Decision Support System to Prioritize Ventilators for COVID-19 Patients using AHP, Interpolation, and SAW

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Abstrak
        Kekurangan ventilator merupakan masalah yang sering dihadapi rumah sakit selama pandemic COVID-19. Pekerja kesehatan dipaksa membuat pilihan karena perbedaan jumlah peralatan dan nyawa yang membutuhkannya. Dalam situasi normal, semua pasien memiliki hak yang sama untuk menerima perawatan dan peralatan sehingga masalah ini jarang dihadapi, namun menjadi masalah yang jelas ketika peralatan yang tersedia tidak mencukupi. Maka dari itu, mekanisme pemrioritasan yang dapat secara objektif menentukan kebijakan alokasi haruslah dibuat untuk mendapatkan hasil yang terbaik.
        Sistem pendukung keputusan adalah sistem yang dapat mendukung manusia sebagai pembuat keputusan, menggunakan data untuk memutuskan masalah semi-terstruktur atau tidak terstruktur. Tujuan dari penelitian ini adalah membuat SPK untuk pemrioritasan pasien yang membutuhkan ventilator dengan menggabungkan beberapa metode yaitu AHP, Interpolasi, dan SAW. Diharapkan hasil penelitian ini dapat digunakan untuk memeringkatkan pasien berdasarkan criteria dan kebijakan yang telah ditentukan.

***Kata kunci**—SPK, Kesehatan, Analytical Hierarchy Process, Interpolasi, SAW*

Abstract
        Ventilator shortages is a common problem faced by hospitals during the COVID-19 pandemic era. Healthcare workers are forced to make choices because of how big the difference between resources and lives needing it. This issue rarely comes, because normally every patient has the same rights to receive treatment and resources, but it becomes a clear problem when there are barely enough resources. Therefore, a prioritization mechanism that can objectively decide the allocation must be made to achieve the best outcome.
        A decision support system is a system that can support humans using data as decision makers to help them decide semi-structured/unstructured problems. The goal of this research is to create a DSS to prioritize patients who need a ventilator by incorporating two different methods, which are AHP, Interpolation, and SAW. It is hoped that the result of the research can be used to rank patients based on predetermined criterias and policy.

***Keywords**—DSS, Healthcare, Analytical Hierarchy Process, Interpolation, SAW*

1. INTRODUCTION

        A new disease emerged in late December of 2019, in Wuhan, Hubei Province, China. Around 66% of Huanan Seafood Wholesale Market staff was involved in the outbreak, spreading the disease rapidly to other provinces and eventually 222,406,582 cases were confirmed globally by WHO by September 9th, 2021. Some of these patients developed symptoms worse than the

commonly found symptoms: fever, dry cough, fatigue, and some of them needs ventilator support to keep breathing [1].

However, the number of healthcare resources available in hospitals recently cannot keep up and have become scarce. According to GlobalData 880.000 ventilators are wanted globally, and 74.000 are needed in France, Germany, Italy, Spain, and the UK. The same goes for Indonesia where 29.900 are needed while there are only 8.400 available by April 13th, 2020, according to Gugus Tugas Percepatan Penanganan Covid-19. The huge gap between the number of available ventilators and the number of patients in need of ventilators forces healthcare workers to develop a prioritization technique/policy in order to avoid the worst outcome.

Following one of WHO's published policy which revolves around the ethical guide regarding the resource allocation and priority setting for COVID-19, there are four recommended allocation principles to be followed. Two of them can be applied by utilizing a DSS, which are 'Best outcomes (utility)' and 'Prioritize the worst off'. DSS can be used to solve the mentioned problem by prioritizing patients based on their condition, which are assessed by adapting SOFA Score as the criteria.

