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THE APPLICATION OF THE FUZZY AGGREGATION NORMS TO TECHNICAL STAFF TASKS DELEGATION

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Abstract

The methods for calculating professional competence levels of technicians based on fuzzy relations and the optimistic fuzzy aggregation norm has been proposed. Since it is difficult to estimate levels of professional competence of all tasks by all members of a team of technicians, the proposed method depends on a sequence of fuzzy relations which values are relatively easy to estimate and which the S-T-compositions produces the fuzzy relation of professional competence of all technicians. The proposed method is compared with the application of Minkowski metrics which is one of the objective methods of searching the best object in multi-criteria decision systems. Based on these two methods, the ranking of technicians can be prepared. Moreover, the method of results visualization is proposed.

Key Words: professional competence, fuzzy relation, optimistic fuzzy aggregation norm, visualisation, Minkowski metric

Introduction. In our very fast-changing world, members of the technical staff of companies have to acquire more and more skills to keep technological equipment in a well-functioning condition. Since each year new technology and devices appear and the models used so far can be purchased only in new versions, highly improved, the technical staff of each company has to keep studying the instructions and develop their knowledge and skills in maintaining the equipment installed for their purpose or used for service business. It can range from specialist hardware (medical, telecommunication) to everyday office hardware.

Many researchers try to examine business processes to optimize them to make companies more competitive. One way is to find methods to control business actions [18], the other is proposing a method for searching the priorities of knowledge and technology factors to find sustainable competitive advantages [16]. Fuzzy logic based models can be applied to solve many business problems like, for example, controlling teams [10], estimating criteria for assessment of importance of risks for innovative projects [5] or calculating the levels of personal achievements. One of the primary targets for the companies is reducing the operations costs and increasing the valuable amount of job that can be done by a single resource in time [17].

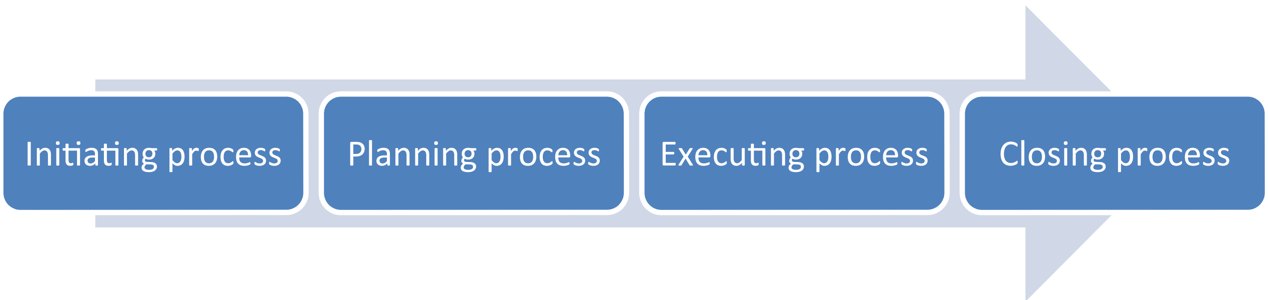

Figure 1. The diagram of stages of business processes

To achieve these goals the companies are continuously trying to improve their processes and their internal systems, that they are using to fulfill the complete Business processes. Each business process contains from different stages (Fig. 1), for example [11]:

1. Initiation,
2. Planning,
3. Execution,
4. Reporting.

Some industries like telecommunications built their standards related to technical operations including equipment maintenance and field operations. Frameworks standard introduces steps, applications and data processing for the process like “Failure to Repair” and “Workforce Management” [13].

- Each of these processes steps can be optimized by:
- Eliminating unnecessary steps,
- Optimized and efficient planning,
- Optimized routing and execution process.

The effective planning makes easier all further steps and execution of remaining work, and during the Planning stage, it is possible to utilize already known data about the job that should be done, locations, equipment, technologies and about the available resources.

The resources (Company Staff) is one of the most changeable objects in companies, as employees are always willing to improve their skills, they learn how to deal with new technologies and how to deal with continuously changing and upgrading equipment.

Such a problem is mainly for the following Business Directions, where usually the business processes are complex:

- Telecommunication operators [17],
- Software development and IT [3],
- Assurance,
- Insurance claims adjustment,
- Civil Defense.

Most of the companies use some systems and tools to support the execution of business processes or process stages. Such systems usually are complex and can apply complex mathematical models for activities optimization and accuracy.

