample

No	Variable	Indexes	Range of values	Outliers
1	Lay-over	y	11.41 – 16.84	21.17; 21.67; 24.56
2	CY	x_1	14 – 63	–
3	Undergr. bunkers	x_2	0 – 8	14; 15; 16; 23
4	Limestone warehouse	x_3	0 – 42	53
5	CS 1 ins.	x_4	72 – 190	229
6	CS 1 out.	x_5	13 – 130	–
7	CWS 2	x_6	18 – 57	–
8	CWS 3	x_7	32 – 95	–
9	CWS 4	x_8	142 – 308	–
10	Agglomerate	x_9	104 – 241	–
11	Limestone	x_{10}	0 – 42	53
12	Coal	x_{11}	0 – 6	12
13	Electrode paste	x_{12}	1 – 9	–
14	Quartzite	x_{13}	37 – 92	118; 128
15	Coke	x_{14}	33 – 220	–
16	Container	x_{15}	14 – 63	–
17	Ore	x_{16}	72 – 239	–
18	Shaving	x_{17}	1 – 16	–
19	Precipitation days	x_{18}	1 – 9	–
20	Number of days with t<0	x_{19}	0 – 10	–

Let us change the variation range of values of numerical characteristic into another range, which is more convenient to use for the data of analytic algorithms, by normalization. Moreover, the variation ranges of different values are coordinated.

If the data outliers, which exceed to the typical dispersion, are not frequent, they determine the scale of normalization according to the previous formula. It will lead to the concentration of the main body of normalized variable x'_i near zero $|x'_i| \ll 1$. In this case, it is more reliable to use the static characteristics of data, namely, average value and dispersion, for normalization. The transformations are calculated for each value of x'_i:

$$x'_i = \frac{x_i - x_{aw}}{\sigma_x} \quad (1)$$

The sample with normalized values is presented in Table 4.

Table 4. The sample unit with normalized values

No	Variable	Indexes	Range of values
1	Lay-over	y	-1.19 –2.93
2	CY	x_1	-1.58 – 1.48
3	Undergr. bunkers	x_2	-0.84 – 2.93

4	Limestone warehouse	x_3	-2.0 – 2.54
5	CS 1 ins.	x_4	-1.88 – 2.67
6	CS 1 out.	x_5	-2.07 – 2.22
7	CWS 2	x_6	-1.81 – 1.82
8	CWS 3	x_7	-1.82 – 1.86
9	CWS 4	x_8	-1.86 – 2.3
10	Agglomerate	x_9	-1.8 – 2.22
11	Limestone	x_{10}	-1.98 – 2.52
12	Coal	x_{11}	-0.92 – 3.49
13	Electrode paste	x_{12}	-2.06 – 2.1
14	Quartzite	x_{13}	-1.42 – 2.46
15	Coke	x_{14}	-2.11 – 2.09
16	Container	x_{15}	-1.58 – 1.51
17	Ore	x_{16}	-1.78 – 2.16
18	Shaving	x_{17}	-1.77 – 1.83
19	Precipitation days	x_{18}	-1.8 – 2.13
20	Number of days with t<0	x_{19}	-0.78 – 2.23

Concept model formation

Let us calculate the correlation matrix that will bring an opportunity to determine the negligible and multicollinear factors. It is known that the factors with coefficient of correlation $r(yx_i) \leq 0.1$ are considered negligible and should be excluded from the further observation. The collinear factors x_i are the factors with the constraint $r(x_i x_m) \geq 0.8$. In this case, one of the factors should be excluded from the observation, but the factor with closer connection to final value is kept. The computations of matrix correlative coefficients are carried out in STATISTICA program by the Multiple Regression Results method. The results of calculations are presented in Table 5.

In the similar way, the matrix computations of correlative coefficients for the sample with changed anomalous values to the average ones and for the normalized sample are conducted.

