Modeling of Regional Limits to the Ferrous Scrap Prices Growth in Russia Based on the Auction Pricing*

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Abstract. One of the instruments of price policy at metallurgical plants in procurement of ferrous scrap is a differentiated approach in setting prices for scrap depending on the region of the country. For these purposes, the mathematical "Auction procurements" model based on the auction principle pricing was developed in order to assess the range of regional scrap prices of scrap stockists taking into account competition between scrap consumers. Construction of such a model will allow taking into account territorial imbalances of scrap offer and demand in the regions, costs of scrap transportation from supplier to consumer for price formation. The model allows estimating limits of growth of regional prices and inter-regional flows of scrap. The article presents the formal structure of the model, the algorithm of its implementation and the results of calculations. The proposed mathematical model implements a differentiated approach to formation of the regional scrap prices range, simulating a competitive activity for scrap collection markets of metallurgical enterprises taking into account market trends.

Keywords: computer modeling of limits price growth, decision making, ferrous scrap

1 Introduction

One of the instruments of price policy at metallurgical plants in procurement of ferrous scrap is a differentiated approach in setting prices for scrap depending on the region of the country [14]. When forming a pricing quotation for a region, decision-makers have to operate with a range of prices to get an idea of the price tolerance range and price point values as final results of the evaluation.

Point estimates of the scrap value do not show the boundaries of the price range as a decision-making area. In this connection, it is interesting to estimate boundaries of the price change interval. The market price of the scrap is formed as a result of negotiations between scrap producers and consumers so the price range may be considered as the area of intersection of interests of the seller and the

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buyer. The lower limit will correspond to the minimum price, at which the seller agrees to sell his goods, and the upper limit – to the maximum price, at which the buyer agrees to buy the goods. It is obvious that the transaction will take place if the price is within the range. Having information about the boundaries of the most likely price, the buyer and the seller have the instrument to justify their decisions and ensure more accurate price positioning corresponding to their expectations [6].

In view of the above, the aims of this research include analyzing the purchase prices for ferrous scrap and developing a regional scrap procurement model for Russian metallurgical companies.

As part of the research, the following objectives were achieved:

– a theoretical analysis of recent developments in mathware designed for calculating the purchase price range for ferrous scrap;
– a method was developed for compiling the range of regional scrap prices and for generating the regional scrap procurement model;
– a mathematical model was developed for procurement auctions that can help estimate the top regional price line for scrap based on consumer competition;
– a logical structure was developed for input and output data for modelling;
– a software package was developed.

2 Review of existing methods for price range determination

Among the most frequently used practical approaches to estimation of the price ranges, we can distinguish economical, statistical one based on the current prices level and technocratic approaches.

With the economic approach, the lower limit of the price is estimated by the seller as the price covering costs and allowing you to get a reasonable profit for this sector of the economy, and the upper limit would correspond to the minimum expected profit of the buyer. However, on the scrap metal market, which is a consumer market, this approach fails to work. Purchase prices in a region ranging from minimum to maximum are formed based on the purchase prices of metallurgical enterprises and are set on the customer's discretion [6].

The statistical approach determines price limits as the confidence interval of the mathematical expectation with unknown dispersion. The interval width characterizes the degree of possible proximity of the sample estimate of the mean scrap price in the region to an unknown value of the average of the universe parent population and is explained not by market conditions but by the random nature of the prices. It will depend on the prices in the region and the sample size, i.e., a wide interval may be obtained both for regions where the number of consumers purchasing scrap is small under low price dispersion, and for regions with large dispersion of mill prices because of a relatively large volume of the sample [1].

Within the framework of the approach based on the current price level, the price range is composed of the price sample values of comparable operations between the lower and the upper quartile of such range [15]. The values of the lower and upper quartiles are respectively minimum and maximum values of the price range. Commercial offers of companies are used as initial data for calculations; for purchasing scrap metal, these are regional prices for certain types of scrap set out by steelworks.

