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COMPUTATIONAL INTELLIGENCE METHODS – JOINT USE IN DISCRETE EVENT SIMULATION MODEL OF LOGISTICS PROCESSES

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ABSTRACT

The objective of the paper is to present the concept of using selected computational intelligence methods in conjunction with discrete event simulation (DES) models of chosen logistics processes. A review of the recent literature in the scope of applications of discrete event simulation methods indicates that researchers who use these methods more and more often employ techniques from the area of computational intelligence, especially in cases when the phenomena, processes or systems modeled feature complexity, uncertainty or non-linearity. The issues discussed in the paper refer to modeling selected logistics processes at the company that produces electricity and thermal energy.

1 INTRODUCTION

Simulation modeling techniques are one of the basic tools used for identification, analysis and optimization of logistic processes and systems. A number of modern logistics process simulation tools use DES approach. References to the applications of DES in the field of logistics can be found in Chung (2004), Robinson (2004), Semini *et al.* (2006) or Banks *et al.* (2010). This kind of simulation is a very useful and often the only tool supporting the analysis of complex logistics systems, including their *dynamics*. However, this tool requires precise data of the researched processes, which not always are available in the form in which they could be directly used in the process of building a model. The actual conditions observed in the industrial practice often go beyond the limits defined by boundary conditions or the models used. This principally applies to all available information on processes, such information being, as a rule, *incomplete* and *uncertain*, as well as to the nature of the processes, which are usually stochastic and reveal strong *nonlinear* relations. For this reason, there has been a growing interest in **hybrid methods** using the traditional approach supported by **computational intelligence models**, exploiting modern methods of information analysis and processing.

Among the techniques of computational intelligence, broadly used in modeling events whose nature is non-linear, multi-dimensional with elements of uncertainty and incompleteness of information, there are *artificial neural networks* and *fuzzy sets* and *fuzzy logic* (see: Hellmich 1997, Babuska *et al.* 1998, Kudlich 2000, Marquardt and Schulze 2000, Perrone *et al.* 2001, Wang and Kusiak 2001, Nucci and Grieco 2006, Panayiotou *et al.* 2000, Zeigler *et al.* 2000, Ostermann 2001, Rabelo *et al.* 2003, Rog and Sevastjanov 2003). The studies conducted by the authors reveal that logistics processes are among the least quantitatively identified processes occurring at power plants and combined heat and power plants (CHPs). Rationalization and/or optimization of these processes might considerably reduce the plant's logistics costs, which the analyses performed have found to be far from low.

2 EXAMINED PROCESSES AND SCOPE OF THE STUDY

The scope of research conducted by the authors of the paper covers selected logistic processes in power and heat generating plants, as well as the related production process. The detailed analysis of research was applied to the processes related to providing the selected heat and power generating plants with the main production raw material, that is hard coal, as well as the processes which include the operations related to unloading, reloading and transport of coal within the company.

All the operations related to unloading, loading or reloading the coal material in the premises of the company increase cost and time of its transport, and may also be a cause of its scattering and destruction. For this reason, the necessity arises for the appropriate organization of unloading and reloading operations in a way that is economically and technically justified. The issues related to the unloading processes are significant because their effectiveness may affect continuity and safety of the main process in power and heat generating plants, namely production of electricity and thermal energy. The process of planning production of electricity and thermal energy plays an important role in effective management over a power and heat generating plant enterprise. Volumes of the generated electricity roughly meet the planned values, but quite large discrepancies appear between the planned and the actual volumes of heat production.

Developing a model of a process or system and then using it for simulation, forecasts and optimization is nowadays a standard research approach. The need for use of a model-based analysis applies especially for systems, such as a system of operational use of a power plant or a CHP. In this hierarchical process, there are numerous interactions between parameters of circulation, load graphs, fuel quality, the repair system and parameters of planned repair cycles, parameters of the economy and financial system, the natural environment and the system environment.

The review of the literature (Mielczarski 1998, Karkula 2007), results of observation and analyses related to logistics processes occurring at the CHP, as well as of interrelations of the logistic processes with other processes taking place at the plant has led to assuming complex nature of these process. Modeling such processes requires using methods and tools sourced from multiple areas of expertise; the idea of a model which could be an effective tool supporting making logistics decisions is based on the use of discrete event simulation mechanisms, statistical methods, as well as of models making use of artificial neural networks and fuzzy set theory. Such an approach leads to a creation of a hybrid model. The following partial models have been separated in the construction of the hybrid model (see Figure 1):

- model of coal delivery, acceptance and unloading,
- model of coal transport process on the plant premises,
- model of demand forecasts for coal for power/heat generation.