Table 5. The matrix of correlative coefficients for primary sampling

Values	y	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}	x_{16}	x_{17}	x_{18}	x_{19}
y	1.00	0.17	0.74	0.40	0.59	0.57	0.30	0.25	0.42	0.66	0.40	0.18	-0.18	0.36	0.53	0.18	0.25	0.18	0.09	0.72
x_1		1.00	0.37	0.07	0.39	0.38	0.20	0.32	0.04	0.37	0.07	-0.06	0.08	0.34	0.15	1.00	0.16	0.28	-0.44	0.10
x_2			1.00	0.22	0.67	0.64	0.28	0.28	0.61	0.65	0.22	0.01	-0.15	0.66	0.59	0.38	0.34	0.32	-0.18	0.33
x_3				1.00	0.23	0.22	-0.29	-0.35	0.12	0.16	1.00	0.13	-0.12	0.23	0.24	0.07	-0.28	0.29	0.11	0.05
x_4					1.00	0.58	0.11	0.34	0.47	0.78	0.23	0.12	0.17	0.46	0.46	0.39	0.45	0.50	-0.22	0.28
x_5						1.00	0.04	0.03	0.56	0.55	0.21	0.18	-0.24	0.61	0.89	0.38	0.02	0.31	-0.08	0.30
x_6							1.00	0.65	0.29	0.25	-0.29	0.25	0.01	0.09	0.05	0.22	0.62	0.24	-0.29	0.14
x_7								1.00	0.15	0.24	-0.34	0.02	0.33	0.08	-0.07	0.33	0.85	0.12	-0.09	0.26
x_8									1.00	0.62	0.12	0.35	-0.05	0.66	0.74	0.04	0.21	0.26	-0.17	0.04
x_9										1.00	0.16	0.26	-0.02	0.42	0.54	0.38	0.21	0.12	-0.30	0.50
x_{10}											1.00	0.12	-0.12	0.23	0.23	0.07	-0.27	0.29	0.12	0.05
x_{11}												1.00	0.18	0.03	0.38	-0.06	-0.10	0.15	-0.20	0.06
x_{12}													1.00	-0.14	-0.22	0.06	0.27	0.03	0.02	-0.23
x_{13}														1.00	0.53	0.33	0.05	0.30	-0.13	0.10
x_{14}															1.00	0.15	-0.09	0.26	-0.08	0.21
x_{15}																1.00	0.17	0.28	-0.44	0.11
x_{16}																	1.00	0.35	-0.06	0.05
x_{17}																		1.00	-0.30	-0.32
x_{18}																			1.00	0.14
x_{19}																				1.00

The Table 5 shows that x_{18} (precipitation days) is negligible factor. The multicollinear factors are x_1 and x_{15}, x_3 and x_{10}, x_5 and x_{14}, x_7 and x_{16}. We exclude x_1 (CY), x_{10} (limestone), x_{14} (coke) and x_{16} (ore).

The conceptual model for the primary sampling will be of the form:

$$y = f(x_2, \dots, x_9, x_{11}, \dots, x_{13}, x_{15}, x_{17}, x_{19}) \quad (2)$$

For the sample, where the outliers were changed onto the average values of corresponding characteristics, the negligible factors are x_1, x_2, x_7, x_8, x_{13}, x_{16}, x_{17}.

The multicollinear factors are x_3 and x_{10}, x_5 and x_{14}. We exclude the factors x_{10} and x_{14} and obtain the conceptual model:

$$y = f(x_3, \dots, x_6, x_9, x_{11}, x_{12}, x_{15}, x_{18}, x_{19}) \quad (3)$$

According to the matrix of coefficients correlation for the normalized sample, the negligible factor is x_{18}; multicollinear factors are x_1 and x_{15}, x_3 and x_{10}, x_5 and x_{14}, x_7 and x_{16}. x_1, x_{10}, x_{14} and x_{16} factors should be excluded.

