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Development of an Automated Quality Management System to Control District Heating

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***Abstract*—**We investigated the management system of heating enterprise, including strategic planning based on the balanced scorecard (BSC), quality management in accordance with the standards of the Quality Management System (QMS) ISO 9001 and analysis of the system based on expert judgment using fuzzy inference. To carry out our work we used the theory of fuzzy sets, the QMS in accordance with ISO 9001, BSC, method of construction of business processes according to the notation IDEF0, theory of modeling using Matlab software simulation tools and graphical programming LabVIEW. The results of the work are as follows: We determined possibilities of improving the management of heat-supply plant-based on QMS; after the justification and adaptation of software tool it has been used to automate a series of functions for the management and reduction of resources and for the maintenance of the system up to date; an application for the analysis of the QMS based on fuzzy inference has been created with novel organization of communication software with the application enabling the analysis of relevant data of enterprise management system.

***Keywords*—**Balanced scorecard, heat supply, quality management system, the theory of fuzzy sets.

I. Introduction

ADEQUATE heating is a necessary condition of achieving a decent life for the citizens. The poor state of heating networks causes significant losses during the heat transportation, reduces the reliability of heat supply and may cause emergency situations in the cities and the deterioration of the quality of public services [1]. These problems may be solved by implementing and maintaining the quality management system (QMS) in the enterprise. Currently, the development of QMS is actively investigated by many groups, for example by A. Klochkov [2], L.A. Kuznetsov [3], K.S. Melnikov [4], R.S. Kaplan and D.P. Norton [5], etc.

Our research revealed that the actual implementation of QMS in the field of heat supply is low not only in Kazakhstan but also in other countries. Therefore, there is a need for further research and adaptation of the QMS in heat supply enterprises to improve its operations and reduce the complexity and the overall cost of the system.

The purpose of this research is to study of the management system of heat supply enterprises and possibilities of its improvement through the implementation of an automated quality management system.

II. Description

The district heating systems (DHS) in many cities represent sophisticated technological complexes consisting of cogeneration plant (usually main cogeneration or heat plant and auxiliary heat plants), feed, and return lines, and consumer-level networks of heat and hot water supply.

Along with ensuring the smooth functioning of the DHS it is necessary to comply with technological requirements of its operating modes (hydraulic and thermal), the reliability of the individual elements, taking into account the technical and economic indicators of heat supply [6].

Management of heat supply enterprise and other enterprises can be divided into two tasks: management of the workforce, management of technological processes. Managements of the workforce may include a quality control that is regulated by the documentation of the enterprise and defining responsibilities and duties of employees. Management of workforce has to comply with regulations for the control of the process and quality of the product, which includes both internal and external standard reference materials and normative documents. This part of the heating system and also takes into account the external factors such as state represented by various government structures because the company depends on the investment policies and the established rates for services rendered. Usually the standards and guidelines of quality management focus on the organizational and administrative component.

Management of technological component provides the quality management of the enterprise. This component is responsible for the definition and implementation of the objectives, for the analysis of quality of the processes throughout the enterprise and for the detailed description of how sub-systems of quality management relate with the technological subsystems. Unfortunately, in international and Kazakhstan's standards of quality, this component is described in general terms and does not give a practical guide to the management of the enterprise.

To ensure the normal functioning of the technological process and organizational structure of the enterprise and all

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business units is created. Thus, the technological part of the heat-supply plant usually includes, the main production part (heat sources e.g. heat plant, auxiliary heat plants), thermal network, supporting production, administrative and management units, production and maintenance staff, and customer service.

Since the main purpose of DHS work is ensuring the reliable and adequate heat supply at a minimum cost of resources while complying with environmental standards, it is necessary to introduce a system to achieve this goal and to evaluate the quality of functioning of the enterprise [7]. Often, one system cannot solve a number of requirements and problems, so most companies are implementing complex systems integrated into one. Example control systems include Quality Management System (QMS), Balanced Scorecard (BSC) system and key performance indicators (KPI). These systems are implemented in the company by a "top-down" approach and function according to the Plan-Do-Check-Act (PDCA) cycle [8], developed by American scientists Deming and Shewhart, which is characterized by continuous improvement of enterprise activity as a result of each cycle.

Our analysis shows that the integration of these systems into heat supply enterprise may allow to:

- continuously improve operations to meet the needs of consumers, employees, shareholders, management, and society;
- improve the quality of heat supply control;
- ensure the preservation and energy efficiency throughout the entire service lifecycle;
- improve the balance sheet by reducing costs;
- effectively manage district heating enterprise;
- improve the reliability of feed and return lines;
- account and monitor the efficiency of employees.

