Modeling of Decision-Making Processes in the Service Management System

Oksana Mulesa
Department of Software Systems
Uzhhorod National University
ORCID: 0000-0002-6117-5846

Olena Melnyk
Department of Software Systems
Uzhhorod National University
Uzhhorod, Ukraine
ORCID: 0000-0001-7340-8451

Petro Horvat
Department of Computer Systems and Networks
Uzhhorod National University
l Uzhhorod, Ukraine
ORCID: 0000-0002-3972-0115

Marian Tokar
Political Science and Public Administration Department
Uzhhorod National University
Uzhhorod, Ukraine
ORCID: 0000-0001-8426-4481

Vladyslav Peresoliak
Geodesy, Land Surveillance and Geoinformatics Department
Uzhhorod National University
Uzhhorod, Ukraine
ORCID: 0000-0002-6255-1559

Hanna Kumar
Political Science and Public Administration Department
Uzhhorod National University
Uzhhorod, Ukraine
ORCID: 0000-0002-4131-3084

Abstract **— The service management system considers the problem of finding the optimal distribution of social services between executors. A mathematical model of the problem in the form of single and multi-criteria optimization problems was built. The decomposition of the task into independent subtasks was performed. An iterative method of finding the optimal distribution of services between executors has been developed. Individual methods and steps are formulated as production rules, making them understandable and allowing one to gain new knowledge.**

Keywords — production rules, knowledge, decomposition, optimization, service management, decision-making, consumer, executor

I. Introduction

The development and implementation of formalized models and methods in the field of public administration allow for an increase in the effectiveness of relevant management decisions [1-3]. The tasks involved are usually multi-criteria [4, 5], and the models characterizing them are multi-factorial. They can often be described by systems of linear equations and inequalities and are reduced to one- or multi-criteria problems of linear programming [6, 7]. A characteristic feature of the stage of building models for such tasks is the need to consider all the multifaceted processes and regulatory restrictions in the researched field.

This research is dedicated to solving the problem of the ratio of consumers and executors of social services in compliance with the standards and wishes of customers. The research's relevance is confirmed by the fact that the system of management and distribution of social services needs constant improvement to ensure the interests and requests of recipients of social services [8]. As shown below, this problem belongs to the sphere of public administration and can be reduced to a decision-making problem, which contains separate optimization problems.

II. Analysis of the Problem

A. The market of social services as a complex system

Consider the social services market, the main actors of which are consumers, executors and customers of such public services. The market is dynamic and regulated. It functions according to the developed rules, regulations and standards. Its environment consists of state and non-state organizations and institutions that respond to citizens' requests and offer their services. Effective service management and skilful decision-making will significantly improve customer service.

The process of deciding to provide a service to a specific consumer goes through several stages:

The stage of forming a base of social service providers describes information about potential executors, types and volumes of services they can provide consumers.

The collection of information about potential consumers characterizes the selection stage of service consumers. Their selection is carried out by socio-demographic portraits, medical anamnesis and taking into account the standards adopted by the customers and established by the relevant regulatory and legal acts.

The stage of distribution of services between executors involves the selection of an optimal ratio between executors and customers that would ensure optimal use of available resources, meet the customer's wishes and satisfy the needs of consumers.

This research is devoted to analyzing the main problems that may occur at the stage of distribution of services between their executors. Decomposition of the task of making the appropriate management decision into subtasks that need to be solved will be performed. An iterative method of finding the optimal distribution of services between performers has been developed, making it possible to use the available resources as efficiently as possible from the customer's point of view.

B. Formalization of the task of distribution of social services between executors

Let is introduce the notation for the main actors and their characteristics.

$S=\{s_1,s_2,...,s_M\}$ – a set of services that can be provided on the market;

$SC=\{\overline{sc}_1,\overline{sc}_2,...,\overline{sc}_K\}$ – a set of vectors with the characteristics of consumer requests for services, where $\overline{sc}_k=(sc_{1k},sc_{2k},...,sc_{Mk})$, sc_{jk} – the ordered volume of the service s_j at the consumer with number k;

$W = \{\overline{w}_1, \overline{w}_2, ..., \overline{w}_N\}$ – a set of vectors with the characteristics of the work executors, where $\overline{w}_i = (w_{i1}, w_{i2}, ..., w_{iM})$, w_{ij} – the maximum amount of service available for execution s_j at the executor with number i.

