In response to the increasing competition in the global market for metal products, Russian metallurgical firms are focused on making full use of technological systems and reducing production costs. Evraz Holding Company is no exception. OAO EVRAZ ZSMK, its largest enterprise, has gained considerable experience in this field in the last five years. The efforts of the entire workforce, the use of the best available technologies, and the development of many important design innovations have ensured consistent high productivity in the metallurgical and rolling shops and outstanding quality of the rolled products.

With uncertainty in the market for metal products, further increases in efficiency must be attained without loss of competitiveness. In a period of limited demand for the plant’s products, innovations should minimize the modifications to existing production processes and should not require further capital investments. It is also important to minimize labor costs in identifying hidden reserves of productivity and the time required to put them into practice. These requirements are met by multifactorial statistical analysis of monitoring data regarding the production process. For more than twenty years, such data has been gathered by plant specialists, in collaboration with experts at Moscow Institute of Steel and Alloys [1–3]. The statistical approach adopted permits simultaneous consideration of the factors influencing metal quality and other indices of efficiency at all the important stages of production. Attention is paid not only to technological operations but also to organizational factors, multidimensional informational graphs, and the results of simulation. The findings are used in selecting effective production conditions so as to improve steel quality, increase productivity, extend tool life, reduce energy consumption, and maximize product yield. However, the results of each statistical analysis cover a relatively narrow range of product types and materials. It is difficult to extend them to a wider product range because many of the variables differ for different production pathways.

Therefore, we need some means of applying the results of individual analyses to a broad range of products. In the present work, we determine the scope for improving the production of high-quality small-diameter bar and wire rod by modifying the rolling conditions. We consider materials that have undergone rigorous testing with cold upsetting, so as to identify surface defects and determine the plasticity: structural carbon and alloy steels for cold extrusion and upsetting, governed by State Standard GOST 10702. The yield of such bar in group 66 is no more than 70–80%, on account of unsatisfactory tests of samples from individual batches in cold upsetting to a third of their initial height.

In determining the characteristics of bar that performs well in subsequent mechanical tests of steel for use in cold extrusion and upsetting, we also require satisfactory values of the bar’s other properties. In what follows, we outline the results of statistical analysis of information regarding the rolling of bars; we recommend the analysis of a significantly expanded
database, including alternative representations of the relevant geometric factors; and we determine the scope for increasing the product yield.

STATISTICAL ANALYSIS OF INFORMATION REGARDING THE ROLLING OF ROUND STRUCTURAL-STEEL BAR ON SMALL-BAR AND WIRE MILLS

Statistical identification of the scope for improving the rolling process entails the collection and organization of adequate information. In this context, data were collected over a three-year period of stable operation of the 250-2 small-bar mill and the 250-1 wire mill, corresponding to the production of 531 batches of round bar from blank of square cross section (side 100 mm). The material employed is structural steel for cold extrusion and upsetting, produced in 226 melts. The bar yield in rolling for different metal batches is judged from the results of cold upsetting to half or one third of the initial height (for products of groups 50 and 66, respectively). In selecting the factors to be considered, we take account of the type of mill (small-bar mill or wire mill); the diameter of the circular profile (6.5–30 mm; 14 categories in all); the content of carbon, silicon, manganese, sulfur, and phosphorus in different melts; the degree of reduction of the metal in smelting (rimmed steel or killed steel); the production period (years); and the number of melts and batches for each type of bar. Collecting such data presents no difficulty, since it is available in the plant records.

We obtain a table of dimensions $531 \times (11 + 1)$ containing values of all the factors and the product yield for each type of bar profile considered. Correlation analysis reveals the distinctive features of the existing rolling process.

1. The reduced yield of steel with different contents of carbon and related elements (silicon, manganese, sulfur, and phosphorus) and of rimmed and killed steel with comparable chemical composition may be attributed to similar factors.

2. There is no significant difference in the product quality for the 250-2 small-bar mill and the 250-1 wire mill, while differences in the volume of products with different profiles (the numbers of melts and batches) have no influence on the product yield.

3. The product yield at a particular rolling state depends significantly on the deformation of the samples in mechanical tests for metal of different groups. (The rejection rate for group 66 is 17 times that for group 50.)

4. Over a particular period of mill operation, with variation in bar profile, the product yield tends to decline.

These results are very reliable, since statistical tests establish the significance of the observed effect (or lack of effect). In addition, the conclusions regarding the whole set of initial data are confirmed by the analogous conditions obtained in the analysis of subsets. That indicates that the results are reproducible and that the initial set of technological data is uniform. Hence, this data set may be used as the sole information base in investigating the quality of bar made from structural carbon and alloy steel for cold extrusion and upsetting at OAO EVRAZ ZSMK.

At the same time, if most of the factors considered have no significant influence on the product yield, while the yield is very different for different products, we must conclude that other factors are at work. It is logical to assume that the geometric parameters of rolling are the key factors [4].

To analyze the rolling geometry on the 250-2 small-bar mill and the 250-1 wire mill, we consider a group of integral factors corresponding to the production pathways; and descriptors of individual elements of the grooves. The first group includes the number of passes in the rolling pathway; the total metal extension in the mill; the minimum and maximum individual extensions of the metal within specified rolling pathways; and the rolling speed when the bar leaves the last groove. The second group includes absolute parameters of elements of the grooves in oval–round and oval–ribbed–oval systems used in each rolling pass: specifically, the groove width $B$ and height $H$; the radius $r$ at the groove peak; the radius $R$ at the junction; the gap $S$ between the roller shoulders; and the bar area on leaving the groove ($F_g$).

Comparison of the integral factors shows that they are significantly different for rolling pathways producing different bar profiles. The number of passes varies from 12 to 23 (by almost 100%). The total extension in rolling square blank (side 100 mm) to obtain round bar with diameters of 30 and 6.5 mm differs by a factor of 20.5. The rolling speeds corresponding to extension of the metal at constant rates differ from 7.0 to 32.5 m/s in the last pass (that is, by a factor of 4.65). The reduction conditions correspond to significantly different extension in each pass.

Thus, the significant differences in the deformation conditions on the 250-2 small-bar mill and the 250-1 wire mill at OAO EVRAZ ZSMK may be consistent with the observed variations in the yield of structural-steel products. Accordingly, we need to consider not only the influence of the integral factors on the product yield but also the influence of individual elements in the rolling grooves. To ensure minimum geometric correction of the rolling process, we must study the change in the characteristics under the influence of each of the identified elements $B$, $H$, $r$, $R$, $S$, and $F_g$. The degree of independence of these dimensions for the available data set is estimated on the basis of correlation analysis. Calculation of the correlation matrices of these individual elements for the longest rolling pathway and combined data sets derived for all the basic rolling pathways reveals close correlations between all the variables considered. That indicates