As a part of the technocratic approach, estimate of the price range is based on a mathematical model of a process or an object. Mathematical models represent schematic reflection of the influence impact of various factors on the price level. In [5, 7], the problem of modeling regional prices and inter-regional deliveries on the scrap market of the United States is considered. The prices for two grades of the ferrous scrap are calculated (low-residual scrap, a circulating scrap in the production activity of metallurgical enterprises and high-residual scrap, a depreciation scrap, its source is out of use steel products collected from local inhabitants) in each region of the US (that is, regional distribution of prices is considered). Distribution of the scrap for a particular user is determined on the basis of a logistic choice model based on the prices of scrap suppliers. This model takes into account the regional distribution of demand and offer of the scrap. In addition, the inter-regional flows of scrap metal and the sensitivity of the equilibrium values of prices to changes on the scrap market are assessed (taking into account appearance or exit from the market of major consumers, etc). The model proposed in that paper includes a number of assumptions that may not work on scrap markets of other countries: the assumed market model is perfect competition; a logistic choice model for the spatial distribution of scrap is used based on the idea of heterogeneity in the behavior of market agents [2, 3, 11, 12]; other assumptions include the model for determining ratio in consumption of scrap of the first and the second type; assumption on proportionality between the population of the region and volume of offer of the second scrap type in the region and the quadratic form of dependency of the scope of offer on the price of scrap. Moreover, a weak point of the model is the need for appropriate choice of the parameters (B, a) for each time period. Another drawback is that the model does not take into account seasonal variations in the scope of demand and offer of the scrap metal. Issues of the spatial pricing equilibrium are subject of many studies beginning with Hotelling's model [8]. The existence of equilibrium in formal spatial models was studied by Aspremont, Gabszewicz, Thisse [4], Palma et al. [2, 3, 11, 12], Sheppard, Haining, Plummer [13] and others.

To construct the interval estimation of scrap prices on the Russian market, the current price level and technocratic approaches can be used. In the approach based on the current price level, the price range will reflect the current situation on the scrap market. The use of mathematical models allows getting an alternative estimate of the price range taking into account factors inherent in the mechanism of the model. That is, the use of mathematical models allows excluding the impact of the irrational behavior of the players on the scrap market and allows obtaining justification of high or low prices of the scrap by regions.

The paper deals with the construction of interval estimation of price on the basis of a mathematical model. When forming the price range, the estimation of the lower boundary of the scrap price is suggested from the "export parity" principle for scrap producers on the basis of equality of prices on domestic and foreign markets. The price in the "export parity" mechanism is calculated as the minimum level of scrap prices, to which scrap stockists and sellers are oriented. The upper limit should reflect maximum price level, which a buyer (scrap consumer) could offer. In practice, when forming price quotations, scrap consumers are guided by the competition level existing in the region of scrap purchase. If the demand level is below or equal to the level of offer, prices are generally set at the lower limit. If demand exceeds offer, prices are growing as a result of competition between scrap consumers. The extent, to which a particular scrap consumer may increase prices, is modeled on an individual basis based on taking into account the average purchase price of scrap for a metallurgical plant, cost of delivery from the scrap stockist to the plant, terms of delivery proposed by scrap producers in other regions and demand level of the metallurgical plant. The authors developed a mathematical model of "Auction procurements" simulating the process of price competition of metallurgical enterprises for scrap volumes in the regions taking into account the factors described above. This approach has not been covered yet in published works of Russian and foreign researchers [9, 10].

3 Research Methodology

The mechanism of formation of maximum price level for scrap stockists simulates the process of competition for volumes of scrap between consumers and is based on scrap demand and offer ratio departing from the "export parity" prices for producers and taking into account delivery costs to consumers. The model includes a mechanism of interaction of prices of neighboring producers. In the course of iterative calculations, prices of scrap producers increase with some incremental step depending on the selected simulation parameters. The growth of price for a scrap producer will stop when the demand for its stock will be exhibited by a single user only. The criterion for stopping the iterative modeling process is the achievement of equilibrium in the market, i.e., the situation when for the majority of scrap producers the price growth stops. The price range for purchase of scrap by regions of the RF is determined as a range between the lower price level (the price calculated from the "export parity" principle), and the upper price level, the price of the "export parity" plus an allowance calculated by the "Auction procurements" model. The model also designs an optimal regional structure of scrap procurement for each scrap consumer at each price level from the point of view of his individual interests in the form of a list of scrap procures offering the most favorable purchase prices of scrap taking into account delivery costs.