III. The Choice of Platform and Development of an Automated QMS

The implementation of the QMS requires the development and constant monitoring of a huge number of documents and indicators, which are essential for any enterprise operations. Therefore, to create an automated QMS and allow for its further development, it is necessary to use a modern information technology.

We examined and analyzed characteristics and system capabilities of the most common software packages for the development and certification of quality management system for heat supply enterprises such as: ARIS Toolset; Business Studio; FOX Manager ISO; ISO Vision; TRIM QMS; IS Oratnic; ORG - Master of the QMS. The Business Studio system was deemed most efficient and was selected for further work.

Within the Business Studio environment the development process, implementation of the QMS and the maintenance of the system in working condition were performed by a standard procedure [2]-[4]:

1) Setting objectives of the QMS by analyzing the requirements and wishes of all involved parties.
2) Achievement of aforementioned objectives through the optimization of enterprise work, i.e. the application of process approach in QMS implementation.
3) Monitoring and control of both technological and financial parameters and indicators during optimization cycles.
4) Development of QMS documentation and its maintenance according to the requirements of ISO 9001.
5) Creation of a section of the QMS documentation packages for the company and setting the special composition of elements included in a quality manual;
6) Development of automatic report structures, which cover standards for both businesses and ISO 9001.

IV. Development of an Expert System to Analyze the Effectiveness of the QMS

Analysis of quality management systems according to ISO 9001 [9] accomplishes the task of the continuous improvement of business operation by making decisions based on analysis of the following data:

a) Achievement of goals;
b) Customer satisfaction;
c) Results of internal and external audits;
d) The proper functioning of the processes;
e) Completeness of documentation;
f) The degree of implementation of monitoring and preventive actions (MPA);
g) The implementation of decisions of prior analyzes and recommendations for improvement;
h) Proposals for changes that should be made in the QMS aiming at its improvement.

A large number of input data increases the complexity of the model both in case of precise (complex mathematical models) and fuzzy (large rule base). Therefore, we used the above data as input parameters for the fuzzy inference part, on which a two-stage evaluation model system was set. At the first level of the model as the following input data are used: the correct description of the developed processes and inconsistencies that have arisen in the process or have been found as a result of the audit. These input variables will determine the correctness of operation of processes.

On the second level, the rest of the data is used, e.g. completeness of objectives and processes (output parameter level 1), customer satisfaction and implementation of monitoring and preventive actions, including information on the outcome of the previous analysis.

Creation of systems for analysis of qualitative tasks (QMS) includes qualitative (linguistic) and quantitative (data) information necessary to build and implement the system. In view of this, we propose a method of designing fuzzy systems, which allows combining the numerical information linguistically, by supplementing the existing rules framework, created on the basis of numerical data.

To create fuzzy inference system in interactive mode (user interface) in the selected system Matlab we used a package

Simulink, containing Fuzzy Logic Library. To create an application for the analysis of the QMS in Fuzzy Logic for the two-stage model it is necessary to implement two fuzzy inference systems, whereby the output from the first level serves as an input for the second level. With this consideration in mind, the first level of the developed method includes the following steps:

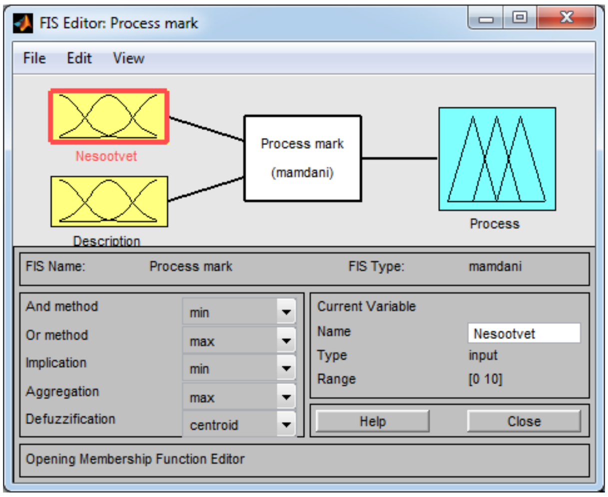

Fig. 1 The system to determine the functioning of the process

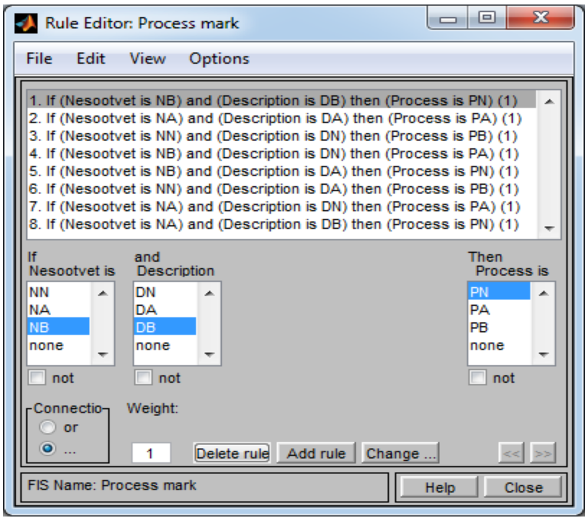

Fig. 2 Creating a rule base in Matlab

1) Creating a database of rules for determining the operation of the process (Fig. 1), comprising two inputs (the correct description - descript, inconsistencies - nesootvet) and one output (correct functioning of the process - process)
2) Development of the rule base on the basis of expert evaluations
3) Assigning each rule the truth degree
4) Creation of a rule base (Fig. 2)
5) Visualizing the adequacy of the developed model assessing the impact of the input variables to the output via the viewer surface fuzzy inference (Fig. 3).
6) Defuzzification using the selected center of gravity method:

$$y = \frac{\int_{\min}^{\max} x \cdot \mu(x)}{\int_{\min}^{\max} \mu(x)} \qquad (1)$$

7) Checking for the adequacy of the developed model in the system viewer of the rules (Fig. 4).

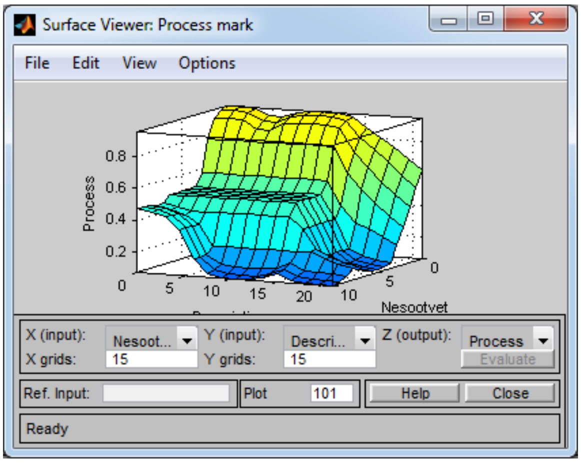

Fig. 3 The surface of the fuzzy system definition

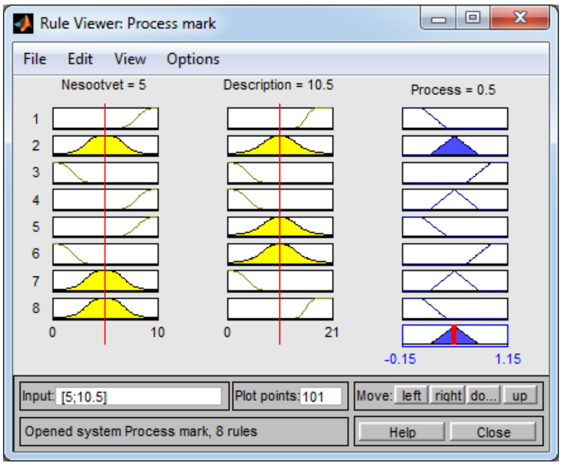

Fig. 4 Viewer fuzzy inference rules for values $x_1 = 5, x_2(i) = 10.5$

TABLE I
THE TEST RESULTS OF THE CREATED MODEL OF FUZZY INFERENCE

№	Nesootvet	Description	Process	δ,%
1	1	1	0.844	4,09
2	5	10.5	0.5	0,00
3	9	20	0.0901	0,14
4	2	19	0.409	5,00
5	8	2	0.437	2,89
6	7	7	0.451	1,96
7	4	15	0.354	1,67
8	3	14	0.527	1,35

Results of the analysis system are shown in Table I. Due to the fact that the relative error does not exceed the 5% in relation to expert data, we consider a model to be developed adequately.

Creating of a second level of functioning of QMS assessment model is similar to creating the first level:

1) Input variables:

- The degree of achievement of the objectives– Goal (min=0, max=100);
- Correctness of operation processes– Process (min=0, max=1);
- The Degree of customer satisfaction– Custom (min=0, max=1);
- The degree of implementation of monitoring and preventive actions (min=0, max=100).