There are research originating from the medical field especially the critical care medicine regarding ventilator prioritization however not much of them seems to implement IT principles, especially DSS to support the decision-making phase. Cardona et al. [2] and Piscitello et al. [3] mostly reviewed algorithms and strategies in 20 countries and USA respectively. In terms of the methods applied in the research, Mukharir and Wardoyo [4] designed a similar DSS with different research objective, and a little different interpolation where the said research also uses profile matching to handle user preference. The closest research is the research done by Rahim et al. [5] which is also a DSS used for patient prioritization, although not specifically for ventilators, and combining AI and AHP based DSS to support decision making.

The criterias are adapted from SOFA Score, an assessment tool to quantifying the degree of organ dysfunction from six different scores: respiratory, cardiovascular, hepatic, coagulation, renal and neurological system according to Lambden et al [6]. Some research found that some of the components might have stronger correlations to mortality than the other. Bels et al. [7], found that the differences in SOFA score trajectories between ICU-survivors and ICU-non-survivors are driven only by some of the components. The use of AHP is very advantageous to apply these findings.

The Analytical Hierarchy Process method is a multi-criteria decision-making method consists of problem defining, decision hierarchy making, pairwise comparison process, and finally obtaining the weight by using the first priorities result to weigh the priorities under the current level, down until the last level [8]. The method is used to support users to create an intuitive importance setting of each criteria.

Interpolation method is used for data scoring, the method is adapted from linear interpolation which is used to estimate a value based on two other values. It is automatically applied to map the values of the alternatives to the defined value range[9].

2. METHODS

2.1 Research Description

This research aims to create a web-based decision support system which operates using AHP, Interpolation, and SAW methods, by adapting the SOFA score as the criteria for the decision making process and is able to rank COVID-19 patients based on said criteria. The flowchart of the system in this research is shown Figure 1.
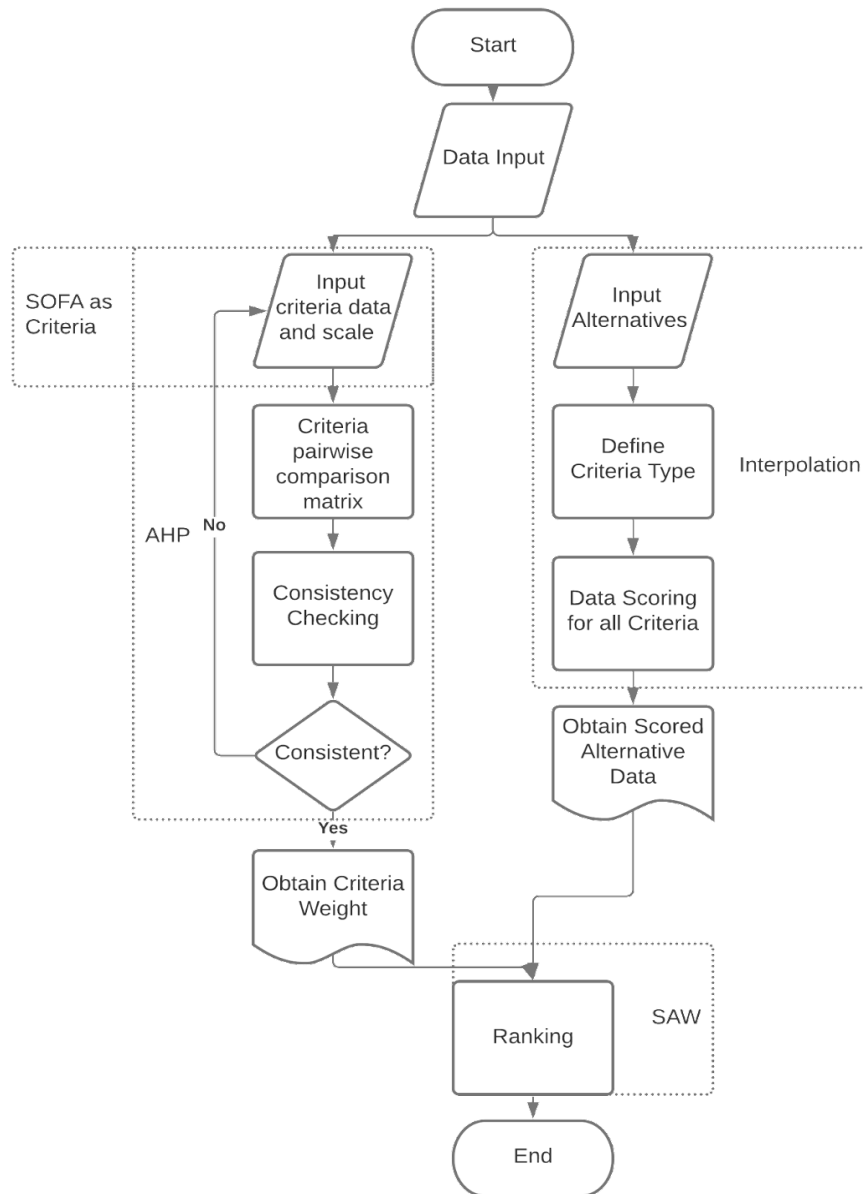
Figure 1 System Flowchart