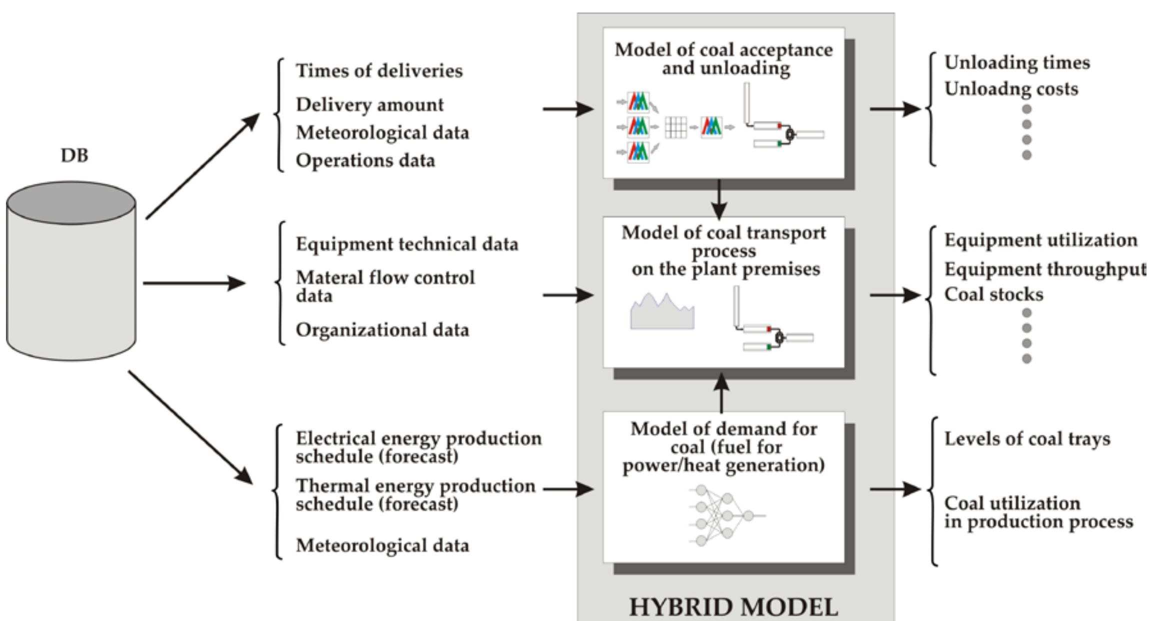

Figure 1. The general idea of a hybrid simulation model of selected logistics processes taking place at the plant under analysis

As the basic modeling environment the DOSIMIS-3 simulator has been chosen. This package is a module-oriented simulation tool, adapted to, inter alia, designing and developing models of logistics systems (Noche 1997, Bukowski and Karkula 2004, DOSIMIS-3 2011). Owing to its module-oriented approach to a modeling problem, DOSIMIS-3 quickly delivers reliable results and may be an excellent tool supporting decision making, even in minor projects. The DOSIMIS-3 package is an interactive, graphic discrete event simulator. and is able to simulate various systems, including complex logistics systems and processes.

3 COAL DELIVERY AND UNLOADING PROCESSES

The models presented, which represent the processes of coal delivery, acceptance and unloading at the power plant has been built with both quantitative and qualitative data. Quantitative data was represented by information on arrival times of consecutive deliveries of fuel to a CHP plant, duration of transport of the delivery from the place of its origin to its arrival at the CHP plant, volumes and capacity of the buffers at railway car unloading stands, duration of train set staying on the premises of the CHP plant or flow capacity of particular elements of this unit of the plant. Qualitative data mostly refers to the strategy of control over the flow of objects (that is train sets, single railway cars, as well as coal and the related information streams) and information obtained as experts' conclusions concerning mostly unloading railway cars in winter. The production of electrical and heat energy is seasonal in nature – it may be observed that the deliveries of coal are also held seasonally. Within a year coal deliveries are carried out in two periods from January to May and from July to December. In Table 1 the aggregated data on the coal deliveries to the investigated company during the five years is shown.

Table 1. Aggregated data used in simulation for a winter period (January)

Year	**Number of deliveries**	**Sum of coal (in year)**	**Average delivery size**	**Min**	**Max**	**Std. dev.**
		[Mg]	[Mg]	[Mg]	[Mg]	[Mg]
1	574	1,021,517	1,780	57	2,374	560.62
2	549	986,757	1,797	56	2,366	559.78
3	519	921,312	1,775	33	2,371	508.76
4	508	976,453	1,922	43	2,423	550.54
5	458	935,383	2,042	57	2,410	503.40

Among basic tasks of model building, there was the determination of mechanisms supporting the generation of flows of coal deliveries to the CHP. In the initial phase of delivery model building, the collected actual data was used as the basis for the creation of a delivery flow generation model. The actual flow is random and in the next step of the model construction, the flow was analyzed just for this randomness. Using the information on arrival times for succeeding coal-carrying car drafts, a variable was introduced described with time intervals, that is times between any two consecutive deliveries (interarrival times).