$X = (x_{ijk})$, $i = \overline{1,N}$, $j = \overline{1,M}$, $k = \overline{1,K}$ – a boolean matrix with information on the distribution of work between executors, where $x_{ijk} = 1$, if the executor under the number i will provide the service s_j to the customer under the number k and $x_{ijk} = 0$ in the opposite case.

The task of finding the distribution of services between executors is to find such a distribution X that satisfies the following conditions and restrictions:

– the condition for the possibility of providing the service:

$$if\ w_{ij} = 0\ then\ x_{ijk} := 0,\ \forall k = \overline{1,K}\ ; \tag{1}$$

– the condition of the absence of fictitious works in the distribution:

$$if\ \ sc_{jk} = 0\ then\, x_{ijk} := 0, \forall i = \overline{1,N}\ \ ; \tag{2}$$

– the condition of not exceeding the maximum available services from the executors:

$$\sum_{k=1}^{K} x_{ijk} sc_{jk} \le w_{ij}\ ,\ \ \forall i = \overline{1,N}\ ; \tag{3}$$

– the condition of indivisibility of the service, which ensures that only one executor provides each service to the consumer:

$$\sum_{i=1}^{N} x_{ijk} \le 1,\ \ \forall j = \overline{1,M}\ ,\ \forall k = \overline{1,K}\ ; \tag{4}$$

– the condition for excluding the trivial (zero) distribution:

$$\sum_{i=1}^{N}\sum_{j=1}^{M}\sum_{k=1}^{K} x_{ijk} > 0\,. \tag{5}$$

In addition to the specified conditions and restrictions, the customer may impose additional ones, which include, for example:

– compliance with quotas for the number of provided services of a certain type:

$$\Delta\underline{c}_j \le \sum_{i=1}^{N}\sum_{k=1}^{M} x_{ijk} \le \Delta\overline{c}_j\ ,\ \ j \in \{1, 2, ..., M\}\ ; \tag{6}$$

– compliance with quotas for the volumes of services provided:

$$\Delta\underline{v}_j \le \sum_{i=1}^{N}\sum_{k=1}^{M} x_{ijk} sc_{jk} \le \Delta\overline{v}_j\ ,\ \ j \in \{1, 2, ..., M\}\ , \tag{7}$$

where $\Delta\underline{c}_j, \Delta\underline{v}_j, \Delta\overline{c}_j, \Delta\overline{v}_j$ – non-negative real numbers, which are determined by standards or by the service customer.

Restrictions (1) – (5) are usually mandatory, (6) – (7) are permissible if necessary. Suppose the set of feasible solutions to the problem is non-empty and contains more than one solution. In that case, the selection of the optimal distribution can be performed by taking into account one or more optimality criteria:

1. Criterion for maximizing the number of provided services:

$$\sum_{i=1}^{N}\sum_{j=1}^{M}\sum_{k=1}^{K} x_{ijk} \to \max\ . \tag{8}$$

2. Criterion for maximizing the volume of services provided:

$$\sum_{i=1}^{N}\left(\sum_{j=1}^{M}\sum_{k=1}^{K} x_{ijk} sc_{jk}\right) \to \max\ . \tag{9}$$

3. Maximum use of available resources:

$$\sum_{i=1}^{N}\sum_{j=1}^{M}\left(w_{ij} - \sum_{k=1}^{K} x_{ijk} sc_{jk}\right) \to \min\ . \tag{10}$$

