Tasks and algorithms in decision making for optimization of working regimes for oil pipelines in a fuzzy environment

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Abstract. This research paper details research into selection and decision making for the optimisation of technological installations in conditions of multi-criteria and fuzzy input data. In the example of main oil pipeline complexes, new mathematical equations were derived for this task and dialogue algorithms to solve them were also developed in order, by means of modification of optimisation principles and compromise decision making schemes. The novelty and originality of the proposed approach lie in the possibility of solving the input task in a fuzzy environment without first transforming to the equivalent determinate variables, which allows for a more accurate and a more adequate solution to the given task. In this paper, one of the algorithms which has been developed (Fuzzy Optimisation Algorithm 3), is used in order to solve the task of effective control of working regimes for heating stations on the Uzen – Samara oil pipeline as it passes through Atyrau.

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Introduction

In practise, there are many situations which call for decision making (selection) for the optimal control of technological installations which are characterised by multiple criteria, that is economic (productivity, profit, cost price etc) technological (quantity, product quality, adherence to technological regimes etc) and ecological (environmental impact, emissions, waste) criteria vectors as well as fuzzy input data. The complexity, large number of parameters and multiple criteria of such industrial installations, as well as the lack of and fuzzy nature of input data, complicate the formulation of mathematical equations and solution of such problems. [1, 2, 3, 4].

Recently, in scientific literature and publications there has been much discussion of this problem and of approaches to the solution of decision making tasks with multiple criteria [5, 6], including those cases with fuzzy input data [6, 7, 8, 9, 10, 11]. Methods for solving these problems in a fuzzy environment are based on the use of methods based on fuzzy set theory [2, 7, 12, 13, 14]. In research papers [15, 16] problems in the selection of optimal routes for main oil pipe lines are discussed and problems in the formulation and solution of tasks with multiple criteria for the selection of optimal parameters and working regimes for technological complexes are considered in papers [3, 6, 7, 8, 17].

This paper researches and presents a solution to the tasks of decision making for optimal control of working regimes for technological installations, major oil pipelines, which are related to the important scientific and practical questions of decision making theory, fuzzy set theory and possibilities, mathematical modelling methods and multi-criteria optimisation and are currently very relevant in the oil transportation field.

In the formulation and solution of these problems, the ideas of compromise decision making schemes, modified and adapted to conditions of fuzzy input data are used[17, 18, 19].

II. Formulation of the Problem:

The problem of decision making can be formulated as follows:

<Decision making tasks> = {given V, V_S, V_P, with obligatory provision of W},

where V is the given condition; V_S is the set of possible states of the object; V_P is the set of possible operators which provide for the transfer of the object from one state to another; W is the desired state of the object. In so doing, the solution of the task of decision making is includes the selection of the operators' order for the transfer of the object from the current state to the required state. In this way, decision making is a process which includes the evaluation of possible decisions (alternatives) and, taking into account the given conditions, carries out the selection of the best version for the given criteria.

The aim of this paper is the characterization and formulation of new multi-criteria tasks for decision making, taking into account the fuzziness of input data, and also the development of effective dialogue algorithms for their solution. In order to achieve this, known ideas of optimization principles and compromise decision making schemes which are modified and adapted to conditions of fuzzy input data are used.

Optimization includes the evaluation of possible decisions, which allow for the selection of the one which is best according to the given economic and ecological criteria. [18].

Let $f(x) = f_1(x),\dots, f_m(x)$ be the criteria vectors, evaluating the quality of the working of the pipeline system. For example, $f_1(x), f_2(x),\dots, f_k(x)$ are the production volume, profit etc, accordingly; $f_{k+1}(x), f_{k+2}(x),\dots, f_m(x)$ are the local criteria values for ecological safety, for example, expenses for protection measures, damage caused by pollution of the environment from oil, oil products and transport emissions etc. Each of *m* criteria depends on a vector of *n* parameters (control actions, regime parameters) $x = (x_1,\dots,x_n)$, for example: temperature and pressure; the flow characteristics of the raw material, expenses for reagents etc. In practise, there are always various limits (economic, technological, financial, ecological) which can be described by several limit functions $\varphi_q \ge b_q$, $q = \overline{1,L}$. Regime control parameters also have their own change intervals, which are given by the technical limits of the system and the demands of nature protection measures: $x_i \in \Omega = [x_i^{\min}, x_i^{\max}]$, where $x_i^{\min}$ is the lower and $x_i^{\max}$ is the upper limit of change of the parameter x_i. The limits may be fuzzy: $\tilde{>}$ greater than or about equal to, $\tilde{<}$ less than or about equal to, $\cong$ – about equal to.