To include the random nature of draft arrivals, statistical methods were used:

- an attempt was made at matching the empirical distribution (developed based on the data collected) with theoretical distributions and at evaluating parameters of those distributions;

- then, supported by appropriate statistical tests, a procedure was implemented with view to proving the hypotheses true.

In the case under question, based on analyses and histograms, the zero hypothesis was accepted assuming the distribution of the variable t_{mp} is exponential. Goodness-of-fit tests were run based on the χ^2 statistic. The results of the tests suggest that it should be assumed there are no grounds for rejecting the zero hypothesis (at the significance level $\alpha = 0.05$). Based on the tests, the following estimates for the parameters of the time t_{mp} distribution were obtained (the λ parameter for the exponential distribution):

- $1/\lambda=19$ [h] – for the winter-spring season;
- $1/\lambda=13$ [h] – for the autumn-winter season.

Thus estimated distribution parameters for the variable t_{mp} were introduced into the model built; precisely, into the model element responsible for generation of loads for objects in the model.

Figure 2 presents a partial model of the tested system, implemented in the DOSIMIS-3 simulation environment, which represents the model of arrival and processing of coal deliveries.

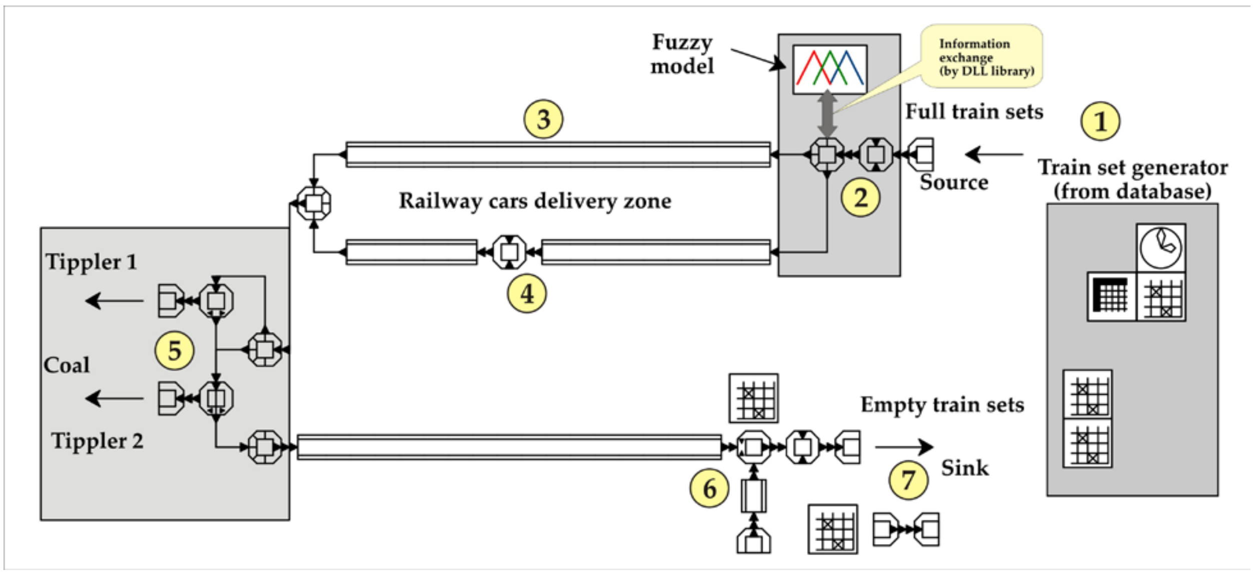

Figure. 2. The model of the process of reception of coal deliveries, unloading railway cars and coupling empty car drafts

Figure 2 indicates the place of arrival of a train set (1). To map this element of the model, the entry element (source) was used. That is at the source that the load (consecutive coal deliveries) is generated. The source is an element where movable entities (called objects in DOSIMIS-3 terminology) are generated and then passed to the system. The next phase in the flow of objects (train set) covers elements at which a decision is made whether it is necessary to defrost cars (2). This part of the model includes, among others, a fuzzy model used for assessment of the degree of freezing a railway car in winter periods. The cars assessed to require defrosting are forwarded to the boiler house (4), and the other cars are directed to the buffer (3) which is up line the tipplers. The railway cars from this part of the system go to the tipplers (5), where they are unloaded, and after these operations are completed, they are directed to the buffer, where they await formation of an empty train set. The procedure of forming return train sets (6) is preceded with the operations related to cleaning railway cars. Once the draft of empty cars is ready, it is forthwith taken over by the carrier and the time of draft stay at the CHP is recorded.

