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Evaluation of Coal Supplied to Soma Thermal Power Plant (Türkiye) with Statistical Process Control Techniques

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Abstract: Statistical Process Control (SPC) is a method developed to ensure that production activities are carried out in accordance with predetermined quality specifications and to minimize the production of defective products/goods by largely preventing non-standard production. Various scientific methods are used when the calorific values of coal fed to thermal power plants are examined in terms of quality. In this study, the calorific values and other specifications of the coal fed to the Soma Thermal Power Plant (Manisa/Türkiye) and whether the process is under control or not are examined by considering the two-year data for tracking and monitoring the process with the Statistical Process Control (SPC) method, taking into account both the design conditions of the power plant and the production parameters. The adequacy of the processes for which stability analysis was performed was evaluated in the next stage. When the two-year control charts ($\bar{X}$ and $\bar{R}$) of units 1-4 and unit 5-6 in the power plant were examined, it was determined that although the process was generally under control in terms of 10-day homogeneity, there were abnormal behaviors showing specific reasons in the $\bar{X}$ chart. Therefore, the process that feeds coal to groups 1-4 and 5-6 of the power plant for the two years in question is unstable. It was also concluded that the process was insufficient to meet the calorific value limits specified on an annual basis.

Keywords: Statistical process control, Soma thermal power plant, process stability, process adequacy.

Introduction

Statistical quality control techniques are applied at every stage of the process, from design, production and post-product services. These techniques are used to ensure the quality expected from the purchased materials, to save on labor and material usage, to reduce inspection costs, to minimize the number of defective products and to improve the relations between the manufacturer and the consumer. These techniques play an important role in controlling the process, identifying the causes of the process that goes out of control, and eliminating them. Variability has an effect on any process getting out of control.

Today, despite the use of high technology, it is not possible to completely eliminate variability. Variability in the process may be due to specific and general causes. Special reasons in the process can be listed as inhomogeneity of the raw material, malfunction of the machine, wear of the tools and equipment used, carelessness of the workers, and failure of any machine in the process if the product passes through more than one machine. General causes can be expressed as common causes that occur randomly in all production factors, but have weak effects on their own and create small differences. Vibration, temperature, humidity, voltage fluctuation are examples of general causes. A process under the influence of general causes is statistically under control (Aydın and Kargı, 2018).

In this study, process analysis and process adequacy analyzes were performed by evaluating the calorific values of coal fed to a thermal power plant that produces electricity, and the results are included.

Material and Mehods

Statistical Process Control (SPC) Method

Statistical quality control techniques play an important role in controlling the process, identifying the causes of the process that is out of control, and eliminating them. Variability has an effect on any process getting out of control.

X mean, R and S quantitative control charts are used in cases where the controlled properties of the products obtained from the process to be kept under statistical control are measured. Process adequacy deals with the stability of the process. When performing adequacy analysis in any process, it is first expected that the process is under control and the data has a normal distribution. In process adequacy analysis, the adequacy of the process can be mentioned as a result of calculating the C_p (shows the relationship between specification limits and process control limits) and C_{pk} (shows the position of the process average relative to the target value and its position between the specification limits) process indices. Necessary precautions are taken into account to ensure that rejected products are separated. In this case, the high rate of defective products requires either widening the tolerance limits or the use of high-tech machines (Aydın and Kargı, 2018).

Control Charts

Graphs in which the changes over time of measurement values obtained from samples taken from production at certain and equal time intervals are determined and called control graphs. Control charts are an effective statistical process control tool that allows the detection and correction of changes resulting from briefly identifiable reasons. In controlling the process average, which of the $\overline{R}$ and S control charts is preferred depends on the sample size (Işığıçok, 2012).

Process Adequacy

Statistical quality control plays an important role in reducing variability, including developing manufacturing-first activities of the product cycle, measuring variability, and analyzing the conformity of this variability to product needs or specifications (Montgomery, 2009). At this stage, process capability analysis examines how a measurable quality characteristic of the process centers and scatters according to the determined target value, lower specification limit (LSL) and upper specification limit (USL). Adequacy analysis measures the variability in the process as well as the extent to which the process complies with customer demands (Kolarik, 1995; Montgomery, 2009). The values taken into account at this stage are C_p and C_{pk} indices (Aydın and Kargı, 2018). One of the valid assumptions in process adequacy analysis is that the process is under statistical control. Control charts are commonly used at this stage. In cases where a quality characteristic can be defined as a measurable variable, the mean and variability of this characteristic should be constantly controlled. The process average is controlled with the $\bar{X}$ control chart, and the process variability is controlled with the S control chart or $\overline{R}$ control chart, representing the standard deviation (Kolarik, 1995; Montgomery, 2009).