Because of that, studying how to install new equipment and maintain the installed one, means that the technical employees have improved their skills and the employee's professional competence increased. The managers need a tool to estimate their employees' knowledge and skills to choose one to be the best to do the next task. One of the solutions to this problem is defining the function, called professional competence, showing levels of technicians' competence in maintaining office devices.

Estimating levels of technicians’ skills. Companies need help because the business environment is getting more and more complicated and competitive, and requires constant learning [7]. Business researchers and practitioners should help firms be more competitive, so they have to study the foundations of concepts used in business [8]. Managers should use lean thinking methods not only for manufacturing [9] but also for employee management. For any enterprise insufficient utilization of the resources is a problem [17]. Especially, for the second of these reasons, the use of a fuzzy relation can be beneficial.

Let us specify the following notation:

- $S=\{S_i, i=1,2,\dots,I\}$ – the set of technicians working for the company;
- $T=\{T_j, j=1,2,\dots,J\}$ – the set of tasks that must be performed by technicians;
- $D=\{D_k, k=1,2,\dots,K\}$ – the set of office devices;
- $Z=\{Z_m, m=1,2,\dots,M\}$ – the set of applied technologies.

Based on these sets, the following fuzzy relations are built:
- $R_1 \subseteq S \times D$, where $R_1(S_i, D_k)$ denotes the level of experience that technician S_i gained servicing and installing device D_k;
- $R_2 \subseteq D \times Z$, where $R_2(D_k, Z_m)$ denotes the level of technology Z_m applied in device D_k;
- $R_3 \subseteq Z \times T$, where $R_3(Z_m, T_j)$ denotes the level knowledge of technology Z_m needed for preforming task T_j;
- $R \subseteq S \times T$, where $R(S_i, T_j)$ denotes the level of task T_j performance by technician S_i.

The problem of estimating levels of tasks performance by technicians can be evaluated directly or by the use of a composition of fuzzy relations, so

(1) $R=R_1 \circ R_2 \circ R_3$,

where $\circ$ denotes $S-T$-composition of fuzzy relations. The associativity of the $max-min$ composition was shown in [14].

On the bases of fuzzy relation R, managers can choose the best technician for the specific task or prepare the ranking of technicians taking into consideration all discussed tasks. To find the best technician for the given task is easy, but how to prepare a ranking of technicians based on all or a few tasks. In the paper, two methods of solving this problem will be presented.

Professional competence In this section, the function called the professional competence will be described. To define this function, we apply the optimistic fuzzy aggregation norm S, which was defined in [15].

Definition 1. Let $x, y \in X$. The function $S: X \times X \to [0,1]$ is called an optimistic fuzzy aggregation norm if it fulfills the following conditions:

(S1) $S(x, y) \in [0,1]$ (normalisation)
(S2) $S(0,0)=0$ (border condition)
(S3) $S(x, y)=S(y, x)$ (commutativity)
(S4) $S(x, y) > max\{x, y\}$ if $x \neq 0 \wedge y \neq 0$ (optimism).

One of examples of an optimistic fuzzy aggregation norm is the following function:

(2) $S(x, y)=x+y-xy$

for $x, y \in [0,1]$. The proof of the fact that S fulfills all conditions (S1) – S(4) is shown in [15]. Fig. 2 presents the graph of this function.

Let us assume that A denotes one atomic ability, which means, the ability to perform one task on one office device and let it be a minimal number, e.g., let us assume that $A=0.01$.

Now we are going to define the personal competence of each technician in maintaining each office device.

Definition 2. The function $PC: S \times T \to [0,1]$ is called professional competence of technicians in performing office tasks, where $PC(S_i, T_j)$ denotes the level of employee S_i's skills of performing task T_j and

(1) $PC(S_i, T_j) = S(PC(S_i, T_j), A)$

after performing this task once more for $i = 1, 2, \ldots, I$, $j = 1, 2, \ldots, J$, S is an fuzzy optimistic aggregation norm defined by (3), and the initial value of $PC(S_i, T_j)$ is estimated when employee S_i starts working for this company.

Since after the maintaining or upgrading any of office devices, the professional competence of technician S_i in performing task T_j increases, also in the case when the technician knows how to do it very well, e.g., installing the same type of a printer as before, this task becomes routine. Hence, the professional competence of technicians in performing tasks is an increasing function.