The module mapping the process of coal acceptance and unloading also includes a submodel responsible for testing coal freeze-up for coal supplied to the plant in winter period. It has turned out that such deliveries pose a serious problem for unloading handling services, may cause disruptions in CHP operations and have a material effect on the time of stay at the plant for individual car drafts. This time affects the costs to be incurred by the plant; therefore, the plant is interested in organizing unloading so that the unloading time be as short as possible (including under difficult winter conditions). The delivery model was extended through combining discrete event models with a fuzzy model supporting the evaluation of the effect of selected factors on the time of stay at the plant for individual car drafts. The process of construction and the analysis of the fuzzy model are presented below.

As practical observations and the authors' research suggest, the subjective ratio assumed for the purposes of the study, the coal freeze-up ratio D_F depends on several factors with the most important ones being:

- air temperature on the day of delivery arrival T_Z,
- average temperature of the previous day $T_{Z(-24)}$ and
- duration of transport of the delivery since dispatching until the arrival at the plant t_{tr}.

Despite the fact that distances between CHP plants and coal suppliers are not very large, this duration, may be as long as several dozen hours. For this purpose, a fuzzy model was built which enables the assessment of coal freezing degree based on the factors described above and supporting the decision whether it is necessary to defrost the train set. This coefficient also plays the decisive role in determining defrosting time for the given railway carriage, thus affecting the total duration of stay of the train set at the CHP plant.

For measuring the freeze-up ratio for the coal supplied, a fuzzy model was built based on the Mamdani-type inference mechanism, binding the above described input variables with the output variable of coal freezing degree D_F. The prototype of the model was built in the MATLAB™ environment and then the appropriately tuned model was implemented in the DOSIMIS-3 package.

A set of information has been collected from the tests and consultations with experts responsible for unloading coal, and it was used as the basis for generation of a base of fuzzy rules of the **IF … AND … THEN …** type for the developed fuzzy model. Upon the definition of space and linguistic values for individual variables, the fuzzy rule base was developed, comprising 27 decision rules. The following listing is an interpretation of a sample decision rule:

IF coal transport time t_{tr} is medium

AND

IF temperature in day of delivery T_Z is very low

AND

IF temperature day before $T_{Z(-24)}$ is low

THEN

freezing degree D_F is high

The process of construction of a fuzzy model for assessment of degree of freezing of railway cars was completed with the analysis of its performance. The response surfaces have been designed for verification and examination of behaviour of the fuzzy model (the decision surfaces), as shown in Fig. 3. These charts show the answer of the model to the changes in two input variables, with the assumption of a specific constant value for the third variable. On the basis of such relationships, the effect of changes in input parameters of the model on its answer may be observed. It is clear that with higher values of temperatures T_Z and $T_{Z(-24)}$ (close to or higher than zero) coal transport duration t_{tr} has almost no effect on freezing degree of railway cars. Changes in this time result in a reaction of the model for low temperatures T_Z and $T_{Z(-24)}$.

A model using a fuzzy model estimating the degree of freezing of railway cars in the winter period has been the built and analyzed in the MATLAB™ environment (Fuzzy Logic Toolbox 2011) . The software used provides a standalone C/C++ code for fuzzy inference engine. A user can use the engine as an alternative tool to simulate the outputs of the fuzzy inference system developed, without using the MATLAB environment. The DOSIMIS-3 package offers the interface (API, Application Programming

Interface) supporting communication with external DLL libraries (Dynamic Linked Libraries), which may be developed by the modeler.

Figure 3 shows the response of the model to the changes in two input variables, with the third variable set to a specific constant value. Based on such relationships, the effect of changes in input parameters of the model on its response may be observed. It is clear that with higher values of temperatures T_Z and $T_{Z(-24)}$ (close to or higher than zero) coal transport duration t_{tr} has almost no effect on freezing degree of railway cars. Changes in this time result in a reaction of the model to low temperatures T_Z and $T_{Z(-24)}$.

The resulting fuzzy subsystem has been used as one of the elements for developing a model of processes for delivery reception, unloading of railway cars and coupling return train sets. This subsystem generated information related to the freezing condition D_F of the train set with coal based on the input data (temperature, transport duration).

