Mérnöki Szimpózium a Bánkiban
(ESB 2023)
http://bgk.uni-obuda.hu/esb/

Improving workforce deployment in fruit buying stations: A fuzzy decision-making framework

[1]Nikola Komatina, [2]Aleksandar Aleksić, [3]Snežana Nestić

[1]University of Kragujevac, Faculty of Engineering, Kragujevac, Serbia, nkomatina@kg.ac.rs
[2]University of Kragujevac, Faculty of Engineering, Kragujevac, Serbia, aaleksic@kg.ac.rs
[3]University of Kragujevac, Faculty of Engineering, Kragujevac, Serbia, s.nestic@kg.ac.rs

Abstract

The problem of scheduling workers is a real problem in workplaces where the time of execution of work operations and tasks does not play a decisive role. In the proposed model, it was taken into account that the considered criteria do not have equal relative importance. The Fuzzy Analytical Hierarchy Process method was used to determine the relative importance of the criteria. In addition, the Fuzzy Linear Programming method was used to optimize the scheduling of workers at workplaces. The decision maker used pre-defined linguistic expressions modelled by triangular fuzzy numbers to express his assessments, both when assessing the relative importance of the criteria, and when assessing the value of each workplace according to each criterion. The model developed in this paper was tested on an example from practice, that is, on a company dealing with the purchase and processing of fruit.

Keywords: scheduling, fruit processing industry, Fuzzy Analytical Hierarchy Process, Fuzzy Linear Programming, triangular fuzzy numbers

1. Introduction

Scheduling problem optimization is often analyzed in the relevant literature. Thus, the authors solved problems in different domains [1,2]. Many proposed models in the literature are based on accurate data, time measurement, and analysis of the operations being performed. However, when it comes to variable and difficult physical jobs, such as the work at the buying station for receiving fruit, factors such as time and the number of repetitions of operations are not always relevant when defining the strategy of the worker's schedule. The employment of workers in such a workplace depends on numerous factors, such as the amount of goods received, weather conditions, the time provided for delivery, etc. Precisely, these facts can be highlighted as the motivation for research.

In this paper, a model that can be applied to the same or similar problem type was presented. The model developed in this paper proposes a new way to solve the problem of worker scheduling, using the Fuzzy Analytic Hierarchy Process (FAHP) and Fuzzy Linear Programming (FLP). All uncertainties that exist in the considered problem are modelled using triangular fuzzy numbers (TFNs). The AHP method [3], extended with triangular fuzzy numbers [4,5], was used to determine the relative importance of the criteria. The input data used to construct the fuzzy decision matrix was obtained by the decision maker, using pre-defined linguistic expressions, also modelled by TFNs. The final schedule of workers at workplaces is determined using FLP for different numbers of total available workers.

The main objective of this paper is to define a simple model for solving the workers' scheduling problem at workplaces where work measurement does not provide satisfactory and representative results. This objective can be presented through the implementation of several sub-objectives: 1) determination of criteria based on which the work of workers is analyzed, 2) involvement of managers in the process of solving scheduling problems, 3) application of the FAHP method for determining the relative importance of criteria in the considered problem, and 4) application the FLP for determining the optimal number of workers at each considered workplace.

The rest of the paper is organized as follows: in section 2, a literature review of previous research is given. In the third section, the used methodology is presented. In section 4, the proposed algorithm for solving the considered problem is given, while the case study is presented in section 5. In the sixth section, the conclusions of this research are given.

2. Literature review and methodology

The methodology used in this paper found its application in solving numerous research and optimization problems. FAHP, as one of the most frequently used fuzzy multi-attributive decision-making methods, has so far been applied in many domains, mostly for determining the relative importance of criteria [6,7]. When it comes to the domain of fuzzy numbers, the scale [1-9] is most often used, which is analogous to the traditional AHP method [3]. Also, the number of considered criteria varies depending on the type of problem. In most of the papers, as well as in this research, three criteria were analyzed.

Linear Programming (LP) is a very useful tool for solving small-dimension optimization problems. It is often used in literature and different scheduling problems were solved using this method [8]. Also, Fuzzy Linear Programming has found its application in practice [9], but for solving scheduling problems it is rarely used in the literature, as is the case in [10].

In the literature, there are papers in which the optimization model is based on a combination of FAHP and FLP [7,11]. The type of problem considered in this paper has not been solved using a similar methodological approach. This is one of the motives for applying the proposed methodology to a problem that is very common in practice, and which has not been adequately treated in the literature so far.