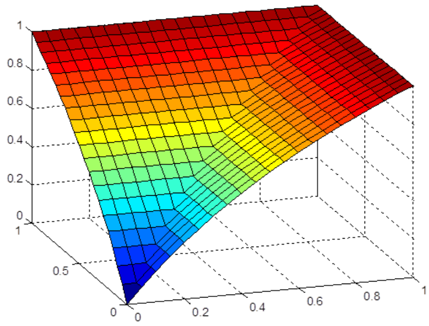

Figure 2 The graph of an optimistic fuzzy aggregation norm S

Definition 3. The function $PC: S \to [0,1]$ is called professional competence of technician S_i, where $PC(S_i)$ denotes the level of employee S_i' skills of performing all technical tasks and, for $i = 1, 2, \ldots, I$,

(2) $PC(S_i) = S_{j=1,2,\ldots,J} PC(S_i, T_j)$.

Assume that the manager of the company possesses the records of the technician results containing the outcomes of the tasks of installation of new equipment, maintaining and exchanging the office devices and prepares the values of fuzzy relation R_1 between technicians and equipment indicating levels of experience in installing and maintaining these devices. Table 1 presents values of relation R_1. This type of evaluation of the skills is common for service organizations and is maintained in HRMS (Human Resource Management Systems) or in FSM (Field Service Management) systems [17].

Moreover, let Table 2 show values of fuzzy relation R_2 between devices and applied in them technologies.

Furthermore, Table 3 presents values of fuzzy relation R_3 between technologies and tasks indicating which tasks need knowledge of the specific technology.

Now, we calculate the initial levels of professional competence of the technicians, which are values of fuzzy relation R calculated with the application of $max - min$-composition to formula (1) and relations $R_1 - R_3$. Hence, Table 4 presents levels of estimated knowledge and skill of all technicians in performing tasks:

Table 1.
Values of fuzzy relation R_1

Technician	Device			
	D_1	D_2	D_3	D_4
S_1	0.1	0.4	0.7	0.4
S_2	0.6	0.5	0.3	0.8
S_3	0.3	0.5	0.7	0.6
S_4	0.4	0	0.2	0.5

Table 2
Values of fuzzy relation R_2

Device	Technology	
	Z_1	Z_2
D_1	1	1
D_2	0	1
D_3	1	0
D_4	1	0

Let us assume that initial values of the professional competence of all technicians in performing all tasks are equal to values of fuzzy relation R.

Table 3
Values of fuzzy relation R_3

Techno-logy	Task		
	T_1	T_2	T_3
Z_1	1	1	0
Z_2	0	1	1

Table 4
Values of fuzzy relation R

Technician	Task		
	T_1	T_2	T_3
S_1	0.7	0.7	0.4
S_2	0.8	0.8	0.6
S_3	0.7	0.7	0.5
S_4	0.5	0.5	0.4
S_5	0.8	0.8	0.1
S_1	0.7	0.7	0.4

Table 5
Values of professional competence

Technician	Task		
	T_1	T_2	T_3
S_1	0.706	0.7	0.424
S_2	0.8	0.806	0.6
S_3	0.703	0.703	0.505
S_4	0.5	0.5	0.4
S_5	0.806	0.806	0.1
S_1	0.706	0.7	0.424

Assume that technician S_1 has performed task T_1 twice and task T_3 four times, technician S_2 – task T_2 three times, technician S_3 – all tasks once, technician S_4 was absent and technician S_5 has performed tasks T_1 and T_2 three times. Then, applying the optimistic fuzzy aggregation norm S given by the formula (3), we get values of professional competence of the technician performing the tasks shown in Table 5.

For example, to calculate the value of professional competence of technician S_1 in performing task T_1 the formula (2) is applied:

$$PC(S_1,T_1)=S\big(S(PC(S_1,T_1),A),A\big)S\big(S(R(S_1,T_1),A),A\big)=S(S(0.7,0.01),0.01)$$

$$S((0.7+0.01-0.7\cdot 0.01),0.01)=S(0.7003,0.01)0.70597.$$

Hence, we can calculate values of professional competence of all technicians applying the formula (4) and present them in Table 6.