Description of "Auction procurements" model and the modeling process. Initial data: n is the number of scrap producers; m is the number of consumers; V^{proc} is the volume of the scrap at the stock of the scrap producer, t; V^{dem} is the demand of the scrap consumer, t; freight rates between procurers and consumers;

freight rates between procurers; c_i^{EP} is the starting prices of producers, calculated by the "export parity" principle according to the formula:

$$c_i^{\mathrm{EP}} = \max_{1 \le k \le 5} \{\mathrm{CP}_k - \mathrm{T}_{i,k}\}, \quad i = 1, \dots, n, \tag{1}$$

where $\mathrm{T}_{i,k}$ are freight rates between the i-th producer and k-th "export hub"; i is the number of the scrap producer; n is the total number of scrap procures; k is the number of the "export hub"; CP_k is the reduced price for the 3A type scrap for the k-th port ("export hub") in rubles, which is calculated by the following rule:

$$\mathrm{CP}_k = (\mathrm{PP}_k - \mathrm{Tax} - \mathrm{CC}_k) \cdot \mathrm{R} + \mathrm{PTS}, \quad k = 1, \dots, 5, \tag{2}$$

where PP_k is the price in the port of shipment k (without freight); Tax is the tax to be paid to the RF budget; CC_k is the cost of cargo handling services; R is dollar exchange rate, RUB; PTS is the scrap type-specific allowance.

Step 1. The iterative process of calculating scrap demand coefficients for each producer.

1. For each particular consumer of scrap, the optimal purchase plan is determined taking into account only its interests, i.e. the problem of minimizing the purchasing cost of scrap for this consumer is solved. In the calculations, the price of scrap per ton for a consumer is defined as the producer's price for scrap plus freight rate from procurer to consumer. For the first step, the producer's price of scrap is used, which is calculated as the "export parity" c_i^{EP} value and initial volumes of procurers' stock. For next steps, the adjusted price calculated at the previous iteration c_i (Step 2) and adjusted volumes of procurers' stocks (cl. 4 of step 1) are used.
2. Total demand for scrap of each of n producers, V_i^{dem} from the part of m consumers on the basis of optimal procurement plans found in cl. 1 of step 1 is calculated.
3. The factor $k_i = \dfrac{V_i^{\mathrm{dem}}}{V_i^{\mathrm{proc}}}$, is calculated, where $i = 1, \dots, n$, V_i^{dem} is total scrap demand for the scrap for the i-th producer; V_i^{proc} is the volume of scrap stocks of the i-th producer.
4. Check of conditions for stopping the iterative process coefficients calculation. In case of equality of the total volume of stocks and scrap demand, the absence of coefficients less than 1 is verified indicating complete satisfaction of scrap consumer's needs. If the condition is fulfilled, then go to step 2, otherwise for producers with coefficients above 1 initial volumes are divided by k_i, for other procurers, initial volumes do not change and we go to cl. 1 of step 1.

Step 2. Adjustment of scrap producer' prices

1. Checking condition for stopping the iterative process of scrap producer' prices recalculation: coefficients are equal to unity for all producers. If this condition is satisfied, then the iterative process is stopped and price modeling is completed. If the condition is not fulfilled, the producers' prices are

recalculated according to cl. 2–3 of step 2 and the transition to step 1 is performed.

2. Change in price Δ_i for the i-th producer is calculated depending on demand/offer ratio for the procurer and its n_i neighboring producers, nearest to him ($j = 1, \ldots, n_i$), within the radius R by an iterative formula (3).

$$\Delta_i^j = \begin{cases} \Delta_i^{j-1} + (-1)^{\frac{1-\mathrm{sign}(k_j - 1)}{2}} \cdot d_{ij}, & \text{if } (k_j - 1) \cdot \Delta_i^{j-1} < 0; \\ (-1)^{\frac{1-\mathrm{sign}(k_j - 1)}{2}} \cdot \max(d_{ij}; |\Delta_i^{j-1}|), & \text{if } (k_j - 1) \cdot \Delta_i^{j-1} \geq 0; \\ \Delta_i^{j-1}, & \text{if } k_j = 1 \end{cases}$$

$$j = 1, \ldots, n_i, \quad (3)$$

$\Delta_i = \Delta_i^{\mathrm{n}_i}$ is the total change in the price of scrap for the i-th producer taking into account the influence of demand and offer of neighboring producers, $\Delta_i^0 = 0$;
Δ_i^{j} is an intermediate value for calculation of the price change Δ_i;
d_{ij} is the price change of the i-th producer under the influence of demand/offer ratio at the j-th procurer, which is estimated in accordance with (4):

