Federal Multi Criteria Decision Making Framework in Distribution of Anti-SARS-CoV-2 Monoclonal Antibody to Eligible High-Risk Patients as Case Study

إطار اتخاذ القرار الفيدرالي متعدد المعايير في توزيع الأجسام المضادة أحادية النسيلة المضادة لـ SARS-CoV-2 على المرضى المؤهلين ذوي الخطورة العالية كدراسة حالة

by

ABEER ALSEREIDI

A thesis submitted in partial fulfilment

of the requirements for the degree of

DOCTOR OF PHILOSOPHY IN COMPUTER SCIENCE
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ABSTRACT

No specific treatment was available for severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) when the epidemic firstly broke out. The urgent need to end this unusual situation has resulted in many attempts to deal with SARS-CoV-2. In addition to several types of vaccinations that have been created, anti-SARS-CoV-2 monoclonal antibodies (mAbs) have added a new dimension to preventative and treatment efforts. This therapy also helps prevent severe symptoms for those at a high risk. Therefore, it is a promising treatment for mild-to-moderate SARS-CoV-2 cases. However, the availability of anti-SARS-CoV-2 mAb therapy is limited and leads to two main challenges. The first is the privacy challenge of selecting eligible patients from the distribution hospital networking, which requires data sharing; the second is the prioritisation of all eligible patients amongst the distribution hospitals according to dose availability. To our knowledge, no research has combined the federated fundamental approach with multicriteria decision-making methods for the treatment of SARS-COV-2, which indicates a research gap. This thesis presents a unique sequence processing methodology that distributes anti-SARS-CoV-2 mAbs to eligible high-risk patients with SARS-CoV-2 according to medical requirements by using a novel federated decision-making distributor (FDMD). A novel FDMD of anti-SARS-CoV-2 mAbs is proposed for eligible high-risk patients. FDMD is implemented on augmented data of 49,152 cases of patients with SARS-CoV-2 with mild and moderate symptoms. For proof of concept, three hospitals with 16 patients each are enrolled. The proposed FDMD is constructed from the two sides of claim sequencing: central federated server (CFS) and local machine (LM). The CFS includes five sequential phases synchronised with the LMs, namely, the preliminary criteria setting phase that determines the high-risk criteria, calculates their weights using the newly formulated interval-valued spherical fuzzy and hesitant 2-tuple fuzzy-weighted zero-inconsistency (IVSH2-FWZIC) and allocates their values. The subsequent phases are federation, dose availability confirmation, global prioritisation of eligible patients and alerting the hospitals with the patients most eligible for receiving the anti-SARS-CoV-2 mAbs according to dose availability. The LM independently performs all local prioritisation processes without sharing patients' data using the provided criteria settings and federated parameters from the CFS via the proposed federated TOPSIS (F-TOPSIS). The sequential processing steps are coherently performed at both sides. The results are presented as follows: (1) The proposed FDMD efficiently and independently identifies

the high-risk patients who are most eligible for receiving anti-SARS-CoV-2 mAbs at each local distribution hospital. The final decision at the CFS relies on the indexed patients' score and dose availability without sharing the patients' data. (2) The IVSH2-FWZIC effectively weights the high-risk criteria of patients with SARS-CoV-2. (3) The local and global prioritisation ranks of the F-TOPSIS for eligible patients are subjected to a systematic ranking validated by high correlation results across nine scenarios by altering the weights of the criteria. (4) A comparative analysis of the experimental results with a prior study confirms the effectiveness of the proposed FDMD. The study of the proposed FDMD implies that it has the benefits of centrally distributing anti-SARS-CoV-2 mAbs to high-risk patients prioritised according to their eligibility and dose availability. It also simultaneously protects their privacy and offers an effective cure to prevent progression to severe SARS-CoV-2, hospitalisation or death.

***Key Terms*:** anti-SARS-CoV-2, monoclonal antibodies, MCDM, FWZIC, TOPSIS

ملخص

عندما انتشر الوباء لأول مرة ، لم يكن هناك علاج محدد متاح لمتلازمة الجهاز التنفسي الحادة الوخيمة فيروس كورونا 2 (SARS-CoV-2), أدت الحاجة الملحة لإنهاء هذا الوضع غير العادي إلى العديد من المحاولات للتعامل مع-SARS-CoV-2.بالإضافة إلى عدة أنواع من اللقاحات التي تم إنشاؤها ، أضافت الأجسام المضادة أحادية النسيلة المضادة لـ-SARS-CoV-2 (mAbs) بُعدًا جديدًا للجهود الوقائية والعلاجية. يساعد هذا العلاج أيضًا في منع الأعراض الشديدة للأشخاص المعرضين لخطر كبير. لذلك ، يعد هذا أحد أكثر العلاجات الواعدة للحالات الخفيفة إلى المتوسطة من السارس. ومع ذلك ، فإن توافر العلاج المضاد لـ SARS-CoV-2 mAb محدود ويؤدي إلى تحديين رئيسيين. الأول هو تحدي الخصوصية المتمثل في اختيار المرضى المؤهلين من شبكة مستشفى التوزيع ، الأمر الذي يتطلب مشاركة البيانات ، والثاني هو إعطاء الأولوية لجميع المرضى المؤهلين بين مستشفيات التوزيع وفقًا لتوافر الجرعة. على حد علمنا ، لم يجمع أي بحث بين النهج الأساسي الفيدرالي وطرق صنع القرار متعددة المعايير لعلاج2-SARS-COV ، مما يشير إلى وجود فجوة بحثية. تقدم هذه الأطروحة منهجية فريدة لمعالجة التسلسل تقوم بتوزيع مضادات السارس CoV-2 mAbs-على المرضى المؤهلين المعرضين لمخاطر عالية مع SARS-CoV-2 بناءً على المتطلبات الطبية باستخدام موزع جديد لصنع القرار الموحد. تقترح هذه الأطروحة موزعًا جديدًا لصنع القرار الفيدرالي (FDMD)لمضادات السارس CoV-2 mAbs-للمرضى المؤهلين المعرضين لمخاطر عالية. يتم تنفيذ FDMD على بيانات مكثفة لـ 49152 حالة من المرضى المصابين بـ SARS-CoV-2 مع أعراض خفيفة ومتوسطة. لإثبات المفهوم ، تم تسجيل ثلاث مستشفيات تضم كل منها 16 مريضًا. تم إنشاء FDMD المقترح من جانبي تسلسل المطالبة: الخادم المركزي الموحد (CFS)والآلة المحلية .(LM) تشتمل المساحات الصديقة لألطفال على خمس مراحل متتالية متزامنة مع LMs ، وهي مرحلة إعداد المعايير ألولية التي تحدد المعايير عالية المخاطر ، وتحسب أوزانها باستخدام الشكل الكروي الغامض ذي القيمة الفاصلة والمتردد 2 (IVSH2-FWZIC) tuple Fuzzy-weighted-incondency-، وتخصص قيمها. المراحل اللاحقة هي الاتحاد ، وتأكيد توافر الجرعة ، وتحديد الأولويات العالمية للمرضى المؤهلين وتنبيه المستشفيات بالمرضى الأكثر تأهيلاً لتلقي مضادات السارس CoV-2 mAbs-وفقًا لتوافر الجرعة. ينفذ LM بشكل مستقل جميع عمليات تحديد الأولويات المحلية دون مشاركة بيانات المرضى باستخدام إعدادات المعايير المتوفرة والمعلمات الموحدة من CFS عبر TOPSIS الموحدة المقترحة-F) .(TOPSISيتم تنفيذ خطوات المعالجة المتسلسلة بشكل متماسك على كلا الجانبين ، ويتم عرض النتائج على النحو التالي: (1)