Based on levels of professional competence (Table 6), managers can use this information in, e.g., two ways:

1) the manager wants to give the prize for each technician whose professional competence is higher than, e.g., 0.96, so the prize should get the following technicians: $S_2$and S_5;
2) the manager wants to prepare the ranking of the technicians concerning their professional competence, so in this case, the ranking of them is as follows: S_2, S_5, S_3, S_1 and S_4.

Table 6.
Professional competence of technicians after performing tasks in a given period of time

Technician	Professional competence
S_1	0.949
S_2	0.984
S_3	0.956
S_4	0.850
S_5	0.966

After developing this method for preparing rankings of technicians, we have also discussed the rank reversal phenomenon which causes some problems in some Analytic Hierarchy Processes [4,12]. In the case of calculating values of fuzzy relations, all professional competences of technicians achieved after performing tasks individually or all of them are calculated separately, so the problem of preparing rankings are reduced to subset of real numbers. Hence, this method does not cause the problem of rank reversal.

The method of preparing rankings based of optimistic fuzzy aggregation norm. Likewise A. Ameljańczyk [1], we define the ranking procedure as the transformation of the set of objects in the sequence of subsets which form the partition of the discussed set. The ideal situation is when all sets constituting the partition have only one element, such a ranking is called linear.

Nowadays, people prepare many rankings, especially in the area of public procurement such as tenders or grants, design contests and so on, which the result has commercial, prestige or financial consequences. These rankings are based on multicriteria procedures and very often the weighted averages are applied with weights adopted subjectively by persons deciding about the results of the competitions [2]. Because of that, it is really important to find a method of preparing rankings which are more objective.

Ameljańczyk proposed the application of Minkowski metrics and the ideal point in the space of objects to calculate distances of objects from this point as a foundation of a ranking procedure.

Table 7.
Professional competence of technicians after performing tasks in a given period of time

Competitor	Criterion A	Criterion B	Criterion C	Result
C_1	2	7	3	0.113615
C_2	4	7	4	0.139942
C_3	5	6	2	0.122479
C_4	6	5	4	0.139942
C_5	6	3	5	0.131254
C_6	6	2	3	0.104662
C_7	5	1	3	0.086483
C_8	3	1	1	0.04901
C_9	2	1	2	0.04901
C_{10}	1	2	2	0.04901

We are going to propose the new method based on optimistic fuzzy aggregation norm (2). Let $A=0.01$ be one atomic unit. Assume that the competition is based on three criteria: A, B and D (exemplary data is presented in Table 7). Assume that estimated numbers estimated for competitors for criteria are integers.

The result function is S given as follows

$$S(C_k)=1-(1-A)^{Crit\,A}\cdot(1-A)^{Crit\,B}\cdot(1-A)^{Crit\,C}$$

for $k=1,2,\ldots,10$. Hence, for competitor C_1, we have

$$S(C_1)=1-(1-0.01)^2\cdot(1-0.01)^7\cdot(1-0.01)^3 = 0.113615.$$

Hence, based on the values of the result function, the ranking of competitors can be prepared. Based on the result function the ranking can be prepared as follows: C_2 and C_4 on position 1, then C_5, C_3, C_1, C_6 ,C_7,C_8 and finally C_9 and C_{10} on the last position. Unfortunately, this ranking is not linear.

Visualization. After receiving fuzzy relation R, we can visualize the employees reference to the tasks using the task maps – the digraph of the professional competence of technicians individually (for example S_1in performing all tasks presented in Fig. 2a and the performance of given task (for example $T_1$by all technicians applying vectors of professional competence (Fig. 2b).

Similarly to [6], we define digraphs G_i, $(i=1,2,\ldots,I)$ for each technician $S_i \in S$, which vertices presents levels of performance of tasks required by the company. Moreover, the central point of the graph represents the situation of the technician $S^{\square}$ who cannot perform any task ($PC(S^{\square},T_j)=0$ for all $j=1,2,\ldots,J$).

Let $P=\{\vec{P}_k, k=1,2,\ldots,K\}$ denote the set of position vectors of technician's professional competence or task's performance relative to the central point and their magnitudes are equal to the unit of measure.

