Control algorithms development for manufacturing and economic systems activity

D V Ivanova¹, A G Salov² and A A Gavrilova³

¹ Samara State Technical University, Institute of Architecture and Construction, Samara, Russian Federation
² Department of Heat and Gas Supply and Ventilation, Samara State Technical University, Institute of Architecture and Construction, Doctor of Sciences, Docent, Samara, Russian Federation
³ Department of Management and Systems Analysis of Thermal Power and Socio-Technical Complexes, Samara State Technical University, Samara, Russian Federation

E-mail: darya.i@inbox.ru, aleksey-salov@rambler.ru, a.a.gavrilova@mail.ru

Abstract. The present study explores the efficiency of the manufacturing and economic entities and aims to improve the controlling mechanisms. Detailed analysis is proven to be required for the occurring manufacturing and economic processes in fuel and energy complex since the manufacturing ramp-up will inevitably entail environmental deterioration. A control algorithm for the activity of a regional manufacturing and economic entity of Samara oblast power grid was developed. This control algorithm allowed to perform an integrated analysis of the entity functioning, to study the internal and external connections between the resources, to design the control systems for the entity functioning, to forecast the development scenarios and suggest alternative options for the power grid activity. The developed control systems for the processes within the thermal power production and related systems contain adaptive capital investment share control systems. They differ from the known systems in the part of ensuring the sustainable decrease of the negative environmental impact while increasing the overall efficiency of thermal energy production in the regional power grid.

1. Introduction

Reinforcement of the federal environmental legislation and enhancement of the energy and resources consumption efficiency establish preconditions for changes in the ways the large industries function [1]. At the same time the modern economic trends require improving the systems research process regarding the functioning of the manufacturing industries based on the present-day information technologies accounting for the complexity of the analyzed objects as well as their multiple contradictory relations with the domestic and external environment.

The purposes of increasing the environmental efficiency and manufacturing and economic efficiency of the manufacturing facilities functioning require the deployment of a systemic approach to the research, recognizing the complexity of the studied object, manufacturing and process interrelations and the interaction between the material, energy and human resources [2].

That paper focused on efficiency of the manufacturing and economic entities and aims to improve the controlling mechanism. A control algorithm for the activity of a regional manufacturing and
economic entity was developed for this purpose. The given algorithm contains the six main stages, shown at the figure 1.

**Figure 1.** A control algorithm for a manufacturing and economic entity, Samara oblast power grid (by stages).

2. **Designing a control algorithm for activity of a manufacturing and economic entity**

In the line of work following the presented algorithm, a theoretical methodology was developed, furthermore, a research was carried out with the use of actual statistical data on the functioning of a manufacturing and economic entity with Samara oblast power grid acting as such, see the published studies [3], [4], [5].

Fuel and energy complex is a major source of pollutants intensely impacting the environment as a whole, especially the ambient air. Currently the Russian legislation tightens the requirements for such industrial facilities / sources of pollutants along with the financial feasibility of the effective use of resources and energy efficiency initiatives.

Thus, the research on the environmental efficiency and manufacturing and economic efficiency of the given entity (the regional thermal power industry in Samara oblast) and designing a control algorithm for its activity is of high relevance.

The power grid of Samara oblast operates 7 thermal power stations located in the surroundings of the city (1 station in Syzran, 1 station in Novokuybyshevsk, 2 stations in Togliatti, 3 stations in Samara). For that reason analyzing the activity of the power grid requires acknowledging the impact from the manufacturing and economic systems of the region and city districts.

The research on the activity of a manufacturing and economic entity comprises several consecutive processes, including the following:

- selection and structuring of the research objects,
- goal setting and selection of theoretical basis and methodology,
- collection and statistical analysis of the characteristics and parameters of the manufacturing and economic systems functioning (power grid, city district and oblast),
- mathematical modeling of the processes occurring in the systems, including the identification and quality assessment of the models,
- researching the properties of the developed models and designing the control systems for the manufacturing and economic entities on their basis,
- simulation modeling of the processes occurring in the control systems and making forecasts on the functioning of the manufacturing and economic entities.

Let us review the consecutive stages of the algorithm and their components. The figure 2 provides details on the initial four stages of the algorithm.