The proposed model consists of three parts. In the first part, uncertainty modelling is performed and a set of considered criteria is defined. In the second part of the model, the FAHP method is applied to determine the relative importance of the criteria, and after that, in the third part, FLP is used to determine the optimal number of workers in the considered workplaces.

In this paper, the problem of work optimization, i.e., the allocation of workers at different workplaces, $s, s = 1, \dots, S$, at the buying station for receiving fruit, is solved. In this case, s represents the index of the considered workplace, and S is the total number of considered workplaces. The proposed model is based on respecting criteria, $k, k = 1, \dots, K$, where k represents the index of the considered criterion and K represents the total number of considered criteria.

The work measurement option, in this case, would not bring satisfactory results, because the scope of work is complex, and the operations are not always identical. For an easier understanding of the considered problem, below is a short notation and description of the expressions used. $\tilde{w}_k$ is the relative importance of the considered criterion, $k, k = 1, \dots, K$. The decision matrix, where the considered workplaces are evaluated, $s, s = 1, \dots, S$, according to each considered criterion, $k, k = 1, \dots, K$, is denoted as $\left[\tilde{M}_{sk}\right]_{S\times K}$. The weighted decision matrix is denoted as $\left[\tilde{O}_{sk}\right]_{S\times K}$. The linguistic expressions used to assess the relative importance of criteria are:

Equally important, Q_1 (1, 1, 1)
Slightly more important, Q_2 (1, 1, 3.5)
Moderately more important, Q_3 (1.5, 3, 4.5)
Much more important, Q_4 (2.5, 5, 7.5)

Extremely more important, Q_5 (5.5, 7, 8.5)
Absolutely more important, Q_6 (6.5, 9, 9)

To assess the value of each workplace according to each criterion, the linguistic expressions shown in Table 1 were used. These expressions were also modelled by using TFNs.

Table 1. Linguistic expressions used for the assessment

The time required to perform an operation	**Physical effort at the considered workplace**	**Exposure to working environment conditions**	**TFN**
Very short period of time, T_1	Very low physical effort, E_1	Favorable working environment conditions, C_1	(1, 1, 3)
Short period of time, T_2	Low physical effort, E_2	Almost always favorable working environment conditions, C_2	(2, 4, 6)
Medium long period of time, T_3	Moderate physical effort, E_3	Changing working environment conditions, C_3	(3, 5, 7)
Long period of time, T_4	High physical effort, E_4	Bad working environment conditions, C_4	(4, 6, 8)
Very long period of time, T_5	Extreme physical effort, E_5	Very bad working environment conditions, C_5	(7, 9, 9)

All mathematical operations with TFNs in this paper were performed according to [12]. Linguistic expressions were modelled based on the experience and knowledge of the participants in this research, as well as based on the nature of the considered problem.

3. The proposed algorithm

The steps of the proposed algorithm can be presented as follows:

Step 1. Fuzzy pair-wise comparison matrix for determining the relative importance of criteria, $k, k = 1, \dots, K$. The assessment is made by the manager of the buying station using pre-defined linguistic expressions:

$$\left[\widetilde{W}_{kk'}\right]_{K\times K} \tag{1}$$

where $k, k' = 1, \dots, K; k \neq k'$.

Step 2. Checking the consistency of the assessments made in Step 1. First, it is necessary to defuzzify the pair-wise comparison matrix $\left[\widetilde{W}_{kk'}\right]_{K\times K}$ [13]:

$$[W_{kk'}]_{K\times K} = defuzzified \left[\widetilde{W}_{kk'}\right]_{K\times K} \tag{2}$$

where $k, k' = 1, \dots, K; k \neq k'$.

After that, the consistency check is performed using the Eigenvector method [3]. Decision makers' assessments are considered to be consistent if $CI \leq 0.1$.

Step 3. Determination of weights vector of each considered criterion, $k, k = 1, \dots, K$, by using fuzzy algebra rules [12]:

$$\widetilde{w}_k = (w_{kl}, w_{km}, w_{kn}) \tag{3}$$

where w_{kl} is a lower value of fuzzy number membership function, w_{km} is a modal value of the fuzzy number membership function, i w_{kn} is an upper value of the fuzzy number membership function.

Step 4. Constructing the fuzzy decision matrix:

$$\left[\widetilde{M}_{sk}\right]_{S\times K} \tag{4}$$

As assessments of the relative importance of the criteria, these assessments were made by the manager of the buying station.