Decisions must be made by selecting the most effective (optimal) solution – the optimal working regime for the main oil pipe line system, which provides for the critical values of the criteria vectors while satisfying the given limits and taking into account the preference of the Decision Maker ie the director or Production staff. In our case, the DMs are the operators who control the oil pumping regimes for the pipeline and control and select the working regimes for components of the pipe line system, for example re-pumping stations (pumps) or oil heating stations, which ensure the optimal values of local control criteria: pumped volume, safety and reliability regime etc.

Results

We have formulated the mathematical equation describing the task of optimal decision making for the control of oil pipelines in conditions of multiple criteria and fuzzy input data.

Let there be a normalised vector of criteria in the form of $\mu_0(x) = (\mu_0^1(x),\dots,\mu_0^m(x))$ and *L* be a limit with fuzzy instructions $f_q(x) \tilde{>} b_q$, $q = \overline{1,L}$. Supposing that the membership function which satisfies the limit $\mu_q(x)$, $q = \overline{1,L}$ for each limit is constructed as the result of expert procedures and dialogue with the DM and with experts / specialists. Let the weighting factors reflecting the mutual importance of the criteria ($\gamma = (\gamma_1,\dots,\gamma_m)$) and limits ($\beta = (\beta_1,\dots,\beta_L)$) at the moment of formulation of the task [20, 21] be known.

In this case, the task of selecting the optimal working regimes for main oil pipelines, taking into account economic and ecological criteria, can be written in the form of the following equation for decision making in a fuzzy environment:

$$\max_{x \in X} \mu_0^i(x),\ i = \overline{1,m}$$

$$X = \{x : \arg\max_{x \in \Omega} \mu_q(x),\ q = \overline{1,L}\}$$

based on ideas of *the key factor method and Pareto Optimisation Principle* we derive the general optimisation formula with several criteria and limits [22, 23] which can be written as follows:

$$\max_{x \in X} \mu_0^1(x), \tag{1}$$

$$X = \left\{ x : x \in \Omega \wedge \arg\left(\mu_0^i(x) \ge \mu_r^i\right) \wedge \arg\max_{x \in \Omega} \sum_{q=1}^{L} \beta_q \mu_q(x) \wedge \sum_{q=1}^{L} \beta_q = 1 \wedge \beta_q \ge 0, i = \overline{2,m},\ q = \overline{1,L} \right\} \tag{2}$$

where $\wedge$ is the logical symbol «AND», requiring that all related assertions are TRUE, μ_r^i

is the threshold value for local criteria $\mu_0^i(x), i=\overline{2,m}$, as appointed by the DM.

In accordance with the key factor method, the key (most important) criteria are optimised, and the remaining local criteria become part of the limits. According to the Pareto Optimisation Principle, the DM selects the optimal solution from effective sets, for which the improvement of one value leads to the worsening of another.

By changing μ_r^i and the vector for the importance of the limits $\beta=(\beta_1,...,\beta_L)$, it is possible to derive a family of solutions (1) – (2): $x^*(\mu_r,\beta)$. The choice of the best solution is carried out by means of dialogue and taking into account the DM's preference. In order to solve multi-criteria tasks for decision making with the formulae (1) – (2) it is suggested that the following dialogue algorithm, based on the modification and combination of the key factor principle and Pareto optimisation in a fuzzy environment are used. .

Fuzzy Optimisation Algorithm 1.