At the first stage of selecting and structuring the research objects a structural analysis was performed on the selected object, the regional power grid of Samara oblast.

Fuel and energy complex of Samara oblast is a large power grid of the Central Region of the Russian Federation. Annually the power production hits the ten largest industries in the structure of Samara oblast industrial manufacturing based on its share within the Gross Regional Product.

The power grid performance is dependent on the consumer demand for the thermal power, i.e. demand from the chemical, petrochemical, metallurgical, automotive and machine-building industries comprising the regional industrial complex. Since the regional industrial complex is the main consumer of the generated power and a supplier of the power grid resources, the functioning mechanisms of the complex must be observed when analyzing the regional power grid.
Figure 2. Control algorithm for the activity of a manufacturing and economic entity, Samara oblast power grid (part 1).

The seven thermal power stations are located in the vicinity of cities thus contributing to the amount of fuel burnt within the city limits or in the closely surrounding area. Evaluating the actual impact the power grid has on the population requires monitoring not only the emissions from the thermal power stations, but also the ambient air composition. Since the majority of the power grid manufacturing facilities of Samara oblast are located at the territory of Samara city district, the highest relevance is given to researching the environmental parameters resulting from the functioning of the manufacturing and economic entity of this city district.

Thus, the infrastructure modeling of the power grid relations with the domestic and external environment proved that the three manufacturing and economic systems are to be researched: the industrial and economic system of Samara city district, The regional industrial complex of Samara oblast and Samara oblast power grid itself.

2.1. Statistical analysis
At the next stage of the algorithm, collection and analysis of the characteristics and parameters of the systems functioning, the following activities were carried out:
• the quantitative and qualitative analysis of the harmful substances emissions (gross and differentiated values by chemical components) representing the environmental performance of the manufacturing facility,
• analysis of the characteristics and technical and economic parameters of the manufacturing facilities functioning (incl. the integral and current functioning parameters) representing the manufacturing and economic performance of the entity,
• research on the resources usage efficiency for the environmental criterion (the value of the gross harmful substances emissions),
• research on the system stability as defined by the phase portrait on the coordinate plane.

As a result of the second stage execution with the use of actual statistical data on the manufacturing facilities functioning parameters, it was established that the basic resources usage efficiency by the power grid, manufacturing and economic systems of the city district and oblast was low. The pollution load on the air basin of Samara oblast districts is considerable and the environmental investing efficiency is insufficient. The environmental parameters of the manufacturing facilities being poor defines the necessity of improving the functioning efficiency of the studied systems. More detailed analysis is proven to be required for the occurring manufacturing and economic processes since the manufacturing ramp-up will inevitably entail environmental deterioration.

2.2. Model analysis

The next step defined the structures and parameters of the mathematical models.

The mathematical modeling relations represented by curried production functions such as the Cobb-Douglas function were selected as research tools allowing to define the quantitative relations and dependencies between the input and output quantities of manufacturing and economic systems. Two classes of mathematical models were developed for the research purposes: two- and three-factor ones. The type of the production functions of the selected models was identified by statistical data on the functioning, economic and process characteristics of the functioning of each entity.

The quality assessment of the models and identification results was performed by the method of least squares and defined by the value of the following test statistics: Student's t-test, F-test, the coefficient of determination $R^2$, the standard deviation $\delta$ and Durbin-Watson statistic $DW$.

If the following stages revealed the poor quality of the selected mathematical model in the course of identification by qualitative parameters or if the identified parameter was insignificant, changes were introduced into the model structure within the given block.

The next stage of mathematical modeling of the functioning processes occurring in the power grid system or related systems included developing models on the basis of the actual statistical data and further research of the entity as per the drawn conclusions. The parameters of the developed models were identified, their quality assessed. If the mathematical model quality was defined as poor and did not satisfy the research objectives, the previously unaccounted factor was introduced into the model. The mathematical models with parameters identified to be of low significance were not used for the research on the properties of the entity.

The models of sufficiently high quality were used to study the properties and describe the functioning patterns of the entities: Samara oblast power grid, the regional industrial complex and industrial and economic system of Samara city district. It has been established that the mathematical models based on two- and three-factor non-homogeneous production functions resulting from this stage accurately describe the relation between the production output, consumed resources and the integrated environmental criterion.