2.2 Criteria Weighting

By using the mentioned AHP method, the first step of the process is creating the decision-making hierarchy structure. The second step is to create a pairwise comparison matrix. For this system, the AHP is used only for criteria weighting, so there will only be one pairwise matrix comparison. And once the matrix is made, weight is obtained by calculating F value, and normalizing it.

Finding F value is done by calculating the product of each matrix row, shown below [10]:

$$M_i = \Pi_{j=1}^{n} b_{ij} \ , i = 1,2,\dots,n \tag{1}$$

Obtaining the F (nth root of product), where n is the number of criterias:

$$W_i = \sqrt[n]{M_i}, i = 1,2,\ldots,n \tag{2}$$

Normalization of each F is the weight (W):

$$W_i = \overline{W}_i \Big/ \sum_{j=1}^{n} \overline{W}_j, i = 1,2,\ldots,n \tag{3}$$

Validating the result of the comparison by calculating lambda max and CI to find CR. If CR is less or equal to 0.1, the comparison is valid and consistent. The formula is shown below:

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{4}$$

$$CR = \frac{CI}{CR} \tag{5}$$

2.3 Alternative Scoring

Linear interpolation is being adapted as a scoring method for determining the rank of the alternatives. This process will interpolate all of the alternative's values by first identifying the dmin, dmax, smin, and smax of the data group. The formula for this method is shown in equation 4:

$$Score(x) = \frac{x - dmin}{(dmax - dmin)}(smax - smin) + smin \tag{6}$$

Below is the definition of each element:

$dmin$: The minimum alternative data value on a certain criteria.
$dmax$: The maximum alternative data value on a certain criteria.
$smin$: The lower limit of the interpolated range.
$smax$: The upper limit of the interpolated range.

2.4 Final Ranking

SAW (Simple Additive Weighting) method is used for obtaining the sum of product between the interpolated values and the criteria weights corresponding to them.