2. Given $p_q, q=\overline{1,L}$ - the number of steps for each q^{th} coordinate and the range of priorities for local criteria $I_k=\{1,...,m\}$ (the main criteria must have priority 1), the values of limit weighting vectors are entered $\beta=(\beta_1,...,\beta_L)$, taking into account the importance of the local limits.

3. The DM appoints the threshold values (limits) for local criteria $\mu_r^i(x), i=\overline{2,m}$.

4. $h_q=1/p_q, q=\overline{1,L}$ is determined ie the step size for changes to the coordinates of the weighting vector β.

5. The group of weighting vectors $\beta^1,\beta^2,...,\beta^N$ are determined, $N=(p_1+1)(p_2+1)...(p_L+1)$, , with a variation of coordinates at intervals of [0.1] with steps h_q.

6. Term sets $T(X,Y)$ are determined and the membership function which satisfies the limits $\mu_q(x)$, $q=\overline{1,L}$ is constructed.

7. The key factor is maximised (1) for set *X*, determined by (2), resulting in the following: $x(\mu_r^i,\beta)$, $\mu_0^1(x(\mu_r^i,\beta)),...,\ \mu_0^m(x(\mu_r^i,\beta))$; $\mu_1(x(\mu_r^i,\beta)),...,\ \mu_L(x(\mu_r^i,\beta)),\quad i=\overline{2,m}$.

8. The decision is presented to the DM. If the current results do not satisfy the DM, then the DM assigns new values $\mu_r^i(x), i=\overline{2,m}$ and (or) and the value of β is corrected, after which it is necessary to return to point 3. Otherwise, proceed to point 8.

9. The search for a solution comes to an end, resulting in the final choice of the DM: the value of the control vector $x^*(\mu_r^i,\beta)$; the values of local criteria $\mu_0^1(x^*(\mu_r^i,\beta)),...,\ \mu_0^m(x^*(\mu_r^i,\beta))$ and the degree of satisfaction of limits $\mu_1(x^*(\mu_r^i,\beta)),...,\mu_L(x^*(\mu_r^i,\beta))$.

We are considering the industrial situation, when it becomes necessary to look at the task of optimal decision making in the presence of several criteria (objective function) $\mu(x)=(\mu_0^1,...,\mu_0^m)$ and fuzzy limits with a membership function $\mu_q(x),\ q=\overline{1,L}$, with a known range of priorities $I=\{1,...,m\}$ or known weighting vector for the mutual importance of local criteria $\gamma=(\gamma_1,...,\gamma_m),\gamma_i\geq 0, i=\overline{1,m}$, $\gamma_1+\gamma_2+...+\gamma_m=1$

Then it becomes possible to formulate the following equation for the multi-criteria task of decision making in a fuzzy environment:

$$\max_{x\in X}\mu_0^i(x),\quad i=\overline{1,m}$$

$$X=\left\{x:\arg\max_{x\in\Omega}\sum_{q=1}^{L}\beta_q\mu_q(x)\wedge\sum_{q=1}^{L}\beta_q=1\wedge\beta_q\geq 0\ q=\overline{1,L}\right\}$$

Such a formula is rarely able to be solved, as it requires that *m* objective functions reach a maximum at one point.

The universal solution in such an instance is to construct a Pareto set and for the DM to choose the best solution from this set:

$$\max_{x\in X}\mu_0(x),\ \mu_0(x)=\sum_{i=1}^{m}\gamma_i\mu_0^i(x), \quad (3)$$

$$X=\left\{x:\arg\max_{x\in\Omega}\sum_{q=1}^{L}\beta_q\mu_q(x)\wedge\sum_{q=1}^{L}\beta_q=1\wedge\beta_q\geq 0,\ q=\overline{1,L}\right\} \quad (4)$$

In order to solve the selection equations (3) – (4), we have derived a new algorithm, based on a modification of the ideas of the Pareto Optimisation Principle for working in conditions of fuzzy input data, which is made up of the following steps:

Fuzzy Optimisation Algorithm 2.

1) The values of the weighting vector, evaluating the mutual importance of the local criteria (objective function) $\gamma = (\gamma_1,...,\gamma_m)$, $\gamma_i \geq 0, i = \overline{1,m}$, $\gamma_1 + \gamma_2 + ... + \gamma_m = 1$ are determined based on expert evaluations.