Step 5. Constructing the fuzzy weighted decision matrix:

$$\left[\tilde{O}_{sk}\right]_{S\times K} = \left[\widetilde{M}_{sk}\right]_{S\times K} \cdot \widetilde{w}_k \tag{5}$$

Step 6. Setting up the FLP model:

Objective function:

$$\max\{z\} \tag{6}$$

subject to:

$$\frac{X_s}{\prod_{k=1}^{K} \tilde{o}_{sk}} \geq z \tag{7}$$

$$\sum_{s=1}^{S} X_s = N \tag{8}$$

$$X_s \geq 1 \tag{9}$$

where N is the total available number of workers at the buying station, and X_s is the number of workers in the considered workplace. Both, N and X_s are integer values.

Step 7. Defining the schedule of workers for different scenarios, i.e. at different values of N.

4. Case study and results

The research conducted in this paper is based on real-life data originating from a company that deals with the purchase, processing, and sale of fruit and fruit products. The headquarters of the company is located in the territory of western Serbia. The main resource that the company uses in production is raspberries. The problem that the company faces during the raspberry harvest is the scheduling of seasonal workers. In addition to the 40 to 50 workers that the company has throughout the year, it is necessary to hire seasonal workers during this period. The biggest problem is the buying station itself, where the fruit is received, measured, and further distributed.

Therefore, the main part of the work in the purchase of raspberries goes to the workers who: unload the goods from cargo vehicles and transport them to the weighing scale ($s = 1$), staff who weigh and issue a receipt for the purchased goods ($s = 2$), workers who transport purchased and measured goods to temporary storage, transport machines to refrigerators ($s = 3$), workers who pack goods in temporary storage, transport machines or refrigerators ($s = 4$), workers who wash, sort and empty packaging deliver to producers, which uses packaging for the next harvest ($s = 5$), and workers who drive forklifts and other work machines ($s = 6$). In this research, workers who are responsible for the production and packaging of final products are not considered. The need for workers at the buying station is exclusively considered. The company hires workers at the buying station as needed. Most often, at the beginning and end of the harvest season, there are fewer workers, while the need for workers is greatest in the middle of the harvest. The idea of this research is to optimize the number of workers in the workplaces of this buying station, taking into account three criteria: the time required to perform an operation ($k = 1$), physical effort at the considered workplace ($k = 2$), and exposure to working environment conditions ($k = 3$).

By applying the proposed algorithm described in section 4, the following results are obtained. Figure 1 shows how the number of workers at each workplace changes according to the developed model, depending on the available number of workers. The figure shows the range of the available number of workers between 10 and 50.

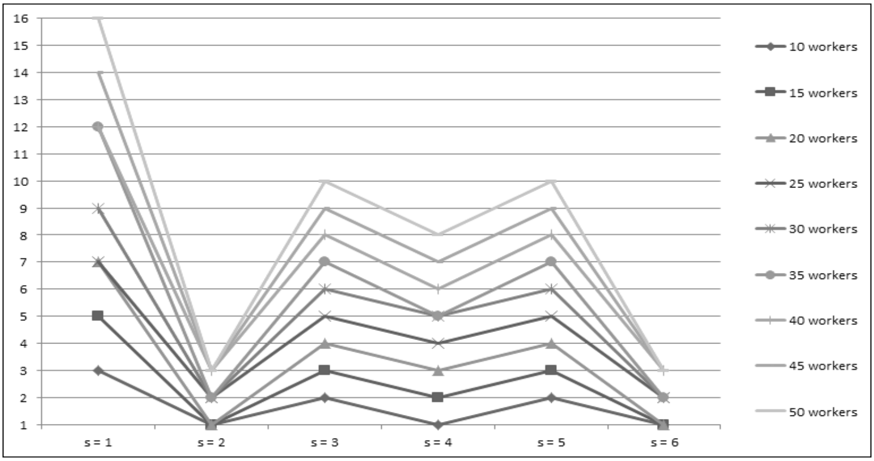

Figure 1. The number of workers at each workplace

The number of workers in workplaces changes in different ways. In fact, workplace $s = 1$ records the biggest changes when it comes to the number of workers. It is necessary to employ more workers in this workplace, which speaks in favor of the fact that this workplace is the most important and most demanding at this buying station. Working in this position requires direct work with clients, requires fast work, and involves physically demanding work (lifting and manipulating loads) and exposure to solar radiation and other weather conditions.