يحدد FDMD المقترح بكفاءة وبشكل مستقل المرضى المعرضين لمخاطر عالية الأكثر تأهيلاً لتلقي مضادات السارس-CoV-2مللي أمبير في كل مستشفى توزيع محلي . يعتمد القرار النهائي في CFS على درجة المرضى المفهرسة وتوافر الجرعة دون مشاركة بيانات المرضى. (2) يزن IVSH2-FWZIC بشكل فعال المعايير عالية الخطورة للمرضى المصابين بـ-SARS CoV-2. (3) تخضع ترتيب الأولويات المحلية والعالمية لـ F-TOPSIS للمرضى المؤهلين لترتيب منهجي تم التحقق من صحته من خلال نتائج الارتباط العالية عبر تسعة سيناريوهات من خلال تغيير أوزان المعايير. (4) تحليل مقارن للنتائج التجريبية مع دراسة سابقة يؤكد فعالية FDMD المقترح. الآثار المترتبة على دراسة FDMD المقترحة لها فوائد التوزيع المركزي لمضادات السارس CoV-2 mAbs-على المرضى المعرضين لمخاطر عالية والذين تم تحديد أولوياتهم بناءً على أهليتهم وتوافر الجرعة ، وفي نفس الوقت حماية خصوصيتهم وتقديم علاج فعال لمنع التقدم إلى SARS-CoV-2 الشديدة أو الاستشفاء أو الوفاة.

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LIST OF ABBREVIATIONS

Abbreviation	Definition
MCDM	Multi Criteria Decision Making
FDMD	Federated Decision Making Distributor
DDM	Dynamic Decision Matrix
DM	Decision making
F-TOPSIS	Federated Technique for Order of Preference by Similarity to Ideal Solution
IVSH2-FWZIC	Interval-valued spherical fuzzy and hesitant 2-tuple fuzzy environment
CFS	Federated central server
NIH	National Institutes of Health
PEP	Post-exposure prophylaxis
PrEP	Pre-exposure prophylaxis
PHI	Protected health information
PRISMA	Meta-analysis (PRISMA)
HCM	Health Care Waste
SLR	Systematic Literature Review
ML	Machine learning
HHD	Hand-held devices
MSIs	Musculoskeletal infections
CP	Convalescent plasma
DBMS	Database management system
FL	Federated Learning

AI	Artificial Intelligence
EHR	E-health records
City DT	city Digital Twin
ECM	Efficacy coefficient method
AHP	Analytical hierarchy process
BWM	Best-worst methodology
WPM	Weighted Product Method
FWZIC	The fuzzy weighted with zero inconsistency
TFNs	Triangular fuzzy numbers
TrFN	Trapezoidal fuzzy numbers
T-SFS	T-spherical fuzzy set
PyFS	Pythagorean fuzzy set
SFS	Spherical fuzzy set
HFS	Hesitant fuzzy set
IVHFS	Interval-valued Hesistant fuzzy set
SCC	Spearman correlation coefficient
CHDs	Chronic heart diseases
SEJ	Structured expert judgment
EDM	Expert Decision Matrix
ACK	Acknowledge message
TD	Treatment dose
HCM	Health Care Waste

CHDs	Chronic heart diseases

CHAPTER 1: INTRODUCTION

1.1.Introduction

This chapter provides a brief overview of the research and presents the problem, motivation behind the study and research objectives. Section 1.2 provides background information on research components, and Section 1.3 examines the research problem. Research questions are formulated. Research objectives are provided in Section 1.5. Relationship between research objectives, research questions and research problem are discussed in Section 1.6. The scope of the study is defined in Section 1.7. The significance of the study is discussed in Section 1.8. Finally, Section 1.9 summarises the layout of this thesis.

1.2.Background

In December 2019, a respiratory sickness called Coronavirus Disease 2019 caused a novel coronavirus known as severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) was found (Helmy et al. (2020). Biopharmaceutical companies have intensified and accelerated their research into potential SARS-CoV-2 vaccines in response to the current critical state to slow down viral spread, illness symptoms and reduce the number of deaths.

Accordingly, vaccines against SARS-CoV-2 were created in less than a year after the virus was discovered. Despite substantial vaccination coverage and efficacy, the number of people infected with SARS-CoV-2 had obviously increased in many countries (Helmy et al., 2020). Many individuals are worried about the safety and efficacy of the SARS-CoV-2 vaccine. The advent of SARS-CoV-2 variants, such as delta and omicron, is one of them (Juan Li, 2021). However, the disease's high death toll has motivated hundreds and thousands of clinical trials (Chakraborty et

al., 2021) that explore feasible therapy solutions (Burgos et al., 2021). SARS-CoV-2 treatments in their current states and the transition from vaccine administration to therapy have become major topics in global research.

At the onset of the pandemic outbreak, no specific medication was available to tackle SARS-CoV-2, and thus many attempts to treat SARS-CoV-2 had been made in response to the urgent need to put an end to this unprecedented phenomenon. In addition to vaccinations, monoclonal antibodies (mAbs) introduced a new dimension to feasible prevention and treatment approaches (Chigutsa et al., 2021). Given that vaccine-derived immunity develops over time, neutralising mAb treatments can provide individuals with rapid and passive immunity while reducing disease symptoms and inhibiting progression (Dougan et al., 2021).

The ideal scenario to tackle SARS-CoV-2 would be controlled through vaccination. If a patient has contracted the virus, an ideal intervention prevents the development of severe symptoms (Mornese Pinna et al., 2021). Treatment with monoclonal antibodies (mAbs) is appropriate for high-risk patients, making it one of the most promising treatments for mild-to-moderate SARS-CoV-2 (Dougan et al., 2021; Suárez-García, Perales-Fraile, González-García, Muñoz-Blanco, Manzano, Fabregate, Díez-Manglano, Aizpuru, Fernández, & García, 2021).

Etesevimab and bamlanivimab are laboratory-made mAb proteins that can mimic the immune system's ability to fight SARS-CoV-2 (HEALTH, 2021). These drugs are given simultaneously and authorised for use after viral exposure (postexposure prophylaxis [PEP] but not for SARS-CoV-2 preexposure prophylaxis [PrEP]). Prophylaxis, sometimes known as preventative

healthcare, refers to activities intended to prevent diseases. Both mAb proteins have been approved for treating mild-to-moderate SARS-CoV-2 symptoms in adults and paediatric patients (patients weighting at least 40 kg and aged more than 12 years) who had positive results from direct SARS-CoV-2 virus testing and were at high risk of developing severe SARS-CoV-2 symptoms (Aleem et al., 2021). Bamlanivimab monotherapy reduces the likelihood of SARS-CoV-2 infection compared with placebo (Cohen, 2021). Although bamlanivimab administration was tested, the combined administration of bamlanivimab and etesevimab can be safer and more effective for PEP than bamlanivimab administration alone.

Treatments for SARS-CoV-2 are focused on reducing symptoms and preventing or postponing complications. If anti-SARS-CoV-2 mAbs cannot be produced and distributed, then the situation can swiftly worsen and exert significant impact on patients' quality of life and economic conditions in the coming years (Bollyky et al., 2020). Any feasible treatment for SARS-CoV-2 would have limited supply at first, and thus identifying who should have priority access is necessary. The development and mass distribution of SARS-CoV-2 medical treatments have become major subjects of interest worlwide (Bollyky et al., 2020). Fair distribution issues have arisen mainly after a framework for SARS-CoV-2 vaccine allocation has been presented and the possibility of vaccine distribution across countries has been examined [13]. This perspective explains how ethical principles should impact the distribution of SARS-CoV-2 drug treatments across nations on the basis of recipient prioritisation (Persad et al., 2020).