2) $p_q, q = \overline{1,L}$ is the number of steps for each q^{th} coordinate is given.

3) $h_q = 1/p_q, q = \overline{1,L}$, the size of the steps for changes in the coordinates of the weighting vector β is determined.

4) The group of weighting vectors $\beta^1, \beta^2,..., \beta^N$ and $N = (p_1+1)\cdot(p_2+1)...(p_L+1)$, the variation in coordinates at intervals of [0.1] with steps of h_q. are determined.

5) If $\mu_0^i(x), i = \overline{1,m}$ and / or γ is found to be fuzzy, then a term set is determined for them, and a membership function is constructed for the limits, that is a degree of satisfaction of the limits $\mu_q(x)$, $q = \overline{1,L}$ is determined.

6) Equations (3) – (4) are solved:

$$\max_{x\in X} \mu_0(x) = \max_{x\in X} \sum_{i=1}^{m} \gamma_i \mu_0^i(x).$$

for the set X , as determined by (4) and a group of solutions are determined for various values of the weighting vector: the value of the control vector - $x(\gamma,\beta)$; the values of local criteria - $\mu_0^1(x(\gamma,\beta)),...,\mu_0^m(x(\gamma,\beta))$ and the degree of satisfaction of the limits - $\mu_1(x(\gamma,\beta)),...,$ $...\mu_L(x(\gamma,\beta))$.

7) The group of solutions which is thus determined is presented to the DM for analysis and choice of the best one. If the current solution satisfies the DM, then proceed to step 8, otherwise the value of γ and (or) β is corrected and it is necessary to return to point 2.

8) The final decision, which satisfies the DM is determined: the value of control and regime parameters $x^*(\gamma,\beta)$ which provide the optimal values for local criteria $\mu_0^1(x^*(\gamma,\beta)),...,\mu_0^m(x^*(\gamma,\beta))$ and the maximum values of membership functions which satisfy the limits $\mu_1(x^*(\gamma,\beta)),..., \mu_L(x^*(\gamma,\beta))$.

By modifying various compromise schemes for decision making for cases of fuzziness, we can derive other formulae for the multi-criteria task of decision making in a fuzzy environment and propose algorithms for their solution.

Using ideas from *key factor and ideal point* methods, then combining and modifying them for cases of fuzziness, the multi-criteria task for decision making in the event of fuzzy input data can be formulated in the following manner:

$$\max_{x\in X} \mu_0^1(x), \tag{5}$$

$$X = \{x : x \in \Omega \wedge \arg\left(\max_{x\in\Omega} \max \mu_0^i(x) \geq \mu_r^i\right) \wedge \arg \mu_q(x) \geq \min \|\mu(x) - \mu^u\|_D), i = \overline{2,m}, q = \overline{1,L}\} \tag{6}$$

where $\|\mu(x) - \mu^u\|_D$ - is the metric *D* being used and the components $\mu(x)$ and coordinates of the ideal point μ^u are determined as follows $\mu(x) = (\mu_1(x),...,\mu_L(x))$, $\mu^u = (\max \mu_1(x),..., \max \mu_L(x))$. Possible variables are used as coordinates of the ideal point μ^u units: $\mu^u = (1,...,1)$.

The essence of the key factor method has been expanded above. The ideal point method allows the optimal solution based on the minimisation of the measure (distance) of the current decision from the ideal decision (point) to be found.

In order to solve the multi-criteria formulae (5) – (6) for decision making, the method proposed in this paper has been developed based on a modification of compromise schemes of the *key factor and ideal point methods.*

Applying ideas from the key factor method to the local criteria vector, and the idea of the ideal point method to the limits, then modifying them for a fuzzy environment, we propose the following algorithm for solving multi-criteria formulae for decision making (5) – (6) in cases of fuzzy input data.