Output model is the evaluation of the efficiency of QMS– Mark (0-100).

TABLE II
THE RULE BASE OF A 2-LEVEL MODEL

№	Goal	Process	Custom	MPA	Mark
1	NG	PN	CN	NKD	1
2	AG	PN	CN	NKD	1
3	BG	PN	CN	NKD	2
4	NG	PA	CA	AKD	2
5	AG	PA	CA	AKD	3
6	BG	PA	CA	AKD	4
7	NG	PB	CB	BKD	3
8	AG	PB	CB	BKD	5
9	BG	PB	CB	BKD	5
10	NG	PA	CN	NKD	1
11	NG	PB	CN	NKD	2
12	AG	PN	CA	AKD	2
13	AG	PB	CA	AKD	4
14	BG	PN	CB	BKD	3
15	BG	PA	CB	BKD	5
16	NG	PN	CA	NKD	1
17	NG	PN	CB	NKD	1
18	AG	PA	CN	AKD	3
19	AG	PA	CB	AKD	4
20	BG	PB	CN	BKD	4
21	BG	PB	CA	BKD	5
22	NG	PN	CN	AKD	1
23	NG	PN	CN	BKD	1
24	AG	PA	CA	NKD	3
25	AG	PA	CA	BKD	4
26	BG	PB	CB	NKD	4
27	BG	PB	CB	AKD	5
28	NG	PB	CN	BKD	2
29	NG	PB	CA	BKD	2
30	NG	PB	CB	AKD	3

2) Division into regions (term sets) and setting membership functions:

- Goal: NG (goals are not met - bad), NA (good), NB (excellent);
- for *Process* data are similar to the 1st level of the model;
- Custom: CN (not satisfied), CA (moderately satisfied), CB (satisfied).
- implementation of MPA: NKD (bad), AKD (good), BKD (excellent);
- Mark: 1, 2, 3, 4, 5.

Since the variables are "Goal" and "MPA" are purely numerical data, the membership functions of these variables are selected from the formulas that lead to their fuzziness. For variables "Custom" and "Mark" membership functions are also calculated.

3) Creation of a rule base model for peer review and optimization of its powers at the expense of the truth of the rules (the total number of rules $T^{вх/вер} = 3^4 = 81$, after optimization is 30, Table II).
4) Check for adequacy of the rule base on the basis of surface analysis. The results of testing of the model have yielded positive results (Table III).

V. CONCLUSION

The testing of the system allows making judgments about its adequacy with regard to the established rules (relative error does not exceed preset 5%). Since the system is adapted specifically to the heat supply enterprises that have no interest in attracting customers, the rules containing large values of the variable “Custom”, do not have a strong influence on the final result.

TABLE III
TESTING OF THE CREATED MODEL

№	Goal	Process	Custom	KD	Mark	δ,%
1	1	0	0	1	7,8	1,27
2	60	0	0	1	8,47	0,35
3	90	1	0	1	27,7	4,15
4	2	0,55	0,55	55	35,7	4,08
5	50	0,5	0,5	50	52,4	0,19
6	98	0,55	0,55	55	73,7	3,03
7	5	0,98	0,98	98	56,2	1,44
8	50	0,97	0,9	97	99,7	1,12
9	100	1	1	100	100	0,20
10	7	0,6	0,2	60	52,2	0,38
11	7	0,95	0,2	10	31	0,00
12	55	0,25	0,55	55	38,6	0,52
13	55	0,85	0,55	55	81,2	0,12
14	85	0,25	0,95	95	58,8	0,00
15	85	95	0,65	0,95	98	0,10
16	2	0,2	0,6	20	11,4	2,70
17	2	0,2	0,8	20	14,9	2,76
18	55	0,6	0,2	60	52,4	0,38
19	55	0,6	0,8	60	67,1	0,00
20	95	0,95	0,05	95	81,2	0,12
21	95	0,95	0,5	95	99,1	0,00
22	15	0,15	0,15	50	8,73	0,80
23	15	0,15	0,15	90	8,73	0,80
24	40	0,5	0,5	10	51,7	0,58
25	40	0,5	0,5	90	76,7	0,65
26	97	0,97	0,97	7	81,5	0,00
27	97	0,97	0,97	67	99,6	0,20
28	5	0,97	0,17	97	31	0,00
29	5	0,97	0,57	97	32,1	0,94
30	5	0,97	0,97	57	52,4	0,38

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