$$d_{ij} = \begin{cases} \mathrm{delta} \cdot (k_j - 1) \cdot e^{-\frac{\mathrm{tar}_{ij}^2}{2\left(\frac{\mathrm{R}}{2.5}\right)^2}}, & \text{if } k_j > 1; \\ \mathrm{delta} \cdot (\frac{1}{k_j} - 1) \cdot e^{-\frac{\mathrm{tar}_{ij}^2}{2\left(\frac{\mathrm{R}}{2.5}\right)^2}}, & \text{if } 0.1 < k_j < 1; \\ \mathrm{delta} \cdot 5 \cdot e^{-\frac{\mathrm{tar}_{ij}^2}{2\left(\frac{\mathrm{R}}{2.5}\right)^2}}, & \text{if } k_j < 0.1, \end{cases} \quad j = 1, \ldots, n_i, \quad (4)$$

where delta is the price change increment step, RUB; tar_{ij} is the tariff distance between the i-th and j-th producer; R is the radius (tariff distance), within which the influence of the demand/offer ratio on the neighboring procurers is taken into account, n_i is the number of neighboring producers within a radius R of the i-th producer.

3. Recalculation of producer' scrap prices taking into account price change Δ_i, provided that the price cannot fall below the price value of the "export parity" according to the rule:

$$c_i = \begin{cases} c_i^{\mathrm{old}} + \Delta_i, & \text{if } c_i^{\mathrm{old}} + \Delta_i > c_i^{\mathrm{EP}}; \\ c_i^{\mathrm{old}}, & \text{if } c_i^{\mathrm{old}} + \Delta_i \leq c_i^{\mathrm{EP}}, \end{cases} \quad (5)$$

where c_i^{old} is the price calculated at the previous iteration.

Parameters of the model delta and R are tuned taking into account the following recommendations:

– delta is the extra charge per unit change of the coefficient: the lower is this step value, the more accurate is the simulation result, but the total computation time of the algorithm increases;

– R is the radius of influence of the scrap producer's price on the prices of his neighbors: a larger radius involves more neighboring producers in the price change process and could destabilize the process of finding an equilibrium price.

  In practice, solving large-scale problems with hundreds of scrap producers and dozens of scrap consumers made vital the questions of ensuring convergence of the algorithm and reducing the computation time. To this end, a number of assumptions were introduced into the model leading to errors occurrence:

– at the step 1, cl. 4, when checking conditions for stopping the iterative process of calculation of coefficients, the condition of the absence of the coefficients less than unity is replaced by the check for number of producers with this coefficient equal to zero; their number should be less than 3% of the total number of producers. The closer to zero is this parameter, the more precise are the calculations, however, the calculation time increases. Relaxing this condition leads to occurrence of "doubled" consumption volumes in the system at each iteration step, i.e. volumes of the same scrap, which are taken into account for several scrap consumers simultaneously; at the step 2, cl. 1 a fixed number of iterations and a posteriori selection of the optimal iteration number at the moment of stabilization of prices is performed. In the condition for stopping the iterative process of producers' prices recalculation instead of checking the equality of coefficients to unity for all producers, the algorithm stops upon reaching a predetermined number of iterations, and then the iteration is selected, according to which, scrap prices of all producers are determined. Iteration selection criterion is as follows: the number of scrap producers with coefficients equal to unity must be greater than 75% of the total number of producers and the increase in the number of stations with coefficient equal to unity in one step should be maximal. Such criterion of iteration number selection allows us to find the moment of stopping the iterative process for price determination, when in the course of the process the price stabilization is reached, i.e., prices do not change significantly anymore and the local minimum of total costs for the purchase of scrap in Russia as a whole is reached. To ensure that an iteration number meeting the specified requirements will be found, the algorithm provides a possibility of reducing the percentage of stations with the coefficient equal to unity below 75% of unit coefficients.

Under these assumptions, the overall price calculation error is the sum of errors at previous iterations.