Medical treatment distribution is inextricably linked to distribution hospitals, also known as 'hospital networks' (Lega, 2005), because this procedure must be coordinated and equitable across

multiple hospitals. A hospital network consists of two or more hospitals in different locations (e.g. regions, states or countries) and supplementary healthcare services and facilities. A hospital network's headquarters is usually located in one of the locations served by network facilities (Association, 2014). In the late 20th century, hospital networks and/or distribution hospitals were designed to improve healthcare delivery efficiency and spread specialised medical services and specialists across the network (Shalev & Shapiro, 2020).

Medical centres can help remove medical service constraints and motivate patients to seek treatment or support by managing and controlling healthcare services, patients' health records and the usage and reuse of health data in distribution hospitals (Albahri et al., 2019). These distribution hospitals pose special hazards to patient confidentiality. In the SARS-CoV-2 pandemic, serious issues about privacy have been cited (Daggubati et al., 2020). The SARS-CoV-2 pandemic and high infection rate have forced governments to reconsider data privacy, which will be a defining undercurrent once the global economy returns to normal (Azad et al., 2020). In these contexts, patient data privacy and the availability of SARS-CoV-2 treatments in distribution hospitals are key issues that must be studied and evaluated in the current scenario.

1.3.Problem statement

The SARS-CoV-2 treatment distribution have been facing two main challenges. The first challenge is addressing the patient privacy challenge within distributed hospitals. The second challenge concerns prioritisation decision-making issues for attaining equitable distribution for SARS-CoV-2 drugs. Figure 1.1 illustrates the problem statement.

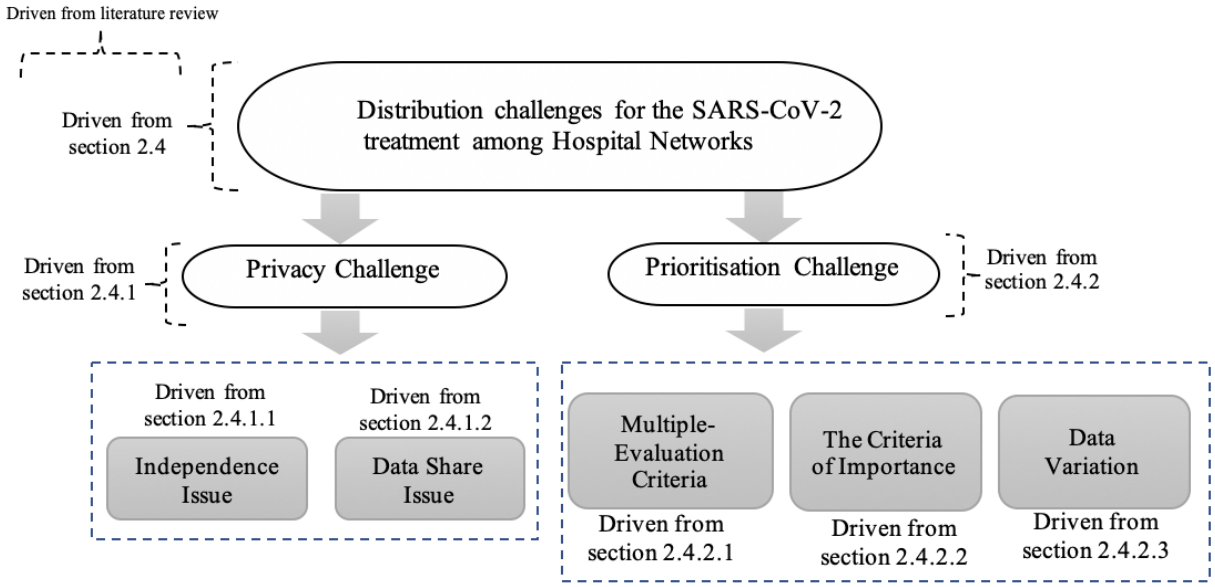

Figure 1. 1 Problem Statement Configuration

Owing to the limitation of the available anti-SARS-CoV-2 mAbs, hospitals or medical authorities should prioritise patients at the highest risk of clinical development (Chigutsa et al., 2021; Dispinseri et al., 2021). To address the first challenge, a holistic approach that fairly distributes anti-SARS-CoV-2 mAbs while considering privacy requirements associated with SARS-CoV-2 health considerations must be developed. Two main issues were considered major concerns for privacy challenge: data sharing and data independence issues. Inability to share patient data in a centralised system with any other parties is a significant problem because of data confidentiality. In particular, private patient data shared by hospitals and medical institution must be secured. Thus, data sharing is considered one of the privacy issues that should be addressed. Local data in the healthcare domain stays private and is never shared with any third party. Accordingly, data independence might be considered a second privacy issue in this case study. That is, distribution hospitals need a holistic, ethical and decision-making approach to address privacy concerns associated with SARS-CoV-2 health considerations. Distributing anti-SARS-CoV-2 mAbs during

a pandemic is tempting, but data privacy rules must be followed. This situation can be challenging in an era where personal protected health information (PHI) and other special categories of data are shared at an unprecedented degree throughout distribution hospitals. Globally, healthcare providers need to establish a new set of decision-making methods that reach a compromise between protecting patients' privacy and enabling the distribution of anti-SARS-CoV-2 mAb treatment according to the workflows of distribution hospitals. In public and private organisations, understanding privacy rules has never been more vital to operating safely in the next normal (Azad et al., 2020).

As for the second challenge, issues that render the prioritisation of treatment recipients a challenging task in distribution hospitals should be addressed. On this basis, importance of criteria affecting the distribution of treatments must be identified. SARS-CoV-2 Treatment Guidelines Panel of the National Institutes of Health (NIH) has recommended the use of anti-SARS-CoV-2 in the treatment of mild-to-moderate SARS-CoV-2 symptoms and SARS-CoV-2 infection PEP in individuals at increased risk of severe SARS-CoV-2 (Chigutsa et al., 2021). Anti-SARS-CoV-2 mAbs are beneficial as PEP or treatment for individuals who have a high risk of severe infection (Mornese Pinna et al., 2021). Fully vaccinated and immunocompetent individuals have a lower chance of contracting severe SARS-CoV-2 than those who are partially vaccinated or fully vaccinated but are not expected to generate significant immunological response to vaccines (Dispinseri et al., 2021; Hasan, 2021). Appropriate guidance about individuals that may benefit the most from treatments are essential when treatment supply restrictions make it impossible to treat all eligible patients (HEALTH, 2021). Only when the treatment must be placed on a 'triage' list, the NIH has suggested prioritising SARS-CoV-2 treatment over SARS-CoV-2 infection PEP and

prioritising anti-SARS-CoV-2 mAb treatment for unvaccinated, partially vaccinated individuals or vaccinated individuals who are immunocompromised, taking immunosuppressive drugs or 65 years or older. Providers or hospitals should utilise clinical discretion when prioritising the use of anti-SARS-CoV-2 mAbs for treatment or PEP in a particular context. The available Anti-SARS-CoV-2 mAbs should be monitored to ensure fair distribution (NIH, 2021).

The prioritisation challenge faced three issues (i.e. multicriteria, criterion weighting and inconsistency and data variation). In these contexts, the three issues can be discussed. Some high-risk criteria, such as age, chronic kidney disease, hypertension, cardiovascular disease, neurodevelopmental disorder, heart disease, receiving immunosuppressive treatment, chronic respiratory disease, obesity, body mass index, diabetes, immunosuppressive disease, pregnancy, sickle cell disease, medical-related technological dependence and SARS-CoV-2 severity were used in assessing patients with SARS-CoV-2. Multiple high-risk criteria should be considered when prioritising eligible patients. Some of these criteria are riskier than others, indicating varied relative importance. Accordingly, inconsistency arises when decision-makers (doctors) subjectively assign importance levels to high-risk criteria. In practice, decision-makers make inconsistent comparisons when establishing weight with pairwise comparison methods (M. A. Alsalem et al., 2021). Moreover, the availability of high-risk criteria differs significantly among patients, and the complexity of prioritisation assignment grows as this difference increases (M. A. Alsalem et al., 2021; Helmy et al., 2020). Therefore, complex multicriteria decision-making (MCDM) problems arise when prioritising patients with SARS-CoV-2 on the basis of aforementioned issues. However, the challenge of prioritising eligible patients based on multiple high-risk criteria remains unsolved. Decision-making is the process of selecting the best option from a set of options while considering

decision criteria and decision makers' divergent preferences (Rezaei, 2016). Decision-makers frequently struggle to articulate a specific preference among relevant alternatives according to a variety of criteria, particularly when depending on complicated, ambiguous, missing or inaccurate information.