Fuzzy Optimisation Algorithm 3:

- The range of priorities for local criteria $I_k = \{1,...,m\}$ is given (the main criterium should have priority 1).
- Based on information received from the DM, the term set for fuzzy parameters *T(X,Y)* is determined by experts / specialists and for each limit the membership function satsifying the limit $\mu_q(x)$, $q = \overline{1,L}$ is constructed.
- The DM assigns threshold values for the local criteria $\mu_r^i(x), i = \overline{2,m}$.
- Coordinates of the ideal point are determined. The maximum values of the membership function $\mu^u = (\max \mu_1(x),..., \max \mu_L(x))$ of the units $\mu^u = (1,...,1)$ (if the membership functions are normal) can be used as the coordinates of the ideal point.
- The type of metric $\|\mu(x) - \mu^u\|_D$ is chosen, and the distance of the current solution x^* from the ideal point - μ^u is determined.
- Equations (5) – (6) are solved and the current solution is determined: $x(\mu_r^i, \|\mu(x) - \mu^u\|_D)$ - the value of the control parameter vector, $\mu_0^1(x(\mu_r^i, \|\mu(x) - \mu^u\|_D))$, $\mu_0^2(x(\mu_r^i, \|\mu(x) - \mu^u\|_D))$, …, $\mu_0^m(x(\mu_r^i, \|\mu(x) - \mu^u\|_D))$ - the values of local criteria and $\mu_1(x(\mu_r^i, \|\mu(x) - \mu^u\|_D))$, $\mu_2(x(\mu_r^i, \|\mu(x) - \mu^u\|_D))$, …, $\mu_L(x(\mu_r^i, \|\mu(x) - \mu^u\|_D))$, $i = \overline{2,m}$ - the values of the membership function satisfying the limits.
- The current solution which has been derived is presented to the DM. If the current solution does not satisfy the DM, then he (she) assigns new values $\mu_r^i(x)$, and (or) a new type of metric $\|\mu(x) - \mu^u\|_D$ is chosen and the search for an acceptable solution is repeated, that is it is necessary to return to the previous point, otherwise proceed to the next point (8).
- The final solution, which satisfies the DM, is found: the values of control and regime parameters $x^*(\mu_r^i, \|\mu(x) - \mu^u\|_D)$, which provide for the optimal values of local criteria $\mu_0^1(x^*(\mu_r^i, \|\mu(x) - \mu^u\|_D))$, $\mu_0^2(x^*(\mu_r^i, \|\mu(x) - \mu^u\|_D))$, …, $\mu_0^m(x^*(\mu_r^i, \|\mu(x) - \mu^u\|_D))$ and maximum values of the membership function satisfying the limits $\mu_1(x^*(\mu_r^i, \|\mu(x) - \mu^u\|_D))$, $\mu_2(x^*(\mu_r^i, \|\mu(x) - \mu^u\|_D))$, …, $\mu_L(x^*(\mu_r^i, \|\mu(x) - \mu^u\|_D))$.

The formulation of the new tasks for multi-criteria selection which are shown, and the algorithms which have been developed in order to solve them are based on the modification of determinate methods of multi-criteria optimisation and compromise decision making and optimisation schemes. The results which are thus derived are in fact an enriching and development of these methods for cases of fuzzy input data.

Practical Application, Comparisons and Discussion of Results

As an example, the proposed approach has been applied to the formulation of equations and the solution of the task of choosing an efficient working regime for heating stations on the Uzen – Samara oil pipeline as it passes through Atyrau. The main function of the oil heating station is to provide for the safe and continuous working of the heaters and their related equipment, and also to maintain the optimal technical working of the 'hot' oil pipeline. In so doing, the following decision making tasks in order to optimize criteria are involved:

- the minimization of the cost price for oil heating and pumping;
- the minimization of fuel and operation costs;
- the maximization of the pumped volume and labour productivity;
- an increase in the degree of reliability of the mechanism and apparatus;
- an increase in the ecological safety of the oil pipeline.

The volume of oil pumped can be determined by the indicators of various apparatus (flow meters etc.) In our case, the pumped oil volume is measured in tons / hour [705-725]. As for evaluating the quality and ecological safety, this is much more complicated. Evaluating the quality of the working of technological and industrial oil pipeline systems or the ecological safety of the working of the object with a single figure is very difficult and not always possible. Often these indicators are difficult to measure quantitatively and are characterised by uncertainty and fuzzy input data. In essence, qualitative indicators and indicators for ecological safety are often characterised by limits such as 'not more than' or 'about' that is they are fuzzy.