2.5 System Analysis and Design

The system works by following the flowchart from figure 1, it is designed to be used for a single user to speed up the process of ranking. To use the system, users must be registered to the user's database, users can register and login to then use the other functionality of the system. Once logged in, users can then enter patients as alternatives, calculate the weight and entering the obtained weight to customize the criteria, choose the principles that is going to be used, and finally view the final ranking result as well as the calculation. The system is designed to work like the activity diagram Figure 2.
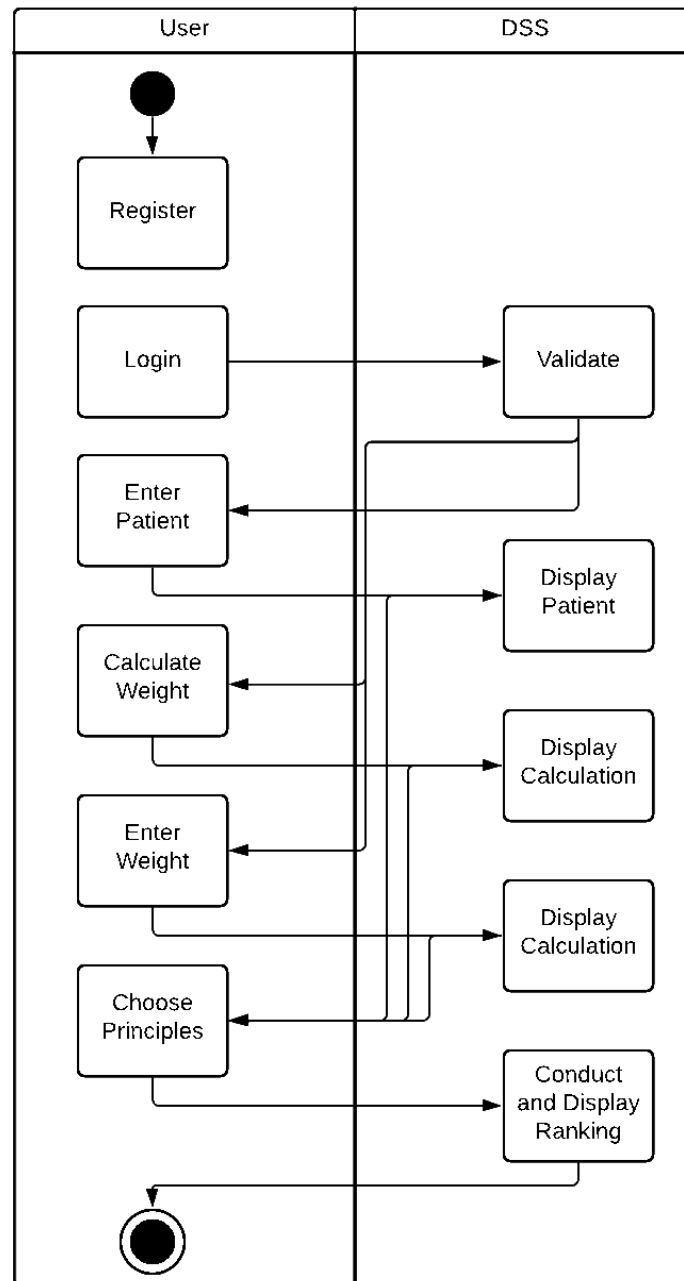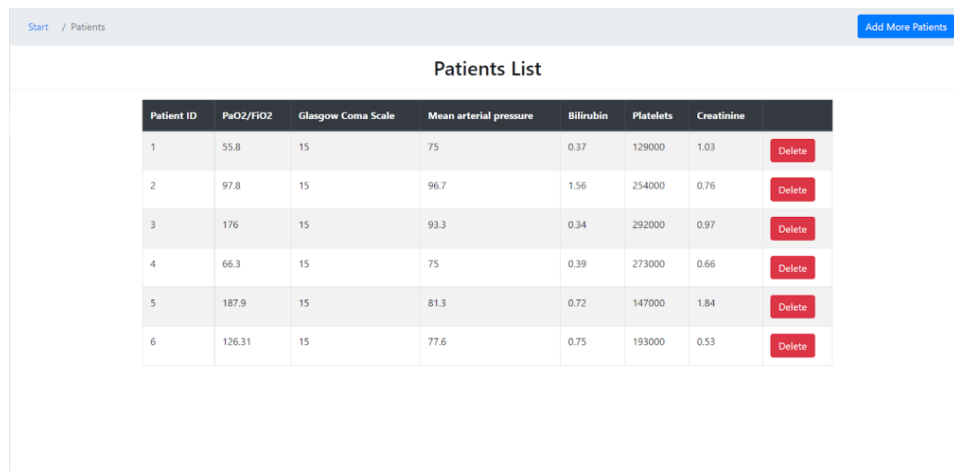
Figure 2 Activity Diagram