To address both challenges, aside from analysis, multicriteria decision making (MCDM) is a method that assists specialists in organising and resolving any prioritisation problem (M.A. Alsalem et al., 2021). MCDM is a decision theory extension that encompasses any decision with multiple goals and is a method for evaluating alternatives based on numerous competing criteria and then combining them into a single overall evaluation (M. A. Alsalem et al., 2021). As a result, MCDM has been used in the context of SARS-COV-2 with a variety of applications and delivers significant benefits as a decision science support approach. The identification of a prioritising issue (second challenge) of SARS-COV-2 treatment recipients as an MCDM issue has been studied in the literature. According to Mohammed et al. (2021), the proposed intelligent framework based on the MCDM context has been successful in dealing with the patients' prioritisation issue over distribution hospital networking. As discussed in Chapter 2, no research has attempted to integrate the federated fundamental into MCDM approaches for SARS-COV-2 treatment, and this situation is considered a theoretical gap. This integration is critical for bridging the gap and resolving anti-SARS-CoV-2 mAb distribution scenarios within distribution hospitals. As a result, the development of a federated basic idea known as the 'Federated-Decision-Making Distributor (FDMD)' is required to address the challenges of ensuring the privacy of health SARS-COV-2 data and prioritising anti-SARS-CoV-2 mAb receivers across distribution hospitals.

1.4.Research Questions

The following research questions were drawn up to help guide the direction of this research:

i. What are criterion for evaluation the anti-SARS-CoV-2 monoclonal antibodies that adopt to be used for distribute the most eligible patients ?

ii. What are the requirements needed to construct a distribution methodology for anti-SARS-CoV-2 monoclonal antibodies among most eligible patients in hospital networks?

iii. What are the criteria that have been used in the evaluation and benchmarking of the most eligible patients for the distribution of anti-SARS-CoV-2 monoclonal antibodies?

iv. What are the suitable techniques for developing a federated decision-making methodology (FDMD) methodology for anti-SARS-CoV-2 monoclonal antibody distribution among most eligible patients?

v. Are the results of the proposed FDMD methodology valid?

1.5.Objectives of the research

This study aims to develop a novel FDMD methodology for anti-SARS-CoV-2 monoclonal antibody distribution for eligible high-risk patients. The objectives of this study are as follows:

i. To investigate the anti-SARS-CoV-2 monoclonal antibody distribution among most eligible patients in hospital networks without sharing patient data records and highlight the weakness of this approach.

ii. To identify a dynamic decision matrix based on the crossover of ‘patient’ and ‘15 multiple high-risk evaluation criteria of patient level (mild and moderate)’.

iii. To formulate a novel FWZIC weighting method for determining the importance of criteria that overcome vagueness and ambiguity issues and call it IVSH2-FWZIC.

iv. To formulate a TOPSIS method based on federated fundamental to prioritise the most eligible patients under federated environments and call it F-TOPSIS

v. To develop a novel FDMD methodology for the federated prioritisation of the most eligible high-risk criteria patients according to an identified dynamic decision matrix using formulated TOPSIS and FWZIC methods

vi. To evaluate and validate the proposed FDMD methodology through sensitivity analysis and systematic ranking with a benchmarking check list.

1.6.Relationship between research questions, research objectives and research problem

Research questions define the research's direction and focus, whereas research objectives provide solutions to the research questions. Table 1.1 shows the questions and how they are answered by objectives and which element of the research problem will be solved when each research objective is achieved.

Table 1. 1 Relationship among Research Questions, Research Objectives and Research Problem

Research Questions	*Research Objectives*	*Research problem mapping*					
		Specific Problem					General problem
		Important of Criteria	Data variation issue	Multi criteria issue	Data share Issue	Independence Issue	(Prioritisation and Privacy Challenges)
1. What are criterion for	1. To investigate the anti-SARS-	–	–	–	–	–	–

evaluation the anti-SARS-CoV-2 monoclonal antibodies that adopt to be used for distribute the most eligible patients ? 2. What are the requirements needed to construct a distribution methodology for anti-SARS-CoV-2 monoclonal antibodies among most eligible patients over hospital networking.	CoV-2 monoclonal antibodies distribution among most eligible patients over hospital networking without sharing patient data records and highlight the weakness. .						
3.What are the criteria that have been used to evaluate and benchmark the most eligible patients for distributing anti-SARS-CoV-2 monoclonal antibodies?	2. To identify a dynamic decision matrix based on the crossover of the ‘patient’ and ‘15 multiple High-risk evaluation criteria of the patient level in mild and moderate	–	–	–	–	–	–

4.What are the suitable techniques for develop FDMD methodology for the anti-SARS-CoV-2 monoclonal antibodies distribution among most eligible patients?	3. To formulate a new FWZIC weighting method to determine the importance of criteria that overcome the vagueness and ambiguity issue, call it IVSH2-FWZIC.	**X**	–	–	–	–	–
	4. To formulate the TOPSIS method on the basis of federated fundamental to prioritise the most eligible patients under federated environments, call it F-TOPSIS	–	**X**	**X**	–	–	–
	5. To develop a novel FDMD methodology for federated prioritisation of the most eligible High-risk criteria patients based on identified a dynamic decision matrix using formulated TOPSIS and FWZIC methods	**X**	**X**	**X**	**X**	**X**	**X**
5. f) Are the results of	6. To evaluation	–	–	–	–	–	–

proposed FDMD methodology valid?	and validate the proposed FDMD methodology in the basis of sensitivity analysis, systematic ranking and benchmarking check list.						

1.7 Scope of the research

The scope of this research is defined by the following considerations:

i. This research focuses on the distribution of anti-SARS-CoV-2 monoclonal antibodies among most eligible patients through hospital networking without sharing patient data records.

ii. Development of a novel FDMD methodology that applies formulated TOPSIS and FWZIC methodologies for the federated prioritisation of the most eligible high-risk patients and is based on an identified dynamic decision matrix.

Figure 1.2 represents a general view of the study, including the research method, research type and research domain.