In practise, it is desirable that economic criteria (productivity, profit, pumped oil volume etc) and qualitative indicators are maximised, and that ecological impact on the environment is minimised. However, it is well known that the criteria are often conflicting and it is often not possible to improve them simultaneously. The task at hand, is to find the optimal solution which is a compromise, depending on the industrial situation and plans, and also one which satisfies the DM.

Thus, using the above mentioned formulations of the task, the task of decision making for an optimal regime of processes involved in the transportation of oil along the main oil pipeline can be given as follows:

Let $f(x) = F(f(x)) = \mu_0^i(x), i = \overline{1,3}$ – the normalised local criteria evaluating the pumped oil volume ($\mu_0^1(x)$), temperature ($\mu_0^2(x)$) and pressure ($\mu_0^3(x)$) at the heater output. Suppose that for each fuzzy limit describing the ecological indicators $\varphi_q(x) \gtrsim b_q, q = 1,2$, a membership function to satisfy it $\mu_q(x)$, $q = 1,2$ is constructed. The range of priorities for local criteria $I_k = \{1,2,3\}$ and a weighting vector, reflecting the mutual importance of these limits. $\beta = (\beta_1, \beta_2)$ are either known or derived.

Criteria and limits depend on the parameter vector $x_i, i = \overline{1,4}$ (x_1 – temperature, x_2 - pressure, x_3 - fuel used, x_4 - oil output at the heater exit). These dependencies are determined based on mathematical models which have been developed in research papers [24, 25].

The tasks which have been formulated for a fuzzy environment with some fuzzy input data can be written similar to (5) – (6) in the form of the following multi-criteria tasks for fuzzy optimization (fuzzy mathematical programming) for working regimes for oil pipeline systems:

$$\max_{x \in X} \mu_0^1(x), \tag{5}$$

$$X = \left\{x : x \in \Omega \wedge (f_i(x) \geq b_i) \wedge \arg\left(\mu_q(x) \geq \min_{x \in \Omega} \left\|\mu(x) - \mu^u\right\|_D\right) i = 2,3, q = 1,2\right\} \tag{6}$$

where $f_i(x), i = 2,3$ – is the limit function for temperature and pressure at the exit of the oil heating station, $\left\|\mu(x) - \mu^u\right\|_D$ is the D metric which is used, $\mu(x) = (\mu_1(x), \mu_2(x))$, $\mu^u = (\max \mu_1(x), \max \mu_2(x))$ or $\mu^u = (1,.1)$.

The solution to this task is the value of the vector for optimisation of regime parameters $x^* = (x_1^*, x_2^*, x_3^*, x_4^*)$ which provides for the extreme values of the criteria while still satisfying the given limits and being the preference of the DM or satisfying him or her.

In order to solve equations (5) – (6) we use a modification of the algorithm, Fuzzy Optimization Algorithm 3.

A range of priories is given for local criteria $I_k = \{1,2,3\}$ (the main criteria are determined to be the pumped oil volume for the pipeline which has priority 1, the temperature at the heater output has priority 2 and the pressure at the heater output has priority 3).

Based on information received from the DM, experts / specialists determine the term set for fuzzy parameters and a membership function satisfying the limits, is constructed for each limit $\mu_q(x)$, $q = 1,2$.

Based on the results of the evaluation carried out by experts and research, the following membership functions satisfying the limits have been constructed:

$$\mu_1(x) = \exp(0.20\,|\,a_1 - 50.0\,|\cdot 0.5);$$
$$\mu_2(x) = \exp(0.10\,|\,a_2 - 80.0\,|\cdot 0.7);$$

where a_1, a_2 are the average numerical values of fuzzy parameters: temperature and pressure at the exit of the heater (oil heating station) accordingly.