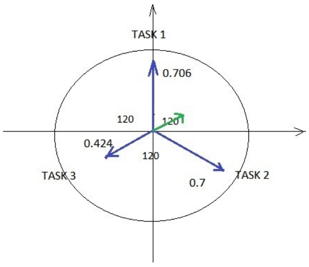

Figure 2a The digraph of the professional competence of S_1 in performing all tasks

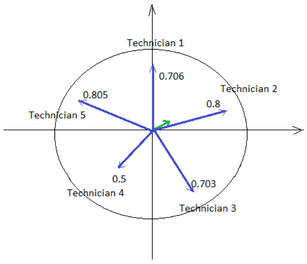

Figure 2b The digraph of task T_1 performance by all technicians using vectors of professional competence

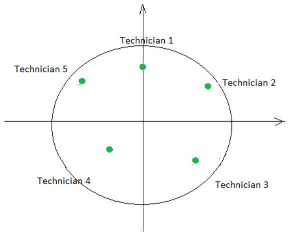

Figure 2c Visualization of task T_1 performance by all technicians

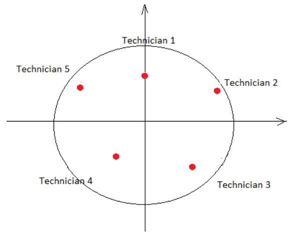

Figure 2d Visualization of task T_2 performance by all technicians

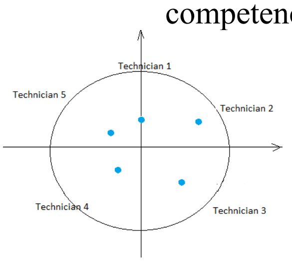

Figure 2e Visualization of task T_3 performance by all technicians

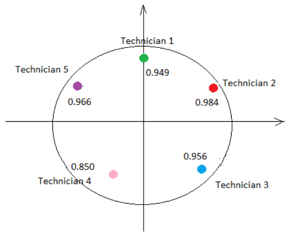

Figure 2f Visualization of levels of professional competence of all technicians

Thus, to establish components of the position vectors of all tasks evenly, let

$$\vec{P}_k = \begin{pmatrix} \cos\left(\frac{\pi}{2} - \frac{2\pi}{K}(k-1)\right) \\ \sin\left(\frac{\pi}{2} - \frac{2\pi}{K}(k-1)\right) \end{pmatrix} \quad (3)$$

for all $k = 1, 2, \ldots, K$.

Therefore, for each $i = 1, 2, \ldots, I$, the result vector $\vec{P}^i_{res}$ is equal to

$$\vec{P}^i_{res} = \sum_{k=1}^{K} R(S_i, T_k) \cdot \vec{P}_k. \quad (4)$$

where $K = J$. Hence, e.g., for $i = 1$, we have (see Fig. 2a), the result vector representing the level of professional competence of technician S_1 in performing all tasks is green):

$$\vec{P}^1_{res} = 0.706\begin{pmatrix} 0 \\ 1 \end{pmatrix} + 0.7\begin{pmatrix} 0.5\sqrt{3} \\ -0.5 \end{pmatrix} + 0.424\begin{pmatrix} -0.5\sqrt{3} \\ -0.5 \end{pmatrix} = \begin{pmatrix} 0.238 \\ 0.122 \end{pmatrix}.$$

Now, we solve the opposite problem of calculating the result vector for tasks T_j, $(j = 1, 2, \ldots, J)$, where vectors are built on the basis of professional competence of technicians performing all tasks T_j. Thus, for each task T_j, the result vector $\vec{M}^j_{res}$ is equal to

$$\vec{M}^{j}_{res} = \sum_{k=1}^{K} R(S_k, T_j) \cdot \vec{P}_k, \tag{5}$$

where $K = I$.

Since there are five technicians, there are five position vectors $\vec{P}_k$. Let us consider the digraph for task T_1 (Fig. 2b, the result vector representing the levels of professional competence of the team is green). Thus,

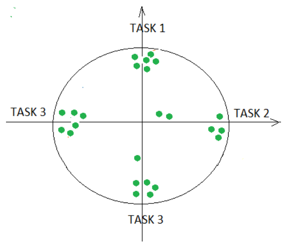

Figure 3a Visualization of the professional competence of a team of technicians according to tasks