Evaluation of Coal Fed to Soma Thermal Power Plant (Manisa/Türkiye)

Soma B Thermal Power Plant, operating in the Soma district of Manisa province (Türkiye), consists of 6 units, each with an installed power of 165 MW, and the total installed power of the power plant is 990 MW. The 1st unit was put into operation in 1981, the 2nd unit in 1982, the 3rd unit in 1985, the 4th unit in 1986, and the 5th and 6th units in 1992. The annual production capacity of the power plant is 8,672,400,000 kWh and its nominal capacity is 6,435,000,000 kWh. The internal consumption of the power plant is around 12%. The installed power of Soma thermal power plant is 1.35% of Türkiye's installed power based on the average values of the last years. Units 1-4 are designed for coals with 2,400 kcal/kg, 32% ash and 21% moisture, and units 5-6 are designed for coals with 1,550 kcal/kg, 52% ash and 18.8% moisture. If the lower calorific value of the coal given to units 1-4 of the thermal power plant exceeds 2,800 kcal/kg, and the lower calorific value of the coal given to units 5-6 exceeds 1,900 kcal/kg, the amount corresponding to the lower calorific value exceeded is not included in the calculation. It can be said that most of the coal supplied to units 1-4 of the thermal power plant is the mix obtained from the coal preparation facility and there is no problem in terms of the calories of the delivered coal and it is within normal limits in terms of operating conditions. It is not possible to say that the coal supplied to 5-6 units of the thermal power plant is within normal limits. As contracted, Half of the unit price is paid for coals with lower calorific value in the range of 2,000-1,600 kcal/kg are given to units 1-4, and 1,300-1,040 kcal/kg to units 5-6. If the lower calorific value of the coal supplied to -6 units falls below 1,040 kcal/kg, no fee is paid by the buyer (Taksuk et al., 2020).

Table 1 Distribution of 100 kcal/kg coals given to units 1-4 for the years in which the evaluation was made

	First Calculation Year		Second Calculation Year	
Calorie Range	Total Amount of Coal (Ton)	Total Coal Ratio (%)	Total Amount of Coal (Ton)	Total Coal Ratio (%)
900-1999			9.367,40	0,23
2000-2099	30.141,34	0,73	120.749,74	2,95
2100-2199	195.600,82	4,73	375.746,90	9,19
2200-2299	751.742,80	18,16	861.509,26	21,07
2300-2399	950.537,00	22,96	1.221.902,84	29,89
2400-2499	1.147.837,66	27,73	865.819,58	21,18
2500-2599	689.916,36	16,67	404.068,80	9,88
2600-2699	274.101,68	6,62	137.566,08	3,37
2700-2799	70.939,14	1,71	67.562,76	1,65
2800-2899	28.612,86	0,69	20.368,48	0,50
2900-2999			3.421,12	0,08
Total	**4.139.429,66**		**4.088.082,96**	

As can be seen in Table 1, 85.52% of the total 4,139,429.66 tons of coal was supplied to units 1-4 of the thermal power plant in the first calculation year, and 82.03% of the total 4,088,082.96 tons of coal was given in the 11-month period of the second calculation year in the range of 2,200-2,600 kcal/kg, which can be considered as the target range.

Table 2 Distribution of 100 kcal/kg coals given to units 5-6 for the years in which the evaluation was made

	First Calculation Year		Second Calculation Year	
Calorie Range	Total Amount of Coal (Ton)	Total Coal Ratio (%)	Total Amount of Coal (Ton)	Total Coal Ratio (%)
1300-1399	267.524,04	6,88	50.288	1,97
1400-1499	339.227,86	8,73	160.934	6,29
1500-1599	568.953	14,64	570.071	22,28
1600-1699	1.034.232	26,61	846.897	33,11
1700-1799	981.621	25,25	532.828	20,83
1800-1899	431.083	11,09	213.884	8,36
1900-1999	191.660	4,93	68.282	2,67
2000-2099	41.001	1,05	26.993	1,06
2100-2199	29.248	0,75	6.992	0,27
2200-2299	1.498	0,04	970	0,04
2300-2399				
2400-2499	1.100	0,03		
2500-2599			1.207	0,05
2600-2699				
2700-2799				
2800-2899			26.287	1,03
2900-2999			52.522	2,05
Toplam	**3.887.149**		**2.558.155**	

Whereas, 86.32% of 3,887,149 tons of coal in the first calculation year and 90.87% of 2,558,155 tons of coal in the second calculation year were within the target range of 1400-1900 kcal/kg (Table 2)