2.6 System Implementation

The system consists of many parts, however it can be divided into three big main parts which are: 'users, criteria, and interpolation'. Using flask framework and python language, the end result user interface is shown Figure 3 - 7.
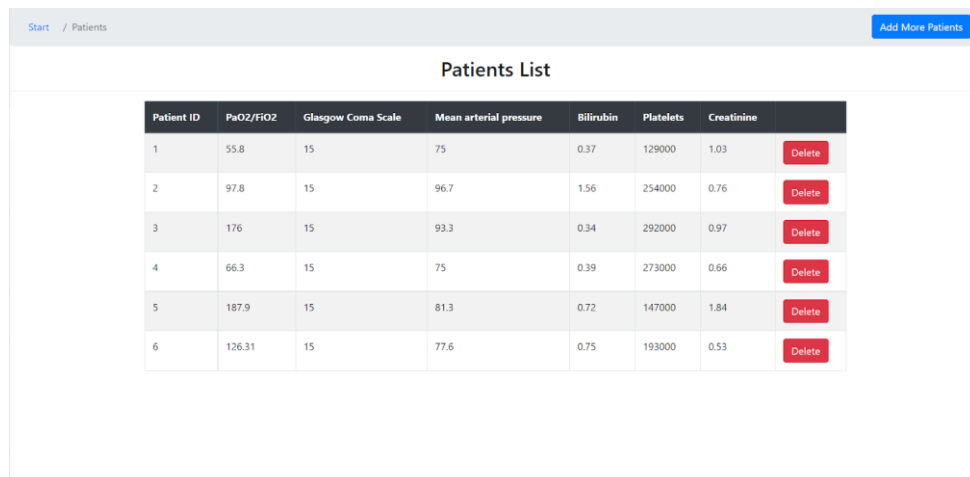
1. Patient List

Figure 3 Patient list User Interface

2. Criteria Importance

Figure 4 Criteria Importance User Interface

3. Criteria Weight Setting is shown below:

Figure 5 Criteria Weight Setting User Interface

4. Principle Selection is shown below:
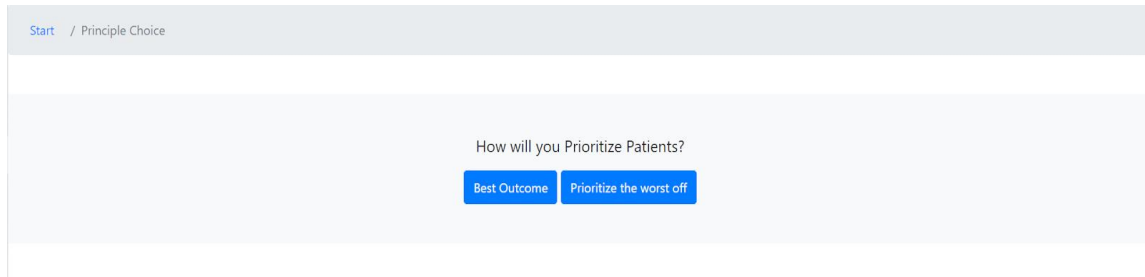
Figure 6 Principle Selection User Interface