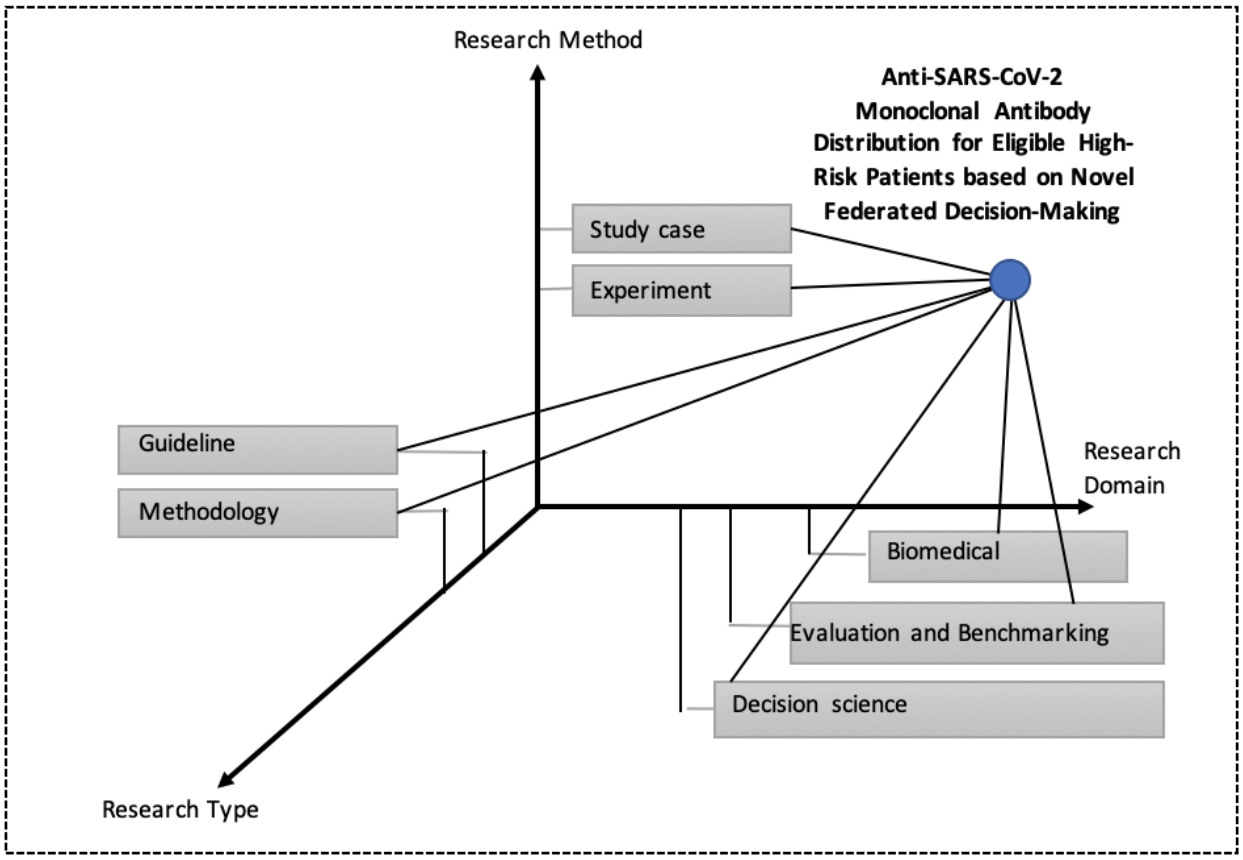

Figure 1. 2 Research Scope

Research method

The study aimed to address the SARS-CoV-2 treatment distribution challenges, namely, privacy and prioritisation. The outcomes of this study was based on experimental research comprising numerous phases. The first phase is the establishment of preliminary settings and consists of three stages: identifying criterion set, determination of criterion weight with the IVSH2-FWZIC weighting method and evaluation procedure. The second phase is the federation of the positive and negative ideal vectors. The third phase is confirmation of treatment availability. The fourth phase

is the prioritisation of the patients, and the fifth phase is matching patient eligibility for treatment distribution.

Research Type

The outcomes of the research indicate the research type. The first output is the methodology performed through several phases for the selection and evaluation of high-risk patients eligible for SARS-CoV-2 treatment. The second output is a complete guideline of all processes in the phases that can be used in the development and enhancement of other application domains, such as organ donation and transplantation, customer services in banks, military operations, strategic information and marketing strategy.

Research Domain

A novel FDMD methodology is developed for the prioritisation of the most eligible high-risk patients from several hospital and distribution of anti-SARS-cov-2 monoclonal antibodies. Therefore, the research belongs to the biomedical domain. The develop FDMD methodology for federated prioritisation is used in evaluating and benchmarking eligible high-risk patients according to identified dynamic decision matrix (DDM) using decision science (formulated TOPSIS and FWZIC method).

1.8 Significance of the study

As mentioned in Figure 1.3, the outcome of this research would be beneficial for healthcare services in COVID-19 outbreak. This study will help combat SARS-Cov-2 and reduce the symptoms of mild-to-moderate patients with high-risk criteria. Moreover, it will facilitate the selection of the

most eligible patients with high-risk situation and the distribution of limited anti-SARS-CoV-2 mAbs and tackle the challenge of the data sharing of the patients. Two main beneficiaries will be able to benefit from the output of this study. The first one is the Ministry of Health that contains treatment centers, medical centers and hospitals branches, the significance is all medical organisations will be able to provide the eligible high risk patients for treatment distribution (Alsalem, M. A., 2022) . The second one are the researchers and universities that can use the methodology to experiment different ranking methods based on federate, experiment different weighting methods, integrate other framework and applied the method in fuzzy environment.

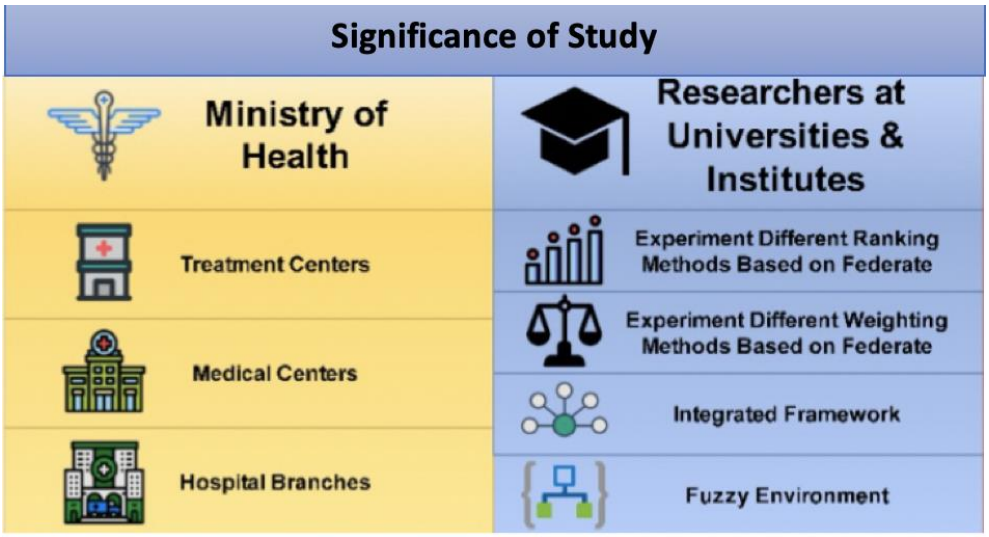

Figure 1. 3 Significance of the study

1.9 Thesis layout

The study consists of five chapters. The first chapter presents the background, objective, scope and significance of the research and introduces the research problem. The other chapters are organised as follows:

Chapter two: ‘Literature review’. In this chapter, the use of multiple-criteria decision-making (MCDM) in combating SARS-CoV-2 is discussed, and current challenges in using MCDM methods introduces in related studies are pointed out. The main two challenges of treatment distribution are identified and described in detail: privacy and prioritisation. The theoretical background of MCDM in COVID-19 is explored, particularly the evaluation and development directions. Moreover, this chapter includes studies on federated fundamentals in the medical domain, and a literature survey of eight studies was conducted. The point of view for MCDM and treatment distribution was described. The theoretical background for FDMD fundamental solution is explained. Validation and evaluation procedures for FDMD solution were identified. The main aims of this chapter is to determine research and theoretical gaps and propose a solution to treatment distribution challenges.

Chapter three: ‘Research Methodology’. This chapter introduces an overview of the key phases for developing a treatment distribution methodology for anti-SARS-CoV-2 monoclonal antibody for eligible high-risk patients from different hospitals with a novel FDMD distributor. An overview of the methodology structure of FDMD is described in Section 3.2. The methodology is divided into two sections. Section 3.2.1 presents the first section, that is, formulated MCDM theory under federated fundamental, and Section 3.2.2 presents the second section, that is, FDMD. Section 3.3 presents the procedures of validation and evaluation. Finally, Section 3.4 summarises this chapter.