To detalize the mathematical formulation of the problem, let us list the sources of the original data and factors with a significant influence on the simulation results, in this case, on the scrap conveyance plan. In the study only the volumes of scrap carried by railroad transport are considered since the sole carrier of goods by rail in Russia is Russian Railways JSC, and it maintains a complete database on volumes of scrap metal shipment, points of departure/delivery, preparation and organizations – consignors/consignees, etc. By the estimate of

IA “Metal-Courier”, in 2015 the railway transport transported about 77% of the total amount of scrap collected in the RF. Scopes of delivery by water and road transport are not taken into account, as there is no single all-Russian database on these shipping operations. R/w stations are considered as both consumers and producers of scrap. The number of scrap producers (n) is taken to be equal to the number of departure stations per the database of Russian Railways JSC, the number of scrap consumers (m) is equal to the number of scrap reception stations. Using the database of r/w transportation of scrap for the selected period for each station of departure and destination, aggregated volumes of scrap are determined, which are taken as volumes of stocks (V_i^{proc}) and volumes of demand (V_i^{dem}), respectively. The problem was solved only for the part of the scrap flows, which is supplied by the producers who are not subsidiaries of the metallurgical plants (independent suppliers), since it is assumed that volumes of scrap transported by subsidiaries cannot be reallocated.

The following initial data was used: data on railroad transportation of ferrous scrap in the RF provided by Russian Railways JSC (departure station and destination station, the organization – consignor and organization – consignee, the amount of cargo, kind of cargo, date of dispatch); handbooks of railway tariffs 10-01 between r/w stations of the RF, statistical data on prices of scrap metal of 3A type in the “export hubs” (seaports: St. Petersburg, Novorossiysk, Rostov-on-Don, Vladivostok and the border crossing on the border with Belarus); the cost of services in the “export hub” for handling scrap metal; dollar exchange rate; data on subsidiaries of metallurgical plants carrying out scrap collection; quotations of purchase prices for scrap of 3A type for a number of particular metallurgical enterprises in Russia’s regions.

On the basis of the calculation results in terms of r/w stations, we calculated the weighted average cost indices by regions of the RF and formed the reports for major metallurgical plants.

Software was developed for algorithm implementation and for pre-processing of initial data and report generation. Microsoft Office Excel 2007 with the Visual Basic for Application programming language was used as a development tool. The software is a MS Office Excel add-in programme (`*.xlam`). The source data is stored in Oracle Database 10g on a server. The programme communicates with the database via ADO (with Oracle OLEDB Provider). This technology is designed for both local databases and File/Server and Client/Server databases. Oracle SQL Developer 4.1.1 was applied for SQL queries and PL/SQL units.

4 The results of calculations

The results of price modeling for scrap of 3A type, based on the “Auction procurements” model are illustrated by the example of calculations for May 2015 for the RF as a whole and for MMK OJSC.

Figure 1 shows the distribution of average weighted purchasing prices by regions of the RF for the billing month: prices calculated by the “export parity” principle, actual prices and the maximum scrap price level per “Auction procurements" model. The width of the interval between the price by the "export parity" and "Auction procurements" model characterizes the possible level of warm-up in prices in the collision of interests of buyers. Therefore, the maximum width of the interval is observed in Chelyabinsk, Sverdlovsk, Kurgan and other regions where scrap demand exceeds offer significantly.

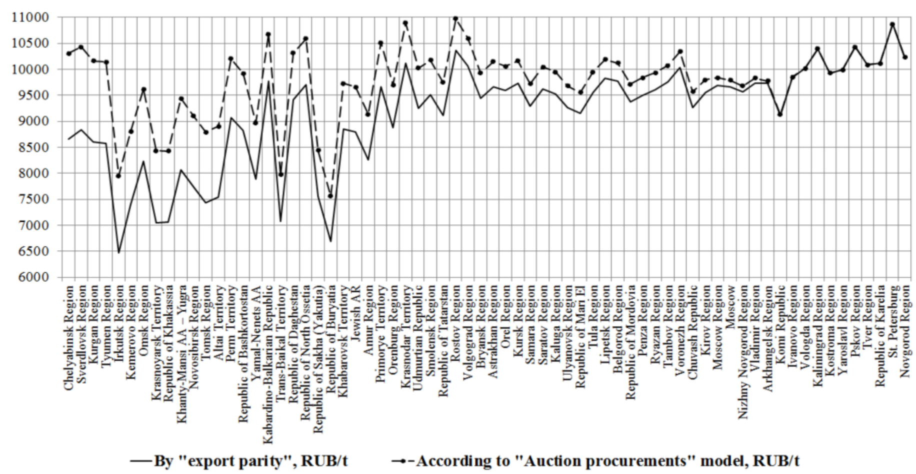

Fig. 1. Weighted average prices for scrap without delivery in the regions of the Russian Federation by the "export parity" principle, prices by the "Auction procurements" model, May 2015

Figure 2 shows the distribution of weighted average prices for scrap including delivery from regions of the RF to MMK OJSC by "export parity" actual and the "Auction procurements" model prices for May 2015.