5. Result Section is shown below:
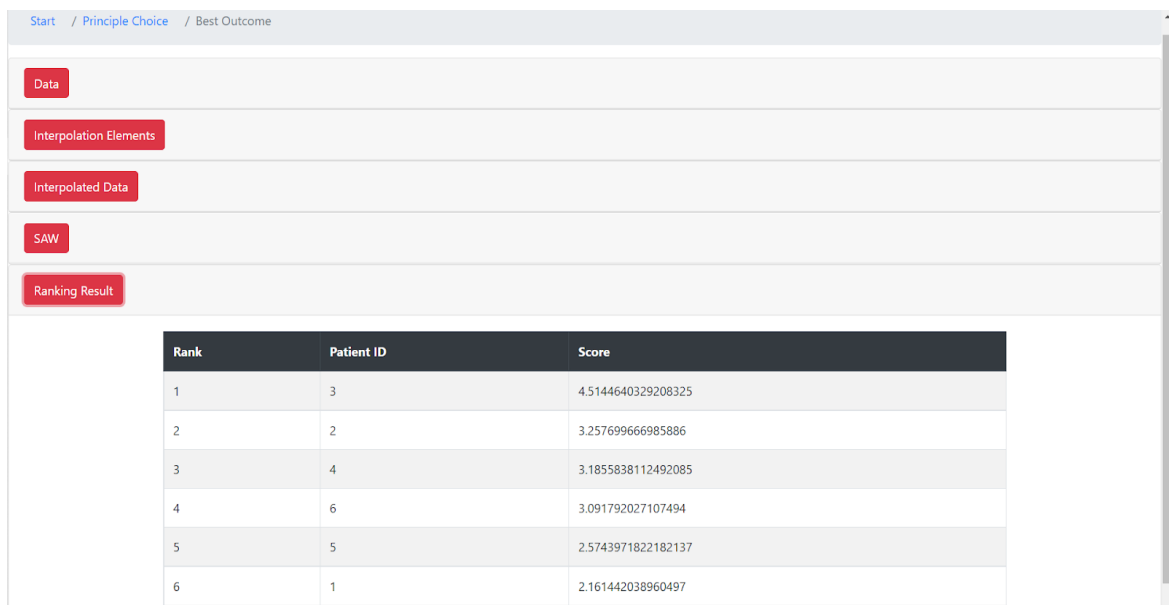
Figure 7 Result Section User Interface

3. RESULTS AND DISCUSSION

3. 1 Data

The data used in this research are obtained from the journal 'Respiratory Parameter Has a Great Impact in Determining Sepsis Condition in COVID-19 Patients at Saiful Anwar Hospital Malang: Case Report'. 6 COVID-19 confirmed patients with sepsis, from 22-61 years old, with parameters same as SOFA [11].

Table 1 Data Used in This Research

| Characteristic Sample and SOFA Score								
Parameter		Female-1	Male-1	Female-2	Female-3	Male-2	Female-4	Mean
Age		50	22	47	61	59	57	49
Respiration	PaO2/FiO2	55,8	97,8	176	66,3	187,9	126,31	118,35
		4	4	3	4	3	3	
Coagulation	Platelets	129000	254000	292000	273000	147000	193000	182500
		1	0	0	0	1	0	
Liver	Bilirubin	0,37	1,09 1,56	0,34	0,39	0,72	0,75	0,61
		0	1	0	0	0	0	
	OT/PT	30/50	156/329	24/13	38/15	115/109	106/80	
Cardiovascular	MAP	75	96,7	93,3*NE	75*NE	81,3	77,6	83,15
		0	0	2	2	0	0	
Awareness	GCS	15	15	15	15	15	15	15
		0	0	0	0	0	0	
Renal	Creatinine; Urine Output	1,03	0,76	0,97	0,66	1,84	0,53	0,96
		0	0	0	0	1	0	
Total SOFA Score		5	5	5	6	5	3	4,8**