4. Maximization of the number of consumers to whom services are provided in full. To formalize this criterion, we introduce a function $\chi(\overline{sc}_k)$ whose values are calculated according to the rule:

$$\begin{aligned} &if\ \ \forall j = \overline{1,M} : sc_{jk} \ne 0\ \exists i \in \{1, 2, ..., N\} : x_{ijk} = 1 \\ &then\ \chi(\overline{sc}_k) := 1\ else\ \chi(\overline{sc}_k) := 0. \end{aligned} \tag{11}$$

The optimality criterion has the form:

$$\sum_{k=1}^{K} \chi(\overline{sc}_k) \to \max\ . \tag{12}$$

5. Uniformity of service provision. For each consumer, we consider a vector $\overline{\rho}_k = (\rho_{1k}, \rho_{2k}, ..., \rho_{Mk})$ whose components are calculated according to the rule:

$$\rho_{jk} = \begin{cases} 1,\ if\ sc_{jk} > 0; \\ 0, if\ sc_{jk} = 0. \end{cases} \tag{13}$$

Then the optimality criterion has the form:

$$\max_{k=1,K} \frac{\sum_{j=1}^{M}\left(\rho_{jk}-\sum_{i=1}^{N}x_{ijk}\right)}{\sum_{j=1}^{M}\rho_{jk}} \to \min . \quad (14)$$

The customer of services can also add other criteria for the optimality of allocations.

Depending on the number of criteria, the problem will be a single-criteria Boolean programming problem [9] or a multi-criteria optimization problem [10].

The process of finding optimal distribution options for the given problem can be divided into several stages.

III. Decomposition of the Task of Finding the Optimal Distribution of Services to Applicants

We will decompose the decision-making task of finding the distribution of services between executors into stages [11]. It is worth noting that the stages' sequence may differ in different tasks. We will describe the following stages:

The stage of formation of a set of feasible solutions to the problem. A distribution is feasible if it satisfies the initial conditions of the problem. Thus, the implementation of this stage consists of the construction of all possible distributions of services between executors that satisfy constraints (1) – (5) and, if necessary, (6) – (7). Construction can be done by direct selection. Let us denote the set of feasible solutions through FX .

The stage of specification of quota values. The stage consists in specifying non-negative values $\Delta\underline{c}'_j$, $\Delta\underline{v}'_j$, $\Delta\bar{c}'_j$, $\Delta\bar{v}'_j$ for which the following conditions are fulfilled: $[\Delta\underline{c}_j, \Delta\bar{c}_j] \subset [\Delta\underline{c}'_j, \Delta\bar{c}'_j]$ and $[\Delta\underline{v}_j, \Delta\bar{v}_j] \subset [\Delta\underline{v}'_j, \Delta\bar{v}'_j]$. The specified values are asked by the customer of services or established by regulations.

The limit values of the boundaries can be set based on the following conditions:

$$\Delta\underline{c}_j \le \sum_{k=1}^{K}\rho_{jk} \text{ , } \Delta\underline{c}_j \le \Delta\bar{c}_j \text{ , } j \in \{1,2,...,M\} \text{ ; } \quad (15)$$

$$\Delta\underline{v}_j \le \sum_{k=1}^{K}sc_{jk} \text{ , } \Delta\underline{v}_j \le \Delta\bar{v}_j \text{ , } j \in \{1,2,...,M\} \text{ . } \quad (16)$$

The stage of forming a set of Pareto-optimal solutions. A solution will be considered Pareto-optimal if there is no other solution that would improve this one according to a certain criterion of optimality. Denote the set of Pareto-optimal solutions by PX . Initially $PX = \varnothing$. Let the assessment of the optimality of the distribution be carried out according to a set of criteria $\{f_1(X), f_2(X),..., f_G(X)\}$. Without loss of generality, we will assume that all criteria go to the maximum. Then, to form a set, PX we apply the rule:

$$\begin{aligned}&\forall X \in FX : \textit{if } \exists g \in \{1,2,...,G\}: \\ &\forall X' \in FX, X' \ne X, \ f_g(X) \ge f_g(X') \\ &\textit{then } PX := PX \cup \{X\}.\end{aligned} \quad (17)$$

The stage of finding optimal solutions to the problem.