Chapter four: ‘Results and Discussion’. This chapter reports the findings about the evaluated eligible treatment patients, and a mechanism for treatment distribution is discussed. Section 4.2 reports the IVSH2-FWZIC results, and the importance of criteria is discussed. Basically, experts’ preferences are transformed through mathematical computations to illustrate the overall weight of high-risk criteria. Data augmentation results are reported in Section 4.3, followed by the DDM for

eligible treatment patients (Section 4.4). Section 4.5 presents the results of the positive and negative ideal vectors in the LM and CFS. Section 4.6 presents the results of the eligible treatment patient's scores and ranks at LM using the F-TOPSIS method. The patients' prioritisation results in the CFS are described in Section 4.7. The results of the prioritisation of eligible treatment patients based on IVSH2-FWZIC and F-TOPSIS are tested and evaluated using three assessment processes in Section 4.8: sensitivity analysis assessment for CFS and Spearman correlation coefficient (SCC), statistical analysis of the correlations of nine scenarios with the rank results of IVSH2-FWZIC and systematic ranking of LM and CFS and comparison analysis assessment.

Chapter five: 'Conclusion and future work'. This chapter highlights the contributions and implications and limitations of the study and future work. In Section 5.2, the research contribution is described. Section 5.3 reports the research implications, and Section 5.4 presents the research limitations. Furthermore, in Section 5.5, the recommendations for future work are elaborated. Finally, the research conclusion is presented in Section 5.6.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter provides a theoretical basis for multiple-criteria decision-making (MCDM) in SARS-CoV-2 response and points out contemporary challenges in using MCDM methods in related studies. This comprehensive review mainly explores studies conducted on MCDM in the COVID-19 pandemic and intensifies its competencies, capacity and authority in two areas: development and evaluation. This study adopted a systematic review approach to classify academic literature that focused on MCDM development in SARS-Cov-2 response. The systematic review purported to find gaps in the literature, point out distribution challenges and issues in SARS-CoV-2 treatment in hospital networks and explore existing methods and techniques for MCDM in the COVID-19 pandemic. The study depended on a methodical appraisal to survey all challenges encountered in the contemporary distribution for SARS-CoV-2 treatment across multiple hospitals, such as privacy and prioritisation challenges. This chapter comprises various parts. Section 2.1 briefs a description of the chapter. Section 2.2 discusses the systematic review protocol. Three main questions are raised in this chapter. The first question was ‘Why seeking SARS-CoV-2 treatment distribution is essential?’ (Section 2.3). The second ‘What are the current distribution challenges for the SARS-CoV-2 treatment taken? The Hospital Networks?’ (Section 2.4). The third was ‘How can be evaluating current SARS-CoV-2 treatment scenarios within distributed hospitals according to the above challenges?’ (Section 2.5). Section 2.6 focuses on theoretical basis for FDMD fundamental solution. Section 2.7 provides data sets related to COVID-19 studies. Section 2.8 presents a literature review for the validation and evaluation of FDMD solution. Lastly, Section 2.9 provides the chapter summary. Figure 2.1 illustrates the framework of the literature review.

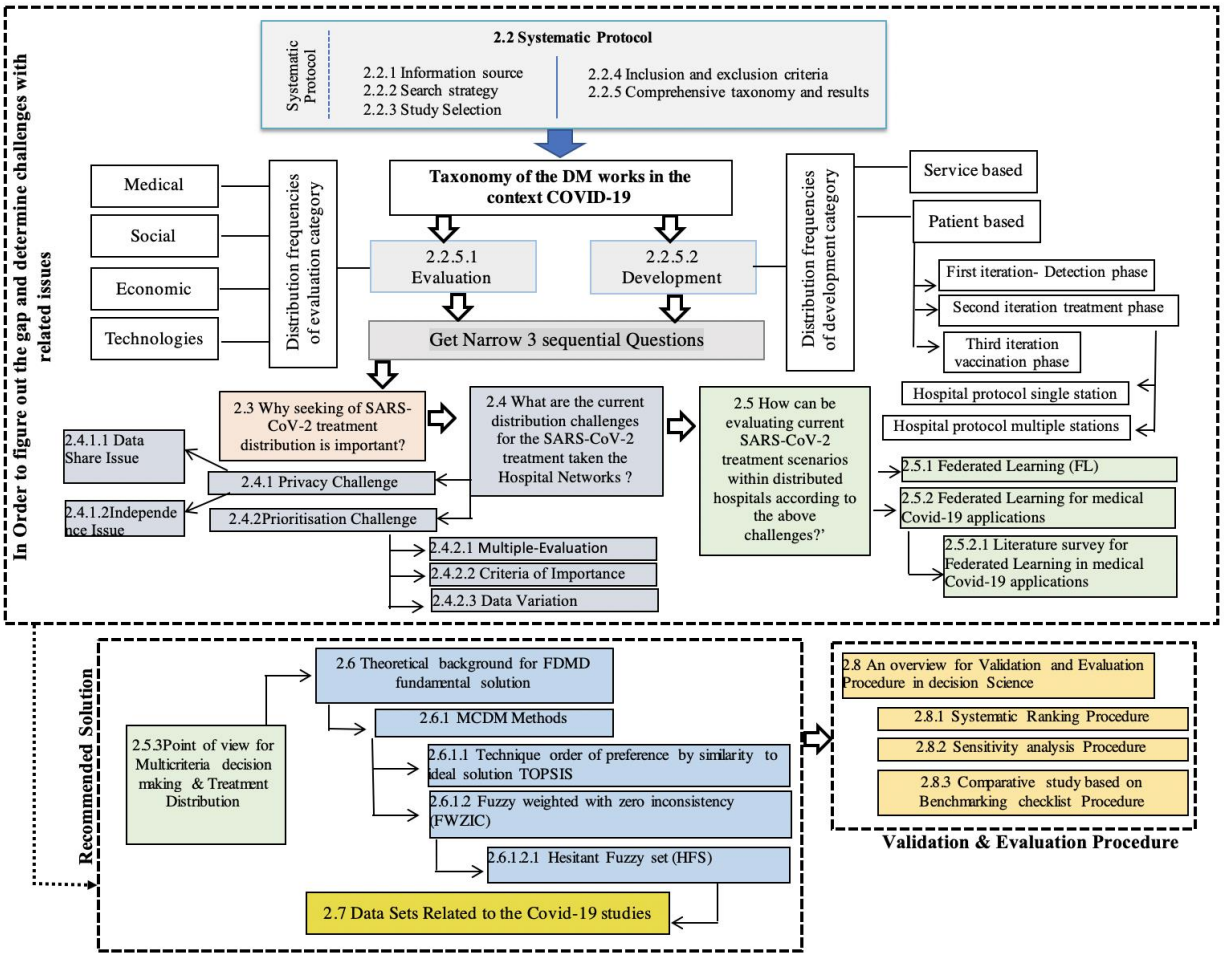

Figure 2. 1 Literature Review Framework

2.2 Systematic Literature Review Protocol

This study conforms to the SLR protocol guidelines. The SLR protocol facilitates exhaustive comprehension of research interest and supplements future studies with extensive information. In addition, SLR protocol has a well-defined process compared with traditional review procedures, thus substantiating research interpretation, especially in the identification of relevant studies on the basis of recognised systems of measurement. The SLR protocol is a top notch review process because of its enormous effect on various study areas and scientific disciplines. It comprises

processes, such as identifying the extent and breadth of research, scrutinising mechanisms, selecting studies and extracting and interpretating information.