We obtain the same conceptual model like for the primary sampling:

$$y = f(x_2, \dots, x_9, x_{11}, x_{12}, x_{13}, x_{15}, x_{17}, x_{19}) \quad (4)$$

The next stage is development of the regression model of the car stay time on the house track.

Development of the regression model

The calculation of linear regressional dependence for each conceptual model obtained by the analysis is carried out in STATISTICA system. The regression coefficients for each model is calculated. The value of every coefficient is determined according to Student's t-test, coefficient of correlation and determination, standard and ratio errors of approximation and the expected value of Fisher's F-test are also determined. The results of the calculations are presented in Table 6.

Thus, the equation of linear multi-regression for the primary sampling is of the form

$$\begin{aligned} y = 7.872 + 0.219x_2 + 0.087x_3 + 0.022x_4 + \\ +0.019x_5 + 0.108x_6 - 0.036x_7 + 0.009x_8 - \\ -0.02x_9 - 0.062x_{11} + 0.176x_{12} - 0.027x_{13} - \\ -0.022x_{15} - 0.001x_{17} + 0.582x_{19}) \end{aligned} \quad (5)$$

The equation for the sample with exchange of the anomalous observations into the average values is of the form

$$\begin{aligned} y = 9.668 + 0.08x_3 - 0.016x_4 + 0.022x_5 + \\ +0.071x_6 + 0.005x_9 - 0.225x_{11} - 0.023x_{12} - \\ -0.018x_{15} + 0.173x_{18} + 0.148x_{19}) \end{aligned} \quad (6)$$

According to the calculations, the equation of multi regression of sample with the normalized values does not have any intercept terms:

$$\begin{aligned} y = 0.419x_2 + 0.319x_3 + 0.24x_4 + 0.161x_5 + \\ +0.363x_6 - 0.19x_7 + 0.109x_8 - 0.213x_9 - \\ -0.053x_{11} + 0.106x_{12} - 0.199x_{13} - 0.107x_{15} - \\ -0.001x_{17} + 0.606x_{19}) \end{aligned} \quad (7)$$

Table 6. The results of the linear regressional model

Criterion of estimation (under the level of significance $\alpha = 0.05$)	Value
Fisher's F-test (F)	12.76
Table value of *Fisher's F-test* ($F_{tab.}$)	2.65
Coefficient of multivariable correlation (*R*)	0.976
Coefficient of multiple determination (R^2)	0.952
Standard error of regression estimation (σ)	0.071
Limit probability of hypothesis (*p*)	0.00029

Quality test of the regression dependence, significance of the equation and regression factors

In order to test the significance of regression equation and its sufficiency, Fisher's F-test is used as an output data. The results of calculation are compared with the table values, which are determined according to the freeness of bigger or smaller dispersion. In our case, the second sample does not meet the requirements $F = 1.46 < F_{tab} = 2.65$ of the sufficiency condition $F > F_{tab}$. Thus, this regression model is not sufficient.

The regression model is sufficient to the output data in the case when the expected value of the limit probability of hypothesis does not exceed the selected level of significance. According to the examined models with 0.05 level of sufficiency, the first and third models ($p = 0.00029 < 0.05$) are sufficient. The most qualitative model is the model for the third sample with a minimum error of approximation ($\sigma = 0.071$).

In order to test the significance of the regressional factors, let us use Student's t-test. If the expected value of the limit probability does not exceed the accepted level of significance 0.05, the factor is sufficient. The x_2 , x_3, x_6, x_{19} (p-level values are 0.0158, 0.0087, 0.0492, 0.0029 respectively) factors are sufficient for the first sample. x_3 and x_6 (with *p-level* 0.0321, 0.0395 respectively) are sufficient for the second sample. The x_2, x_3, x_6, x_{19} factors (with *p-level* 0.0158, 0.0087, 0.0492, 0.0029 respectively) are sufficient for the third sample.

In order to test the normalcy of distribution of residuals, let us develop the normal probability diagram of residuals for the third sample (Fig.1).