A feasible solution will be considered optimal if all functions from a set of criteria reach their maximum values on it. Let us denote the set of optimal solutions OX . Initially $OX = \varnothing$. Then, to form this set, we apply the rule:

$$\begin{aligned}&\forall X \in PX : \textit{if } \forall g = \overline{1,G} \ \forall X' \in PX, X' \ne X, \\ &f_g(X) \ge f_g(X') \textit{ then } OX := OX \cup \{X\}.\end{aligned} \quad (18)$$

The stage of introducing a fictitious consumer. Let it be permissible for some service to be divided into parts. That is, a situation is possible when the amount of service declared by the consumer can be divided into different parts, which will be provided by different executors. To ensure this possibility, it is advisable to introduce a fictitious consumer according to such a rule.

Let the service s_{j_0} is divisible and its minimally acceptable volume for rendering is the number $\Delta s_{j_0} > 0$. Then, for the user with the number, $k_0 \in \{1,2,...,M\}$ we will enter a fictitious user according to the same rule:

$$\begin{aligned}&\textit{if } sc_{j_0k_0} \ge 2\Delta s_{j_0} \textit{ then } K := K+1, \\ &sc_{j_0K} := sc_{j_0k_0} - \Delta s_{j_0}, \\ &sc_{jK} := 0, j = \overline{1,M}, \ j \ne j_0, \\ &sc_{j_0k_0} := \Delta s_{j_0}.\end{aligned} \quad (19)$$

The stage of reducing a multi-criteria problem to a single-criteria one. Based on a set of criteria, $\{f_1(X), f_2(X),..., f_G(X)\}$ we build one supercriterion according to the rule of additive convolution:

$$f(X) = \sum_{g=1}^{G}\alpha_g f_g(X) \to \max , \quad (20)$$

where $\alpha_g \ge 0, \ g = \overline{1,G}, \ \sum_{g=1}^{G}\alpha_g > 0$.

The weighting factors in (20) are set by the customer of services in view of the priority of the criteria.

IV. Iterative Method of Finding the Optimal Distribution of Services

In the research, an iterative method was built, which is a logical sequence of the previously considered stages. The algorithm of the method is as follows:

Step 1. Form a set of feasible solutions FX .

Step 2. If $FX = \varnothing$, then we proceed to the stage of specification of quotas or the stage of entering a fictitious consumer and return to Step 1.

Step 3. Form a set of Pareto-optimal solutions PX .

Step 4. We find optimal solutions (set OX)

Step 5. If $OX \neq \varnothing$, then select $X_{opt} \in OX$ and proceed to Step 7.

Step 6. We reduce the multi-criteria problem to a single-criteria problem and proceed to Step 3.

Step 7. For the selected optimal distribution X_{opt} perform the following transformations:

$$\forall k = \overline{1,K}, \forall j = \overline{1,M} : if\ \exists i \in \{1,2,...,N\} : x_{ijk} = 1 \quad then\ sc_{jk} := 0; \tag{21}$$

$$\forall i = \overline{1,N},\ \forall j = \overline{1,M} : w_{ij} := w_{ij} - \sum_{k=1}^{K} x_{ijk} sc_{jk} . \tag{22}$$

Step 8. If, after performing the transformations (21)–(22), there are consumers with unsatisfied needs and executors who can potentially perform the corresponding services, then we return to Step 1 to supplement the found optimal distribution. Otherwise, the algorithm is finished.

V. Discussion of the Results of the Implementation of the Developed Models and Methods

The developed models and the iterative method were tested on several model examples. They are flexible concerning the wishes of the service customer and actualize the importance of optimizing the service management system. The obtained conclusions and results can be presented as such remarks.

Remark 1. The transition in Step 6 to the supercriterion can be replaced by any other method of multicriteria optimization, such as the ideal point method, the method of successive concessions, etc.

Remark 2. At step 8, if necessary, adding new consumers and executors to the consideration is possible. This approach is possible when dividing consumers into groups based on the priority of service provision. This problem will be addressed in further research.