2.2.1 Information Source

Strategic research methods that considered SLR protocols are the main mechanistic approaches used in data collection and interpretation. Meta-analysis (PRISMA) stages, as indicated in Figure 2.2, were used. In the entire collection process, the following databases were used in searching, clarifying and extracting studies and drafting the review:

i. 'Scopus', which comprises several publications on various scientific research areas;
ii. 'IEEE Xplore', which contains publications about interdisciplinary technologies associated with various spheres;
iii. 'ScienceDirect', which offers investigative publications from various academic fields; and,
iv. 'Web of Science', which comprises a diverse gamut of publications and studies on social sciences, arts and humanities.

These databases have been used in various publications on SLR in top-ranked journals and scientific research articles, which have been deemed resilient and with a scientific appraisal. The databases were regarded as relevant and appropriate for the review.

2.2.2 Search strategy

Exploration was conducted on 30 November 2020. Two rounds of reiterative search and search surveys were conducted on 27 December 2020 and 16 April 2021. Iterative search was carried out

to ensure that the studies are recent and updated. Boolean operatives were employed, such as 'AND' and 'OR'. Two sets of crucial note words, that is, inquiries were engaged in the development, as indicated in Figure 2.2. The preceding process was executed to find pertinent articles. During exploration and filtration, information from different articles and papers was obtained, and numerous type of publications were selected, such as journals, conference papers and reviews. Latest publications related to the topic of this review were included.

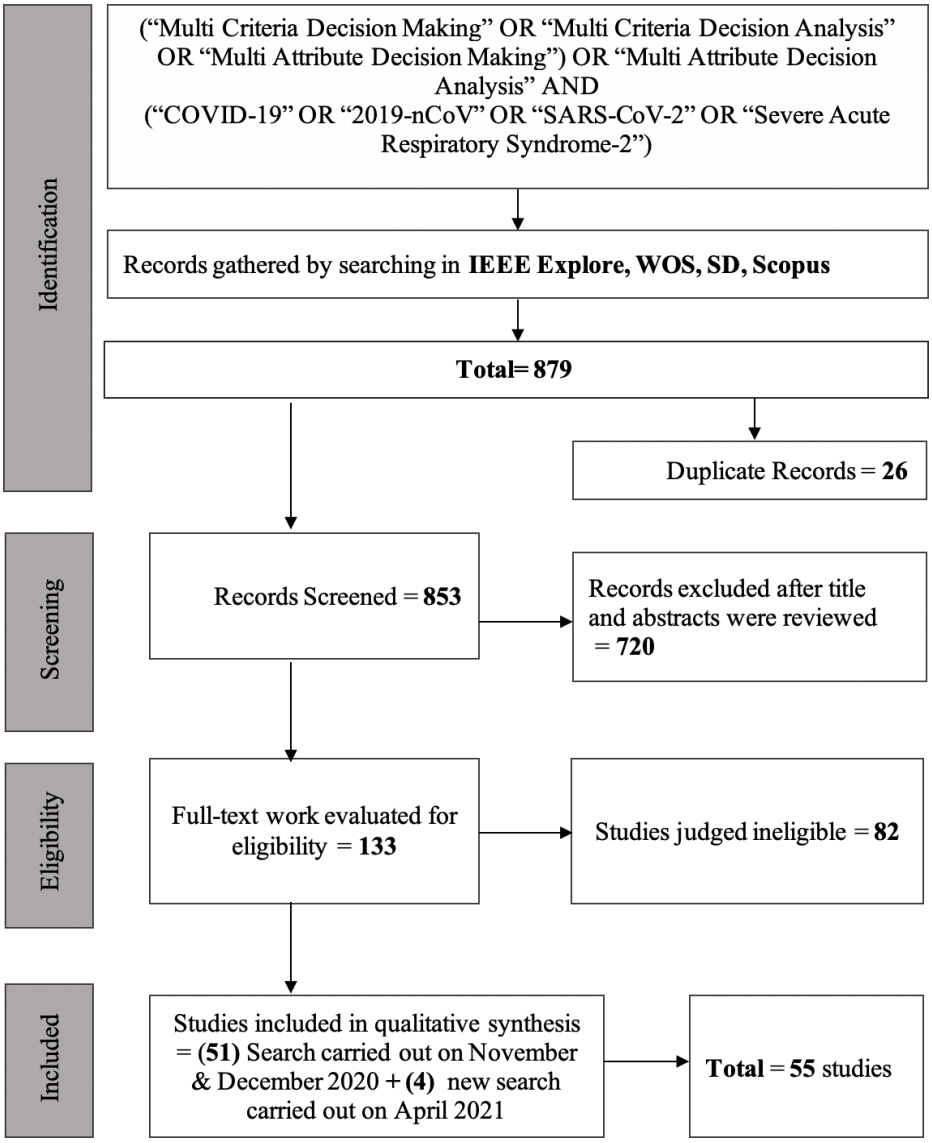

Figure 2. 2 Systematic Literature Review Protocol

2.2.3 Study selection

Articles were collected, and titles and abstracts were scanned and full articles were probed. A total of 879 articles were selected. Duplicate papers (n = 26) were thoroughly checked using other catalogues. Extracted abstracts and titles were extracted according to the inclusion criteria discussed in Section 2.2.4, and relevant articles were identified and verified. Publications that met the inclusion criteria were included. Finally, a full-text scan was conducted. All research articles that did not meet the inclusion criteria were dismissed from the review. A total of 720 articles were excluded because of a high degree of irrelevance, and 51 articles were finally included. Therefore, essential and valuable information from the full texts was analyzed.

2.2.4 Inclusion and exclusion criteria

Relevant publications in the research selection phase were determined using inclusion and exclusion criteria. Publication date was established from the start of the coronavirus pandemic in 2019 to April 2021. All selected articles written in English, including reviews and research papers, were obtained from all databases. Articles that explored COVID-19 MCDM approaches and the integration of MCDM into various applications during the coronavirus pandemic were included.

2.2.5 Comprehensive Taxonomy and Results

This research mainly analysed and explored the literature on decision-making (DM) complications in the COVID-19 pandemic, and 55 studies explored them in two ways. Perspective approaches are based on appraisal and development, as demonstrated in the taxonomy diagram in Figure 2.3.

Notably, 41 papers focused on evaluation (41, 74.5%). They were classified as ‘evaluation-based’, a classification that employs the MCDM perspective to appraise various related scenarios as far as COVID-19 is concerned. Consequently, categorical subclasses were obtained on the basis of assessed situations: therapeutic, social, economic and technology-related cases.

Nevertheless, 14 studies (25.45%) were categorised as ‘development-based’. They used MCDM approaches in constructing frameworks that provide services, detection and intervention or enabling the distribution of vaccines purposely to address all issues regarding COVID-19. This categorical class comprises two subclasses rooted in development direction, that is, service and patient-oriented subsclasses. The study was included in the service-based subcategory. It designed and proposed modernised services that include health system-based programme services (Requia et al., 2020) and coronavirus online detection services (Ahmad et al., 2021). The study focused on providing advanced internet services for the management of the ever-increasing demands of users during the pandemic; these demands lead to restricted movement (Abdulsalam et al., 2020). The patient-based subclass comprises three reiterations of studies that focused on tackling the coronavirus pandemic. The first iteration detected COVID-19, the second iteration was treatment and the third was the mechanical iteration of vaccine distribution.