Process Stability

While examining the process stability and adequacy of the coal fed from the production sites to the thermal power plant, the calorific value variable was taken into consideration as a quality feature and the change of this calorific value variable in the first and second calculation years was monitored on the basis of units 1-4 and 5-6. While the change was monitored on a yearly basis, the stability and adequacy of the groups were examined separately for each year. $\bar{X}$ and $\bar{R}$ diagrams were used in stability analyses, and C_p and C_{pk} indices were used in process adequacy analyses. In the first calculation year of the operation, average calculations were made for the calorific value data and in the graphs, the x-axis time period represents 10-day period.

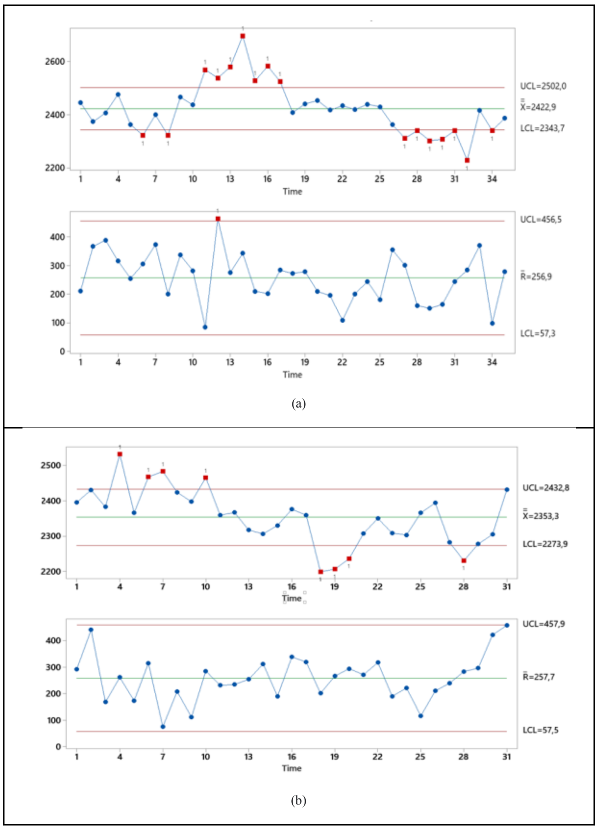

Figure 1 (a)-(b) Control charts on the basis of lower calorific value of coal given to units 1-4 in the first and second calculation years

When the control charts ($\bar{X}$ and $\bar{R}$) of the first calculation year of unit 1-4 were examined (Fig. 1a), it was seen that the process was generally under control in terms of 10-day homogeneity in the charts. Despite this, upper control limit points where abnormal behavior occurred due to special reasons detected in the $\bar{X}$ chart.Therefore, in the first calculation year, the process that feeds coal to groups 1-4 of the power plant is unstable. When the graphs of the second calculation year of the same group are examined (Fig. 1b), it is determined that the process is under control in terms of 10-day homogeneity ($\bar{R}$ graph). On the other hand, the average chart shows points, there are changes (outside the control limits) caused by special reasons in the process, although not as much as in the first calculation year. It was concluded that although there was an improvement compared to the first calculation year, the instability in the process continued in the second calculation year.

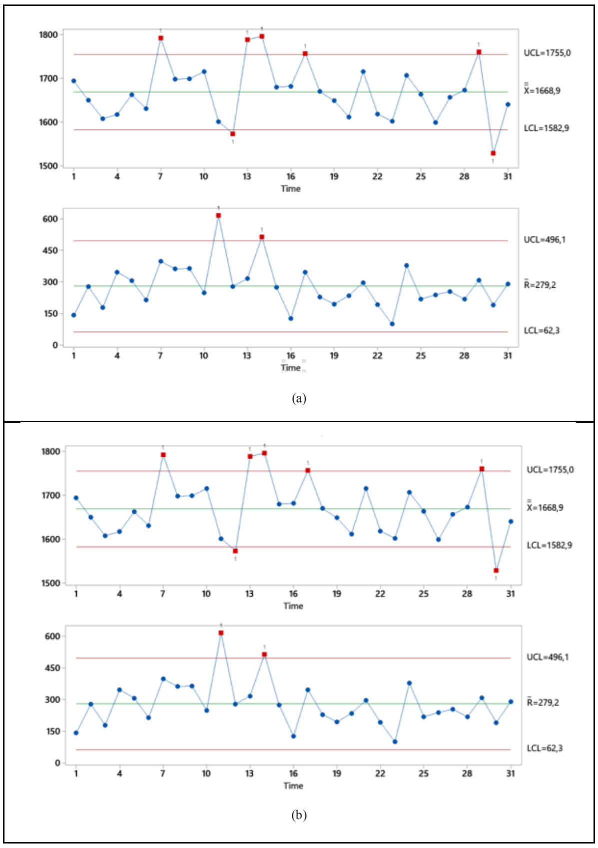

Figure 2 (a)-(b) Control charts on the basis of lower calorific value of coal given to units 5-6 in the first and second calculation years