Workplaces $s = 3$ and $s = 5$ in all mentioned scenarios require one new worker for every five new workers in total. It can also be determined that 20% of the total number of workers need to be employed in these two positions. This percentage does not change in the nine scenarios presented. Workers at the workplace $s = 3$ are not always required to work at a high pace, but the work is physically demanding and workers are exposed to the effects of the working environment, but less than workers at workplace $s = 1$. The situation is similar when it comes to workplace $s = 5$. In the workplace $s = 4$, it is necessary to employ slightly fewer workers compared to $s = 1$ and $s = 3$. Workplaces $s = 2$ and $s = 6$ require the smallest number of workers because the work performed at these workplaces does not require a lot of physical effort and the workers are not exposed to the negative effects of the work environment.

5. Conclusion

This paper presents a new model for determining the optimal scheduling plan of workers at workplaces within the framework of the fruit-buying station. Six workplaces were analyzed in the paper, based on three criteria. To solve this problem, a methodology based on FAHP and FLP was used. The proposed model was tested on the example of a company whose headquarters are located in the territory of western Serbia and which is one of the largest companies in this field in the territory of the entire country. The main contributions of this work are: (a) a new model of workers' scheduling when work measurement does not give adequate results; (b) a sufficiently flexible model which can be adapted to any similar problem; (c) relatively simple model to apply; (d) a similar problem has not been considered in the literature, although this is a real problem in practice. The proposed model has certain shortcomings: (a) The model can only be applied in situations where there is no possibility of measuring work or when measuring work does not give good enough results; (b) The model is adequate for solving optimization problems of small dimensions. If a large number of criteria were considered, and above all, a large number of workplaces, the proposed model would be absolutely limited. Future research directions will be focused on the application of the proposed methodology for solving similar optimization problems.

6. References

[1] Liu, R., Yuan, B., & Jiang, Z. (2017). Mathematical model and exact algorithm for the home care worker scheduling and routing problem with lunch break requirements. *International Journal of Production Research*, *55*(2), 558-575.

[2] Yilmaz, O. F., Cevikcan, E., & Durmusoglu, M. B. (2016). Scheduling batches in multi hybrid cell manufacturing system considering worker resources: A case study from pipeline industry. *Advances in Production Engineering & Management*, *11*(3), 192-206.

[3] Saaty, T. L. (1980). The Analytic Hierarchy Process: Planning, Priority Setting, Resources Allocation. Mcgraw-Hill, New York.

[4] Dubois, D., & Prade, H. (1993). Fuzzy numbers: an overview. *Readings in Fuzzy Sets for Intelligent Systems*, 112-148.

[5] Zimmermann, H. J. (2011). *Fuzzy set theory—and its applications*. Springer Science & Business Media.

[6] Zheng, Q., Lyu, H. M., Zhou, A., & Shen, S. L. (2021). Risk assessment of geohazards along Cheng-Kun railway using fuzzy AHP incorporated into GIS. *Geomatics, Natural Hazards and Risk*, *12*(1), 1508-1531.

[7] Milanovic, M., Misita, M., & Komatina, N. (2020). Determination of the optimal production plan by using fuzzy AHP and fuzzy linear programming. *Journal of Intelligent & Fuzzy Systems*, *38*(4), 4315-4325.

[8] Meng, L., Zhang, C., Ren, Y., Zhang, B., & Lv, C. (2020). Mixed-integer linear programming and constraint programming formulations for solving distributed flexible job shop scheduling problem. *Computers & Industrial Engineering*, *142*, 106347.

[9] Amin, S. H., Razmi, J., & Zhang, G. (2011). Supplier selection and order allocation based on fuzzy SWOT analysis and fuzzy linear programming. *Expert Systems with Applications*, *38*(1), 334-342.

[10] Tavakkoli-Moghaddam, R., Javadi, B., Jolai, F., & Ghodratnama, A. (2010). The use of a fuzzy multi-objective linear programming for solving a multi-objective single-machine scheduling problem. *Applied soft computing*, *10*(3), 919-925.

[11] Mejjaouli, S., & Albathi, R. (2020). Fuzzy AHP and Linear Programming Based Decision Support System for Logistics Service Providers Allocation. In *Proceedings of the 5th NA International Conference on Industrial Engineering and Operations Management Detroit, Michigan, USA* (pp. 3046-3060).

[12] Chang, D. Y. (1996). Applications of the extent analysis method on fuzzy AHP. *European journal of operational research*, *95*(3), 649-655.

[13] Chen, S. H., & Li, G. C. (2000). Representation, ranking and distance of fuzzy number with exponential membership function using graded mean integration method.