Remark 3. If the initial problem is single-criteria, then $PX \equiv OX$ and in Step 5, the optimal solution to the problem will be found.

Remark 4. At the stage of entering a fictitious consumer, it is possible to perform conversion (19) for several services at the same time, and it is also possible to enter several fictitious consumers at once.

VI. Conclusions

The research is devoted to solving the problem of finding the optimal distribution of social services between consumers, which takes place in the service management system. The subject field was analyzed during the research, and a mathematical model of the corresponding problem was built based on the performed analysis.

The proposed task decomposition into various subtasks makes the developed approach flexible and scalable. Replacing or clarifying any stage, following the specifics of its scope, allows to leave other stages unchanged.

The developed methods of solving problems and the iterative method have instructions in production rules, making them clear and understandable. They can be successfully used in the service management system when solving the problem of finding the distribution of social services between executors.

At the following stages, it is essential to solve a similar problem with the queue of consumers, which functions according to the principle of "first in, first out".

References

[1] A. Ranerup, H. Z. Henriksen, “Value positions viewed through the lens of automated decision-making: The case of social services,” Government Information Quarterly, 2019, 36(4): 101377.

[2] A. Ranerup, H. Z. Henriksen, “Digital discretion: Unpacking human and technological agency in automated decision making in Sweden’s social services,” Social Science Computer Review, 2022, 40(2), pp. 445–461.

[3] O. Mulesa, P. Horvat, T. Radivilova, V. Sabadosh, O. Branovskyi, S Duran, “Design of mechanisms for ensuring the execution of tasks in project planning,” Eastern-European Journal of Enterprise Technologies, 2(4 (122)), 2023, pp. 16–22. https://doi.org/10.15587/1729-4061.2023.277585

[4] H. Nazarkevych, I. Tsmots, M. Nazarkevych, N. Oleksiv, A. Tysliak, O. Faizulin, “Research on the effectiveness of methods adaptive management of the enterprise's goods sales using machine learning methods,” 2022 IEEE 17th International Conference on Computer Sciences and Information Technologies (CSIT), 2022, pp. 539–542. IEEE.

[5] H. Xu, A. Kuchansky, S. Biloshchytska, M. Tsiutsiura, “A Conceptual Research Model for the Partner Selection Problem,” 2021 IEEE International Conference on Smart Information Systems and Technologies (SIST), 2021, pp. 1– 6. IEEE.

[6] V. Teslyuk, A. Batyuk,V. Voityshyn, “Method of Recommending a Scrum Team Composition for Intermediate Estimation of Software Development Projects,” 2022 IEEE 17th International Conference on Computer Sciences and Information Technologies (CSIT), 2022. p. 373–376. IEEE

[7] O. Mulesa, I. Myronyuk, O. Kachmar, F. Jakab, O. Yatsyna, "Decision-Making Modeling in Educational Process Organization Under the Conditions of Crisis Situations Forecasting," 2022 20th International Conference on Emerging eLearning Technologies and Applications (ICETA), 2022, pp. 460–465, doi: 10.1109/ICETA57911.2022.9974909.

[8] S. Nahavandi, “Industry 5.0 — A human-centric solution” *Sustainability*, 2019, 11.16: 4371.

[9] T. Thaher, H. Chantar, J. Too, M. Mafarja, H. Turabieh, E. H. Houssein, “Boolean Particle Swarm Optimization with various Evolutionary Population Dynamics approaches for feature selection problems,” Expert Systems with Applications, 2022, 195, 116550.

[10] C. S. Syan, G. Ramsoobag, “Maintenance applications of multi-criteria optimization: A review,” Reliability Engineering & System Safety, 2019, 190: 106520.

[11] O. Mulesa, O. Kachmar, I. Myronyuk, P. Horvat, T. Radivilova, Y. Kykyna, “Designing Semi-Automated Decision-Making Expert Systems for Healthcare Tasks,” In 2022 IEEE 17th International Conference on Computer Sciences and Information Technologies (CSIT), 2022, pp. 235–238. IEEE.