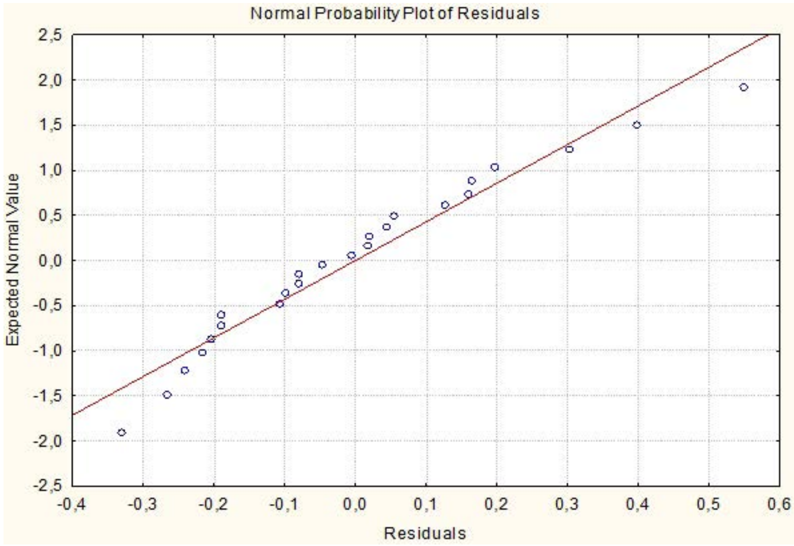

Figure 1. The diagram of residuals of sample regression with the normalized values

According to the analysis of residuals, it can be claimed that the regression model is well developed and the residuals of regression are of the normal distribution.

The support system of decision making on the subject of necessary car number determination for delivery process to the ferroalloy plant is based on the results of time scheduling of car stay on the house track by developed model.

Conclusion

1. The problems of arrangement of material flows in the “suppliers - railway – ferroalloy plant – consumers” system within the frameworks of micrologic system of ferroalloy plant were considered. It was established that the effective interaction with transport operators is possible under conditions of necessary car number for the supply of raw materials and fuel determination. Thus, an important research task is determination of time scheduling of the car stay on the house track of metallurgical plant that is the part of the overall time of car cycle in the delivery route.

2. As parameters of model of cars stay at the enterprise, the volums of cars passing to the points of the most intensive unloading (container yard, underground bunkers, limestone warehouse, inside and outside storage of the charging materials), the volumes of basic goods delivery (agglomerate, limestone, coal, electrode mass, quartzite, coke, ore, etc.), and the weather conditions (precipitations and environment temperature) were considered.

3. On the basis of statistical analysis and collinearity test, some parameters from the initial group were excluded. Three regression models were developed from sufficient parameters. Model parameters are the following: underground bunkers (x_2), limestone warehouse (x_3), inside storage of charging material No 1 (x_4), outside storage of the charging material No 1 (x_5), charge workshop section No 2 (x_6), charge workshop section No 3 (x_7), charge workshop section No 4 (x_8); the volumes of the basic goods delivery (agglomerate (x_9), coal (x_{11}), electrode mass (x_{12}), quartzite (x_{13}), container (x_{13}); and the weather conditions: precipitation days (x_{18}) and number of days with $t<0$ (x_{19}).

4. According to the examined models with 0.05 level of sufficiency, the first and third models ($p = 0.00029 < 0.05$) are sufficient. The most qualitative model is the model for the third sample with minimum error of approximation ($\sigma = 0.071$). In order to test the significance of regression factors, Student’s t-test for accepted level of significance 0.05 was used. In order to test the normalcy of distribution of residuals, the normal probability diagram of residuals for the third sample was developed which confirms the quality of regression model.

5. The decision support system on the subject of determination of necessary car quantity for delivery process to the ferroalloy plant was developed. It is based on the results of time scheduling of car stay on the house track by the developed model.

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