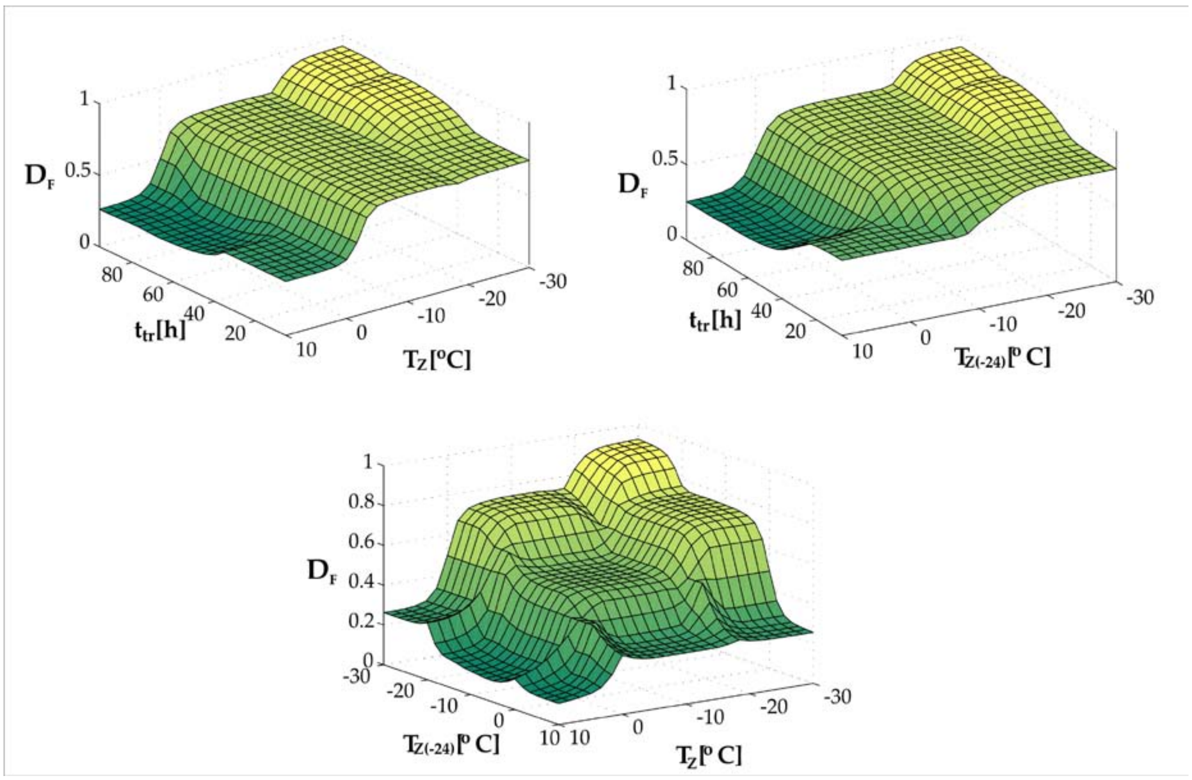

Figure 3. Response surfaces for fuzzy model

The values of this coefficient were in the range *<0, 1>* and, based on them, a decision was made whether the given railway car would be directed to the tipplers or to the defrosting unit. This part of the model was handled by a decision table implemented in the DOSIMIS-3 model.

4 THE PARTIAL MODEL OF COAL DEMAND FOR PRODUCTION

For the purposes of the problem considered, models were built defining hourly demand for feedstock coal and allowing for various factors to be included. These models mapped regression relations between input quantities and the output quantity, that is the demand for feedstock coal D_C. To solve the problem of predicting the demand D_C for feedstock coal combusted in heat and power generation, models were built based on artificial neural networks, as well as on statistical methods (multidimensional linear regression). The first step involved the analysis and selection of input data with a bearing on the demand D_C.

The data used in the research preceding model construction for predicting the demand D_C for feedstock coal covered two years of operation of the plant and included:

- production data (electricity and heat),
- meteorological data (temperature and pressure measured on the plant's premises),
- supplementary data (experts' knowledge and qualitative parameters).

As part of research into demand for coal, various neural models were built and compared among themselves, namely those using multilayer perceptron networks (MLP), radial basis function networks (RBF) and generalised regression neural networks (GRNN), as well as a model based on multidimensional linear regression. In the course of building and analysing MLP-type networks, between ten and 20 models (algorithms) of network training were tested. The reason for building neural models was to identify regression relations between feedstock coal consumption in any given hour as the output value and the input values:

$$D_C = f(D_{EE}, D_{TE}, T_O, p, t_d, k_d, k_m) \tag{1}$$

The following were the values analysed as input variables for the model given by the formula (1):

- hourly production of electricity D_{EE},
- hourly production of thermal energy D_{TE},
- ambient temperature T_O,
- atmospheric pressure p
- day length in minutes t_d,
- day code k_d and
- month code k_m.