The type of limit function $f_i(x), i = 2,3$ is determined and values are given $b_i, i = 2,3$. Based on the research results which have been obtained, the following are determined:

$$f_1(x) = 7 + 1{,}2 \cdot x_1 - 0.25 \cdot x_2 + 5.7 \cdot x_3 -$$

$1.3 \cdot x_4 + 1.8 \cdot x_1^2 + 8.3 \cdot x_3^2;\ b_1 = 55$,
$f_2(x) = 0.25 - 1.31 \cdot x_1 + 7.35 \cdot x_2 - 3.1 \cdot x_3 + 2.25 \cdot x_4 + 9.85 \cdot x_2^2 + 8.7 \cdot x_3^2;\ b_2 = 8.5$

The coordinates of the ideal point are determined. The maximum values of the membership function can be used as the coordinates of this point. In our case, the membership function is normal, therefore $\mu^u = (1,1)$.

The type of metric $\|\mu(x) - \mu^u\|_D$ is chosen, which determines the distance of the current solution ($\mu(x)$) from the ideal point (μ^u). In our case the type of metric is determined as follows:

$$\|\mu(x) - \mu^u\|_E^2 = \sum_{q=1}^{2} (\beta_q (\max_{x\in\Omega} \mu_q(x) - \mu_q(x)))^2,$$

where β_q is the weighting coefficient of the q^{th} fuzzy limit.

The optimisation equations (5) – (6) are solved (in our case mathematical programming methods are used) and the current solution is determined:

- $x(b_i, \sum_{q=1}^{2} (\beta_q (\max_{x\in\Omega} \mu_q(x) - \mu_q(x)))^2)$, $i = 2,3$ is the value of the vector for control parameters;
- $\mu_0^1(x(b_i, \sum_{q=1}^{2} (\beta_q (\max_{x\in\Omega} \mu_q(x) - \mu_q(x)))^2))$, $\mu_0^2(x(b_i, \sum_{q=1}^{2} (\beta_q (\max_{x\in\Omega} \mu_q(x) - \mu_q(x)))^2))$, $\mu_0^3(x(b_i, \sum_{q=1}^{2} (\beta_q (\max_{x\in\Omega} \mu_q(x) - \mu_q(x)))^2))$, $i = 2,3$ are the values of local criteria;
- $\mu_1(x(b_i, \sum_{q=1}^{2} (\beta_q (\max_{x\in\Omega} \mu_q(x) - \mu_q(x)))^2))$, $\mu_2(x(b_i, \sum_{q=1}^{2} (\beta_q (\max_{x\in\Omega} \mu_q(x) - \mu_q(x)))^2))$, $i = 2,3$ is the value of the membership function satisfying the limits.

The DM is shown the current solution. If the current results do not satisfy the DM, then new threshold values $\mu_r^1(x)$, $\mu_r^2(x)$ are assigned by him or her and (or) a new type of metric $\|\mu(x) - \mu^u\|_D$ is chosen and the search of an acceptable solution is repeated, that is it is necessary to return to the previous step, otherwise proceed to the next point (8).

The final solution, which satisfies the DM, is determined: the values of control and regime parameters $x^*(b_i, \sum_{q=1}^{2} (\beta_q (\max_{x\in\Omega} \mu_q(x) - \mu_q(x)))^2)$ which provide for optimal values of local criteria $\mu_0^1(x^*(b_i, \sum_{q=1}^{2} (\beta_q (\max_{x\in\Omega} \mu_q(x) - \mu_q(x)))^2))$, $\mu_0^2(x^*(b_i, \sum_{q=1}^{2} (\beta_q (\max_{x\in\Omega} \mu_q(x) - \mu_q(x)))^2))$, $\mu_0^3(x^*(b_i, \sum_{q=1}^{2} (\beta_q (\max_{x\in\Omega} \mu_q(x) - \mu_q(x)))^2))$ and maximum values for the membership functions satisfying the limits

$$\mu_1(x^*(b_i, \sum_{q=1}^{2} (\beta_q (\max_{x\in\Omega} \mu_q(x) - \mu_q(x)))^2)),$$
$$\mu_2(x^*(b_i, \sum_{q=1}^{2} (\beta_q (\max_{x\in\Omega} \mu_q(x) - \mu_q(x)))^2)).$$

The results which have been obtained are shown in Table 1. (see Table 1).