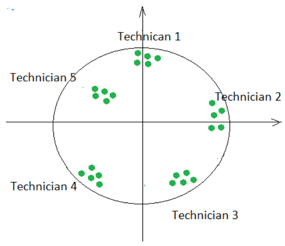

Figure 3b Visualization of the professional competence of a team according to technicians

$$\vec{M}^{1}_{res} = 0.706\begin{pmatrix}0\\1\end{pmatrix} + 0.8\begin{pmatrix}0.95\\0.31\end{pmatrix} + 0.703\begin{pmatrix}0.59\\-0.81\end{pmatrix} + 0.5\begin{pmatrix}-0.59\\-0.81\end{pmatrix} + 0.806\begin{pmatrix}-0.95\\0.31\end{pmatrix} = \begin{pmatrix}0.114\\0.229\end{pmatrix}.$$

Fig. 2c, d and e present the levels of professional competence of all technicians in performing tasks T_1, T_2 and T_3, respectively (the circles show the terminal points of the result vectors). Fig. 2f visualizes the levels technician in performing all tasks. The farther the terminal point of the result vector is, the higher level of the professional competence of the technician is observed. As it can be noticed all technicians possess great skills. However, if the manager needs more precise information, they have to look at visualizations for tasks, e.g.e, there is a big difference for task T_3 (Fig. 2d).

Interpretation of visualization results. The presented method of digital visualization helps to simplify the process of tasks delegation for company managers. The achievements of individual technicians or the teams of them concerning the levels of performing all tasks together or the specific subset of them chosen by the managers can be easily observed. This method of visualization enables the managers to take into consideration two points of view at the same time: the levels of individual technician's professional competence and levels of professional competence of performing the discussed tasks.

Hence, the managers can estimate levels of professional competence of their team analyzing the graphs. Fig. 3a presents the visualization of the professional competence of the team of technicians when the performance of tasks are taken into consideration. As it can be noticed for this team, task 2 is the most difficult because two technicians have low professional competence in performing it and task 1 is the routine for them.

If the manager wants to see their technician team according to technicians, it might be better to use Fig. 3b. Technician 1 is the best in performing all tasks and Technician 5 is the poorest one. This presentation might also be used to see the professional competence of technicians according to time.

Table 8.
Professional competence

Technician	Task			
	T_1	T_2	T_3	T_4
S_1	0.7	0.7	0.7	0.7
S_2	0.2	0.2	0.2	0.2

Hence, taking into consideration all visualizations, it can be seen, that all technicians, except S_5, possess high levels of professional competence in all task and the weakest performance is observed for task T_2, so probably the team needs some training.

The following example presents a specific situation, when looking at these two visualizations is crucial for correct understanding of the professional competence of the team. Let us consider the following example. In the company there are two technicians, they have to perform four tasks and their levels of professional competence of performing these tasks are given in the Table 8.

Notice that in both cases, the result vector of their professional competence of performing these tasks is $\vec{0}$, so we cannot distinguish their competence preparing only the digraph similar to presented in Fig. 2a. Because of that, we present the technicians' professional competence on two diagrams (Fig. 4).

As we can see presenting only result vectors might cause misunderstanding, so we have to show both diagrams.

Conclusions. The proposed methods of calculating levels of professional competences of technicians or values of result functions based on levels of competition criteria are not difficult to understand and consists of a few steps, so levels of the interpretability of the presented are high. At the beginning of the process the experts have to prepare tables with the data, then there must be performed some calculations and in the part of making decision there are prepared some rankings or the decisions are made. These rankings are important aspect for operational use of Professional Competence in maintenance operations. Service Companies apply different strategies for people assignment to the job from assignment of the most skilled technician to the complex activity related to the specialist hardware to assignment of the technician with minimal acceptable level of Professional Competence for low priority and repetitive activities (like facilities preventive service or installation of CPE – Customer Premise Equipment in telecommunication industry). This is why trustful method of Professional Competence evaluations is required.

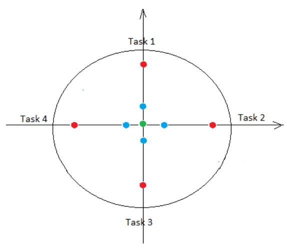

Fig. 4a Visualization of tasks performance by technicians from the perspective of technicians: technician 1 (blue) and technician 2 (red). The resulting vector (green) in the case of both technicians is the null vector.

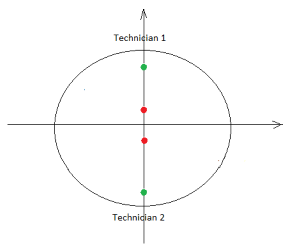

Fig. 4b Visualization of tasks performance by technicians from the perspective of tasks: task 1 (blue) and task 2 (red).

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