When the control chart (Fig. 2a) of the first calculation year of unit 5-6 was examined, it was observed that there were abnormal behaviors showing special reasons in both $\bar{X}$ and $\bar{R}$ graphs. According to this information, it is possible to say that the process that feeds coal to 5-6 units of the power plant is unstable in the first calculation year.

In the second calculation year (Fig. 2b), just like in the first calculation year, it is seen that there are abnormal behaviors showing special reasons in the $\bar{X}$ chart and there is a partial improvement in the change range chart. As a result, it can be said that the process instability that feeds coal to 5-6 units of the power plant continued in the second calculation year.

Process Adequacy

The adequacy of the processes for which stability analysis was performed, and also examined in the next stage. Annual sufficiency indexes of the processes that supply coal to units 1-4 and 5-6 in the first and second calculation years were calculated by taking into account the lower base calorific values of 2,400 kcal/kg for units 1-4 and 1,550 kcal/kg for units 5-6, and the results obtained were presented in Table 3.

Table 3 Adequacy index values of the process that feeds coal to the thermal power plant units 1-4 and 5-6, on the basis of calorific value, by year

Years	First Calculation Year		Second Calculation Year	
Groups	Units 1-4	Units 5-6	Units 1-4	Units 5-6
C_p	0,33	0,30	0,25	0,16
$C_{pkupper}$	0,56	0,58	0,54	0,49
$C_{pklower}$	0,47	0,44	0,49	0,54

As can be seen in Table 3, C_p and C_{pk} <1.0 for both processes that feed coal to thermal power plant groups. These index values indicate that both processes feeding coal to the groups are insufficient to meet the calorific value limits specified on an annual basis.

Here, it can be seen that both groups had problems in controlling the general spread, and lower and upper feature boundaries in the first and second calculation years. Therefore, widespread efforts should be made to improve the process.

Results and Discussion

• When the control charts ($\bar{X}$ and $\overline{R}$) of the first calculation year of units 1-4 are examined, it is seen that the process is generally under control, but in the $\bar{X}$ chart, there are abnormal behaviors showing special reasons (points outside the control limits), and the same situation continues in the second calculation year. Therefore, the process that feeds coal to groups 1-4 of the power plant in the first and second calculation years is unstable.

• When the control chart of the first calculation year of unit 5-6 was examined, it was observed that there were abnormal behaviors showing special reasons in both the $\bar{X}$ and $\overline{R}$ graphs. According to this information, it is possible to say that the process that feeds coal to 5-6 units of the power plant is unstable in the first calculation year.

• In the second calculation year of unit 5-6, just like in the first calculation year, there are abnormal behaviors showing special reasons in the $\overline{R}$ graph. As a result, it can be said that the process instability that feeds coal to 5-6 units of the power plant continued in the second calculation year.

• As can be seen in Table 3, C_p and C_{pk} <1.0 for both processes that feed coal to thermal power plant groups. These index values indicate that both processes feeding coal to the groups are insufficient to meet the calorific value limits specified on an annual basis. Here, it can be seen that both groups had problems in controlling the general spread and lower and upper feature boundaries in the first and second calculation years.

• It is possible to say that the instability and inadequacy in the process is due to the fact that coal is a heterogeneous fuel and shows different properties in the mineral deposit and the selective mining methods cannot be applied effectively during the production stage. Based on these findings, in order to eliminate indecisiveness and inadequacies, and taking the process under control;

1) Selective mining based on a suitable ore deposit model,

2) Implementation of a blending and homogenization program that can provide the coal quality characteristics required by the thermal power plant,

3) In order to carry out this blending and homogenization in a suitable way, some studies should be carried out such as using coal analyzers that can make instant and continuous measurement of coal quality,

4) It is recommended that the mixed product obtained from coal preparation facilities and fed to the thermal power plant be monitored by establishing a good tracking system.

• It is thought that continuous control of the system with the statistical process control method is important in terms of situation analysis and as a result, it would be beneficial to apply the mentioned regulations as a preliminary approach.

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