The comparison and analysis of results shown in Table 1 provides a basis for the following conclusions:

1) The proposed algorithm is more effective in comparison with the determinate method and more accurately concurs with experimental data.

2) In using the proposed algorithms to solve the optimisation task, the adequacy of the solution to the industrial problem is increased, since additional fuzzy data (experience, knowledge) is taken into account and the actual situation is more fully described without being idealised.

3) Applying the algorithm for the solution of multi-criteria tasks for optimal decision making (*Fuzzy Optimisation Algorithm 3*) allows the degrees (function) of membership satisfying one or other of fuzzy limits to be determined, that is the degree of accuracy of the derived solutions.

The reliability of the results obtained and the conclusions are confirmed: the correctness of the research methods used, based on scientific theories for decision making and optimisation, fuzzy set theory, expert evaluation methods; the sufficient convergence of computed models (theoretical) and experimental (experience / industrial) research results.

Table 1. A comparison of results for the solution of multi-criteria tasks for optimal decision making using the proposed algorithm (Fuzzy Optimisation Algorithm 3), using the determinate method and experimental data.

#	Values for Criteria and Limits	Determinate Method [17] (literal data)	Proposed Algorithm (Fuzzy Optimisation Algorithm 3)	Experimental Data (Atyrau Pumping Station)
1.	Volume of pumped oil (productivity), tons / hour, ($\tilde{y}_1$)	707	710	709
2.	Temperature at the heater output, ºC (y_2)	48	50	50
3.	Pressure at the heater output, kgs / cm² (y_3)	8.5	8	8.1
4.	Membership function satisfying limit 1 - $\mu_1^*(x^*(\beta))$	-	1.0	-
5.	Membership function satisfying limit 2 - $\mu_2^*(x^*(\beta))$	-	0.98	-
6.	Optimal value of regime parameters x^* = ($x_1^*,\ldots,x_4^*$): x_1^* - temperature at the heater input, ºC;	35	33	34
7.	x_2^* - pressure at the heater input, kgs /cm²;	10,5	9.8	10
8.	x_3^* - fuel used, kg / hours;	27	25	26
9.	x_4^* - raw material (oil) volume at the heater input, tons / hour;	710	710	710

Note: (-) means that the indicator in question is not determined by the given method. The time required to find a solution is the same for all the methods being compared.

Conclusion

Thus, in this research paper, based on a combination and modification of various optimisation principles, we have proposed new formulations for multi-criteria decision making tasks for the optimisation of industrial installations, for example, technical systems for main oil pipelines and have developed dialogue algorithms for solving the task at hand. The algorithms which have been developed are based on the use of ideas from various compromise schemes (various combinations of the key factor method, Pareto Optimisation Principles and ideal point) for decision making, which have been modified for working in a fuzzy environment. We have shown results from the application of the proposed approach in practise to the optimisation of regime parameters for the working of oil heating stations on the Uzen – Samara oil pipeline as it passes through Atyrau.

The scientific novelty and originality of the results is found in the fact that the task is formulated and solved in a fuzzy environment without being transpormed into determinate formulae. This allows fuzzy data which has been gathered to be fully used, and complicated industrial problems with fuzzy input data are solved more adequately.

The theoretical value of the work is found in a development of decision making theory, and an enriching and generalisation of these theories and methods for optimisation, which take into account fuzzy input data. The practical value of the work lies in the fact that complex industrial problems in conditions of multiple criteria and fuzziness, which cannot be solved or can only be solved with difficulty by traditional determinate methods or stochastic mathematical methods, can be solved effectively. The practical advantage of this approach to solving the problem under consideration is also the fact that, depending on the industrial situation and available input data, the characters of the various DMs make it possible to select the most appropriate algorithm for solving the task, from the group of proposed algorithms.

The prospects for further scientific development in this direction lie in the development of mathematical provision by various intelligent computer systems, for example, intelligent decision making systems, computer control systems, robot systems etc.

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