The developed mathematical models were deployed to study the regularities behind the activity of production facilities and the efficiency of the various resources consumption. The fuel resource has the highest impact upon the total energy output value. Increasing the power grid efficiency required redistribution of the resources, including revamping the existing capital resources, if necessary, or their termination. Releasing funds for the environmental activities has an utterly insignificant impact on the reduction of the emissions concentration in the ambient air. Increasing manufacturing capacity
leads to the growth of the air basin pollution significantly, more than other factors. The submitted model analysis demonstrated that the balance between the resourced has to be restored, main assets reduced and human resourced increased for the economic efficiency to go up.

Consequently, the growth of the thermal and electrical power at the existing level of environmental expenditure is certain to cause the environmental deterioration both in the city of Samara and in Samara oblast. Well-targeted strategic management is needed to increase the efficiency of the reviewed systems, which is made possible by the application of simulation modeling methodology.

2.3. Simulation modeling and designing the control systems
The next step represents the simulation modeling of the manufacturing, economic and environmental processes occurring in the power grid system of the oblast, city and region supported by the previously developed models, intentionally selected for each particular entity. The models selected for the purposes of simulation modeling are the ones with highest accuracy in the description of the entities functioning.

This stage is shown in detail at the figure 3. Within this stage control systems were developed for each of the entities, industrial and economic system of Samara city district, regional industrial complex of Samara oblast and Samara oblast power grid.

For the entity of industrial and economic system of Samara city district the environmental process single-loop control system was designed using the model mathematically represented by a three-factor Cobb-Douglas production function. It defines the value of ambient air pollution by the harmful emissions of the industrial facilities including the thermal power facilities depending on the capital recourses, internal environmental investment and manufacturing capacity values. The given control system helped defining the share of the environmental capital expenditures reducing the harmful substances concentration in the ambient air at the city district level, i.e. the value of the harmful impact on Samara population by the thermal power industry.

The regional industrial complex of Samara oblast, acting as the main power consumer and resources supplier for the power grid, received a double-loop control system intended for increasing the environmental and economic efficiency of its functioning by the gross regional product manufacturing. The inner loop studies the economic efficiency of the system functioning as per the previously selected two-factor mathematical model with the share in the main assets changing value being the controlling value. The outer loop addresses the environmental processes following the previously selected two-factor mathematical model with the controlling value of the environmental share i

The structured control system at the regional level allowed defining the investment share values at which both the environmental parameters of Samara oblast and manufacturing capacity of the region increase sustainably.

With the help of previously selected three-factor simulation models of functioning of the industrial and economic system of the Samara oblast thermal power industry, a double-loop power grid control system was designed. The inner loop is responsible for the economic efficiency of the system functioning with the controlling value being the share in the main assets changing value within the yearly production capacity structure. The outer loop of the system describes the environmental processes, its controlling value is the relative share of industrial investment into the environmental initiatives. The developed control system for the Samara oblast power grid helped forecasting the efficiency of manufacturing facilities functioning as per the environmental criterion and consumed resources particularly critical in the conditions of strengthened environmental requirements for the thermal power facilities. There was defined the capital share sufficient for sustainable reduction of the negative impact of the power industry upon Samara oblast environment at growing production volumes, advancing the efficiency of the power grid activity as per the environmental, manufacturing and economic indicators.
3. Conclusions
The developed single and double-loop control systems for the processes within the thermal power production and related systems contain adaptive capital investment share control systems. They differ from the known systems in the part of ensuring the sustainable decrease of the negative environmental impact while increasing the overall efficiency of thermal energy production in the regional power grid.

Thus the created control algorithm for the activity of the manufacturing and economic entity of Samara oblast power grid allowed to perform an integrated analysis of the entity functioning, to study the internal and external connections between the resources, to design the control systems for the entity functioning, to forecast the development scenarios and suggest alternative options for the power grid activity.

The obtained efficiency indicators of the entity functioning as per the manufacturing, economic and environmental parameters and control recommendations for the entity functioning can be applied at the level of a branch of industry (the regional power grid) as well as at the general manufacturing level of the region (the regional industrial complex).

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