Among the variables referred to above, forecasts concerning the volumes of electricity and heat production undoubtedly exert the largest impact on demand for coal. The drivers of demand for feedstock coal also include weather-related parameters, such as air temperature, wind strength and direction, amount of cloud and, to a lesser extent, air pressure. Among those, data on air pressure and temperature was only available. Given the nature of seasonal fluctuations in demand, an important group of model input parameters is that of qualitative parameters including the day code (ranging from 1 to 7 for consecutive days of the week) and the month code (ranging from 1 to 12 for consecutive months of the calendar year), as well as day length measured from sunrise to sunset. The training process was preceded by data normalising with use of the *minimax* method described in (Neural Network Toolbox 2011). The network training process included 8,760 cases covering a year of the plant's operation, with 60% of the cases representing training data, 20% – validation data and the remaining 20% – testing data. Cases included in these three datasets were selected at random.

Finally, the mean square error (MSE) was selected as the key criterion of the quality of models analysed. In the process of network training, an analysis was performed of a training error runs for training, validation and testing series. Such runs enable training process irregularities to be identified (e.g., overtraining symptoms to be detected) and the modeller to react properly, for instance, by reconstructing network structure (the number of hidden layers or the number of neurons in a hidden layer), selecting alternative activation functions or shortening training time. One of the methods for neural model quality assessment is the examination of the linear regression between network response and the values observed as is shown in Figure 4).

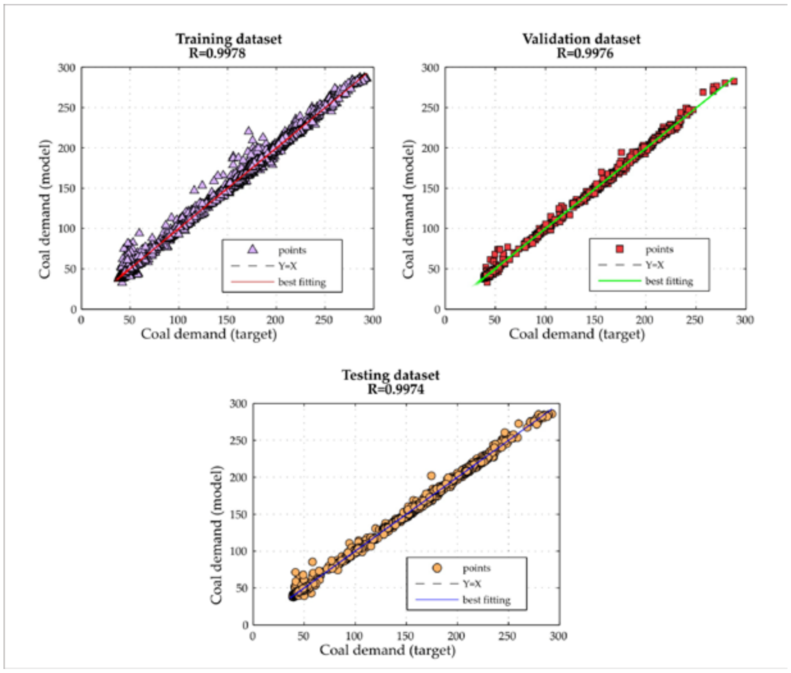

Figure 4. The neural network outputs plotted versus the targets for particular datasets. The solid line indicates the perfect fit (this means that output equal to targets)

Additionally, an analysis of key regression statistics was run, which is typical of such assessment. The results are presented in Table 2. In practice, a value of the quotient exceeding *0.6* is assumed to disqualify the network as a model of the system examined, while any value equal to or less than *0.1* attest to good regression properties of the network.

Table 2. Summary of statistical data for linear regression of assessment of the developed neural network model.

	Training dataset	**Validating dataset**	**Testing dataset**
Average data	116.84	117.38	114.03
Standard deviation data	53.78	53.84	52.14
Average error	0.0055	-0.1051	0.1805
Standard deviation error	3.60	3.75	3.79
Quotient deviation error/ deviation data	0.0669	0.0696	0.0727
Correlation	0.9978	0.9976	0.9974

The comparative tests provided analysis of the solution for the problem with the use of multidimensional linear regression. In comparison with the proposed earlier model of the multi-layer MLP network, the results with the multidimensional regression method are less favourable for the basic indicators of model quality. The model developed based on the MLP type artificial neural network offers less mistakes than the model based on the linear multidimensional regression.

5 HYBRID MODEL

In order to develop a model which allows representation of the basic material flow for the power plant or CHP, that is coal from the reception point, along with delivery until the time of using in production, integration of the partial models described above was done. The static elements of the system modeled were built with use of libraries of standard components of material flow systems (conveyors, accumulating conveyors, crossings, service stations, etc.), as such libraries are available in the DOSIMIS-3 package. The model using artificial neural networks for forecasting consumption of coal in production and a fuzzy model estimating condition of freezing of railway cars in the winter period have been the built and subjected to analysis in the MATLAB™ environment, with the Visual C++ compiler used for their implementation in the hybrid model.