When comparing the actual and model prices, the most interesting are the cases of exceedance of the actual price beyond the upper limit of the price interval calculated by the "Auction procurements" model; here one can say that the enterprise price is overrated with respect to simulated possible price increase under conditions of scrap consumers competing for the regional scrap market. In May 2015 for MMK OJSC actual prices with delivery go beyond the boundaries of the interval only for the Omsk region.

Prices by the "Auction procurements" model correspond to a particular regional scrap purchase pattern. Figure 3 presents charts for actual and model procurement plans for MMK OJSC without taking into account the volumes supplied by subsidiary enterprises. The scrap purchase plan by the "Auction procurements" model shows the regional structure, which could be formed for MMK OJSC, if metallurgical enterprises adhered to the strategy of the fierce price struggle competing for scrap collection markets. As can be seen from the Figure showing the model price levels, MMK OJSC has the scrap purchase structure, which is maximally localized near the enterprise, i.e. the company has

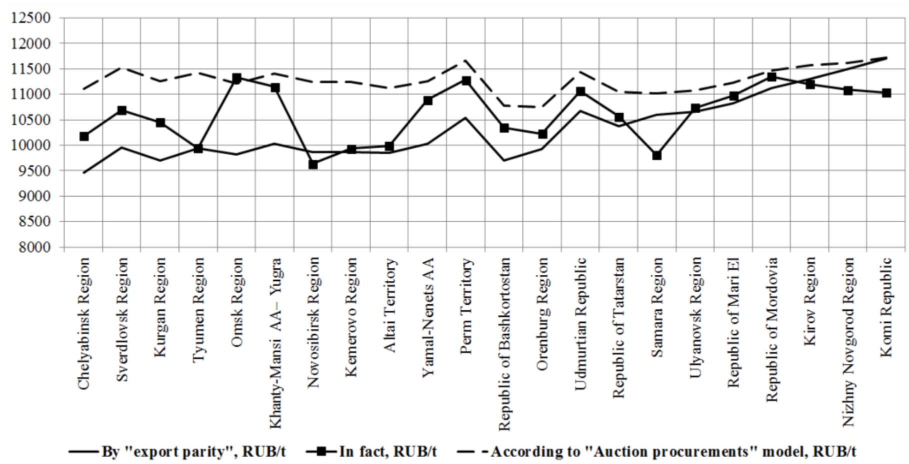

Fig. 2. Weighted average delivered prices of scrap in the regions by "export parity", in fact and by the "auction procurements" model, May 2015

maximum reserve for raising purchase price in home regions as compared with competitors at the expense of savings in delivery.

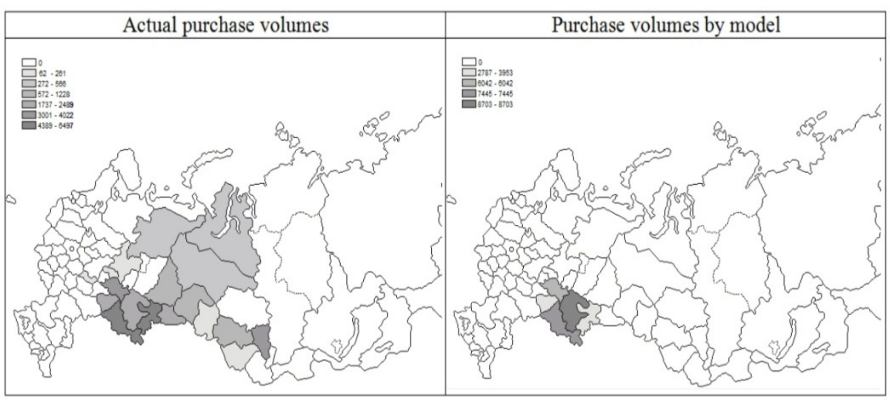

Fig. 3. Charts of actual and model procurement plans for MMK OJSC without taking into account volumes supplied by subsidiary enterprises, tons, May 2015

5 Conclusions

The proposed mathematical model implements a differentiated approach to formation of a regional scrap prices range simulating a competitive activity for scrap collection markets of metallurgical enterprises and taking into account market trends.

Prices yielded by the "Auction procurements" model can be used in management as potentially the highest price levels which can be reached under conditions of competitive struggle between scrap consumers in a situation where negotiations are excluded.

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