3. 2 Evaluation

The system was then tested for multiple scenarios using Selenium IDE, for manual black-box unit testing to test whether all functionality aspects of the system works just as expected. During the testing, with 9 different test cases, the system did not show any errors and all functions are working well.
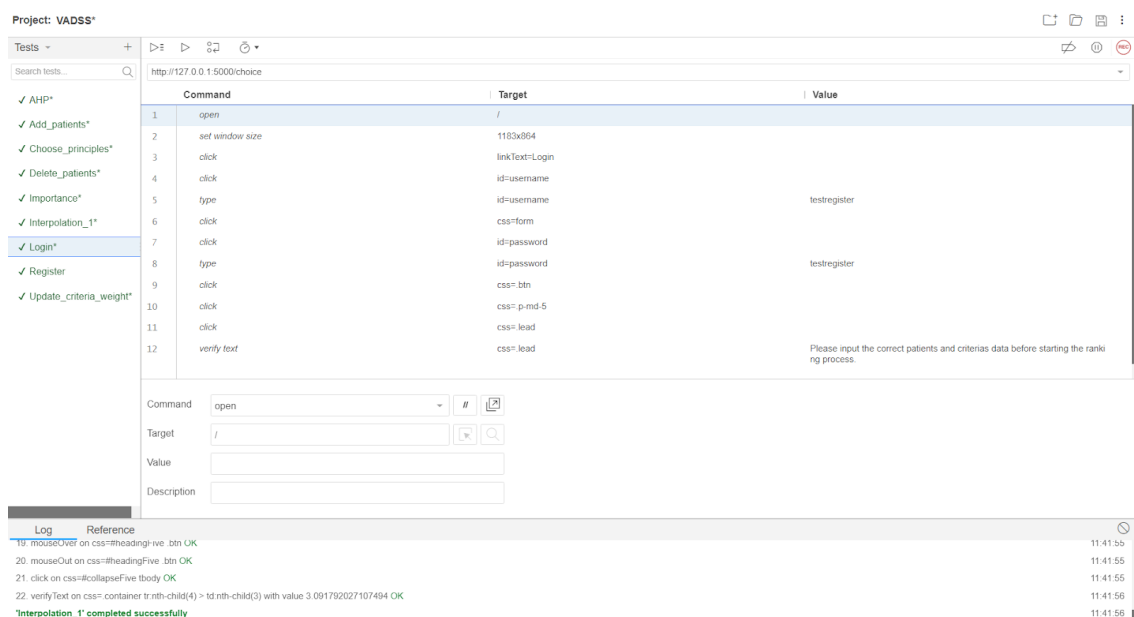

Figure 8 Testing Result

3. 3 Comparison

The system was also evaluated by comparing the result with using the raw SOFA score. The result shows Table 1 that there are differences between using DSS and raw SOFA score.

Table 1 Comparison Result

SOFA Score			DSS	
Patient ID	Total Score	Priority	Patient ID	Priority
6	3	1	3	1
1	5	2	2	2
2	5	2	4	3
3	5	2	6	4
5	5	2	5	5
4	6	3	1	6

4. CONCLUSION

The decision support system made in this research, is intended to be used for ventilator allocation based on the COVID-19 patient's condition. Criteria which are used in this research is adapted from SOFA Score, with each importance of the criteria can be obtained using Analytical Hierarchy Process. The alternatives input is from the patient's data, which will then be interpolated. The type of each criteria (cost-benefit) can be chosen by the user based on the principle used for the ranking. The final ranking is obtained by conducting SAW to each alternative's values and their criterias respectively, with the highest value being the number 1 priority and the lowest value being the last priority.

The result obtained from testing and comparison shows that the decision support system was able to rank the alternatives objectively, fast, and reliably. There are differences in the ranking result between raw SOFA Score and the DSS. The notable advantage of using this DSS when compared to using SOFA only for assessment without other criteria, is that the DSS has a fairly high discriminatory ability which is a big advantage to save time, and also to avoid unnecessary tiebreaker criterias. Another advantage is that it can emphasize the difference in criteria importance through the use of AHP.

There are some suggestions from the author to improve the quality of the research, the system can be improved a lot by combining other criterias. As there are many opinions regarding prioritization criteria, it can be adjusted locally based on where the system is going to be used. Other DSS methods might also be able to be used for the same goal.

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