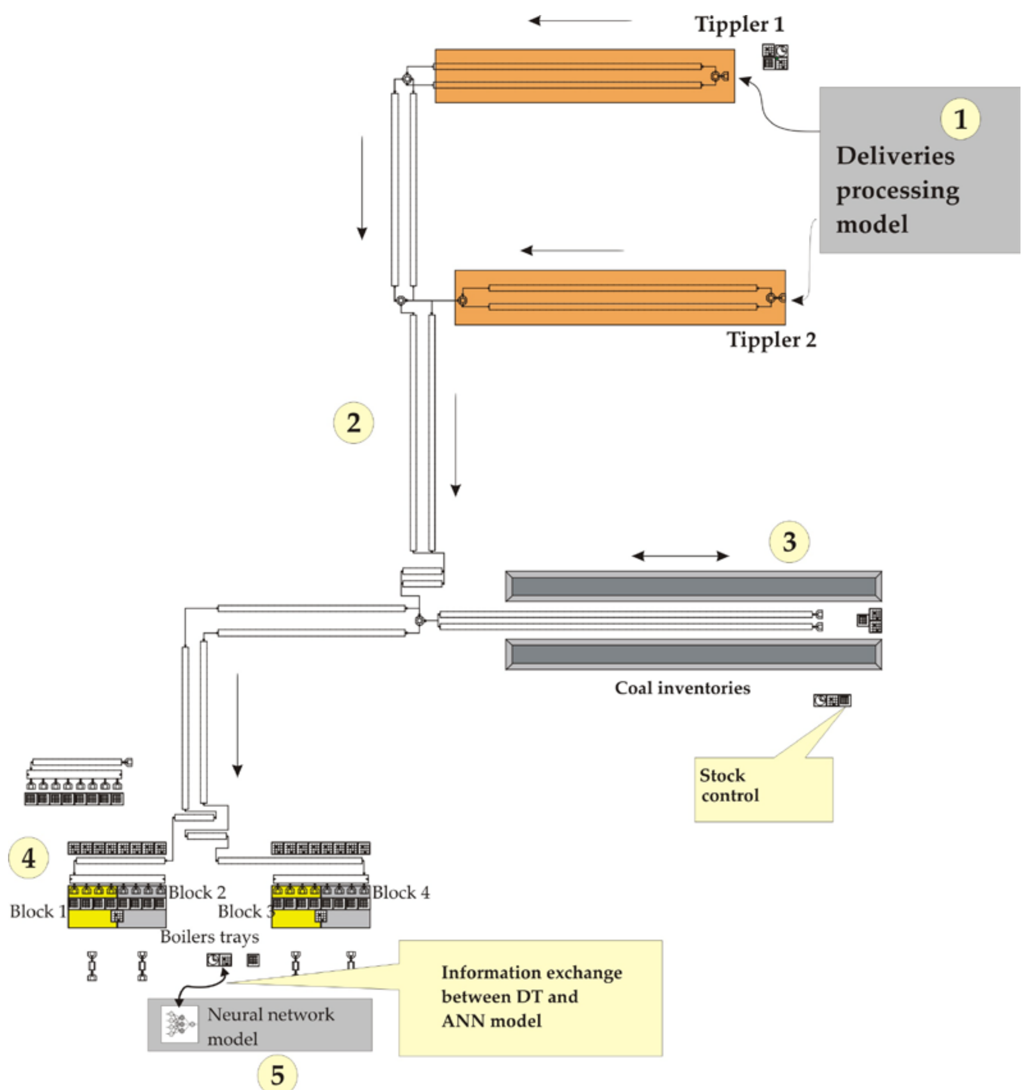

Figure 5. The hybrid model of selected logistics processes implemented in DOSIMIS-3 environment

In presented Figure 5 the following elements of hybrid model can be distinguished: subsystem responsible for coal deliveries and unloading (1), the subsystem which maps coal transport from the point of unloading, with transport equipment – conveyor belts (2), coal storage with decision tables used to control coal stocks (3), the subsystem power unit with four power blocks (4) and neural network module responsible for forecasting demand for coal used in production (5).

The DOSIMIS-3 package offers the interface (API, *Application Programming Interface*) to enable communication with external DLL libraries (*Dynamic Linked Library*) which may be developed by the modeller. The DLL libraries developed in considered case exchange information with the discrete event simulation software, collecting input data from it and returning responses generated by the partial models.

Developed hybrid model of logistic processes taking place at the CHP was used to carry out simulation studies on it. Simulation time of investigated system was set for a period of one year (365 days), and the interval for which intermediate statistics were generated was set for one day.

There appears that there are the following two among key tasks of logistics managers at large-scale power and heat generators: making decisions concerning feedstock necessary for the plant operation and minimizing cost of stocking up and maintaining inventories of the feedstock. Given the observed limitations imposed by the applicable law, provisions of trade contracts and regulations governing operation of the market, the above problems should be treated comprehensively. Another important area of interest for the logistics manager at a CHP is the analysis of changes in inventories and generation of such information and options which would form a basis for making decisions designed to minimize costs related to maintaining coal inventories. With simulation experiments the impact of different coal delivery cycles on coal inventory level was examined (Figure 6).

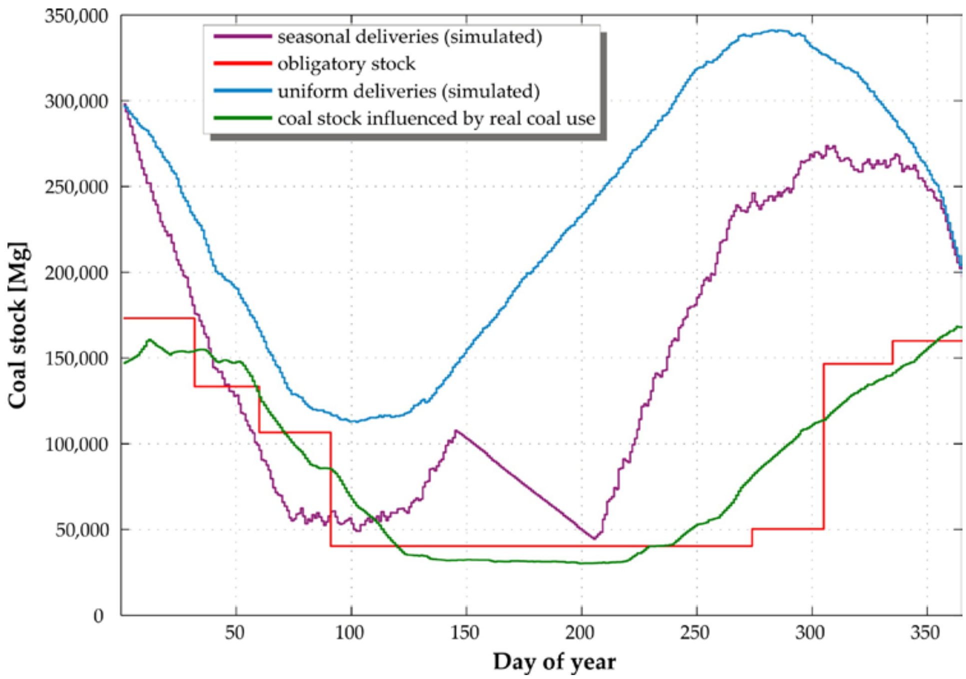

Figure 6. Simulated, real and obligatory coal inventories

Simulation experiments were conducted for two different models of delivery schedules:

- schedule, currently used in the power plant, with estimated parameters of distribution of coal deliveries; there was assumed that deliveries take place in the winter-spring and autumn-winter cycles
- schedule taking into account the uniform distribution of time between successive deliveries during the year; the average number of deliveries n_d was estimated, then the simulation time (365 days = 8760 hours) was divided by n_d variable, and thus determined the average time between arrivals of coal deliveries.

Simulation results show that the second alternative delivery schedules provides „excessive security" associated with the size of stocks. Such a quantity of the stored coal will result in the increasing of capital commitment. Assuming the price of one ton of coal the frozen capital can be easily calculated.

6 CONCLUSIONS

Many power plants and CHPs in Poland use hard coal as their basic fuel for power and heat generation. The increasingly growing competition on the electricity and heat market forces the producers to seek new solutions and reduce cost of operating activity. One of the ways to achieve this is the implementation of the concept and principles of logistics management, as well as of the strategy developed in accordance with these principles, which plays a decisive role in building the plant's competitive edge. However, such strategies require continuous verification and modification. They also have to keep up with ever dynamically changing conditions in which the plant operates, including both internal and external conditions. The simulation models discussed in this paper are effective tools enabling such strategies to be tested and supporting decision-making processes.

The use of methods described leads to a greater accuracy and completeness in problem formulation and model development. The comprehensive approach to the analysis of key logistics processes enables a broad range of phenomena occurring in logistics systems to be taken into consideration in the course of such analysis: from those both of deterministic and stochastic nature, to phenomena the knowledge of and data on are incomplete and uncertain.

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