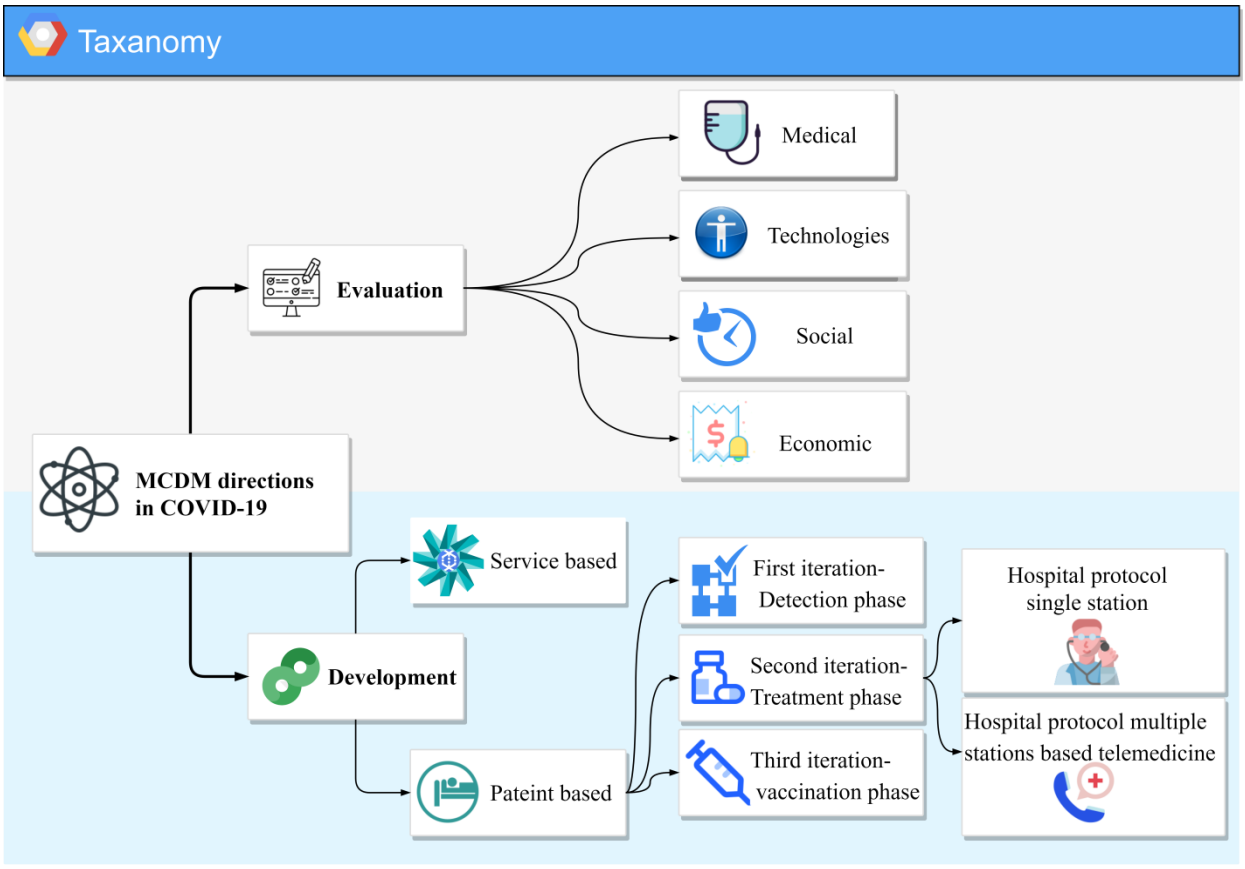

Figure 2. 3 Taxonomy of the DM works in the context COVID-19

2.2.5.1 Evaluation

As shown in Figure 2.3, the 'evaluation-based' category consists of medical, social, economic and technology-related subcategories. Table 2.1 depicts the rate of distributions for the four subcategories that employ MCDM in the context of COVID-19.

Table 2. 1 Distribution frequencies of evaluation category

Ref of study	Medical	Social	Economic	Technologies
(Pamučar et al., 2020)	✓			
(Samanlıoğlu & Kaya, 2020)	✓			

(Ocampo & Yamagishi, 2020)	✓			
(Sarwar & Imran, 2021)	✓			
(Wu & Xu, 2020)	✓			
(Z. Yang et al., 2020)	✓			
(Mahanta & Panda, 2020)	✓			
(Sayan et al., 2020)	✓			
(M. A. Mohammed et al., 2020)	✓			
(Abdel-Basst et al., 2020)	✓			
(O. Albahri, A. Zaidan, et al., 2020)	✓			
(Garg et al., 2020)	✓			
(M.-S. Yang et al., 2021)	✓			
(Shirazi et al., 2020)	✓			
(Naeem et al., 2020)	✓			
(Ortiz-Barrios et al., 2020)	✓			
(Wan et al., 2021)	✓			
(Manupati et al., 2021)	✓			
(Zhang et al., 2020)	✓			
(Bharsakade et al., 2021)	✓			
(Mishra et al., 2021)	✓			
(Baz et al.)		✓		
(Ashraf & Abdullah, 2020a)		✓		
(Jain et al., 2021)		✓		
(Ghorui et al., 2021)		✓		
(Grida et al., 2020)			✓	
(Jamshidiantehrani et al., 2020)			✓	

(Sharma et al., 2020)			✓	
(Khurana et al., 2020)			✓	
(Ghosh et al., 2020)			✓	
(Moslem et al., 2020)			✓	
(Shah et al., 2020)			✓	
(Lam et al., 2021)			✓	
(Duan et al., 2021)			✓	
(Yao, 2021)			✓	
(Altuntas & Gok, 2021)			✓	
(Ecer & Pamucar, 2021)			✓	
(Althaf & Babbitt, 2021)			✓	
(Chauhan et al., 2020)				✓
(Mardani et al., 2020)				✓
(Gong et al., 2021)				✓
Percentages %	51%	10%	32%	7%

Table 2.1 shows the distribution of various studies for each subclass under the evaluation-based approach category. Medical cases were prevalent, explored by more than half (51%) of the studies. Economic-related issues were explored in 32% of the studies, and societal and technology-related issues were explored in 10% and 7%, respectively. A total of 21 studies in the medicinal subclass in the assessment-based class emphasised medical-linked issues that entail three major evaluation domains: stratagems and guidelines, therapeutic tools and medical amenities. In the first research (Pamučar et al., 2020), MCDM approach was designed to create lasting strategic policies for restructuring a healthcare organisation for a coronavirus endemic. Pamucar et al. (2020) argued that the MCDM technique can aid in emergency cases, such as the current epidemic, which has

prompted the integration of the approach into numerous medical interventions designed to minimise perils caused by the epidemic. They formulated four strategic guiding principles and five evaluation criteria. Samanlıoğlu and Kaya (2020) scrutinised hospitals' endurance at various degrees of probability of preparing COVID-19 preventative techniques. They did not determine the best alternatives on the basis of superiority but used MCDM to design options organised according to application and relevance and compared different preventative methods in various countries. Ocampo and Yamagishi (2020) explored an issue projected by the presence of the coronavirus. They affirmed that the mental and physical health of people on total lockdown is an emerging issue in the healthcare system. On the one hand, governments are continuously trying to ease lockdown to preserve and sustain public health and revive the economy. On the other hand, some researchers have stated that governments have struggled to maintain exit approaches and evaded extra waves of issues. Such an important aspect will be considered a contrary idea, specifically whenever a government depends on a trial-and-error method. Recommended conventions for relaxation tactics are connected whenever a relaxation tactic is required, and MCDM emerges as the best solution.

Sarwar and Imran (2021) articulated that various health agencies, such as the World Health Organisation, were struggling to deliver appropriate endorsements and measures to minimise the spread of coronavirus. They explained that the implementation of all recommendations is unfeasible because of many social and physical factors. Mitigation strategies include social and physical restrictions in terms of distance, usage of antiviral agent masks, avoidance of unnecessary travels, good hygiene, consumption of healthy food and health tracking. Priority should be given to tactics that are efficient in mitigating the spread of the coronavirus. MCDM was examined, and strategies for COVID-19 prevention was scrutinised. Wu and Xu (2020) suggested that final and

amicable integration is needed because of the certainty of emergent therapeutic services during the COVID-19 epidemic. They claimed that reactions towards the pandemic affect the rate at which issues decrease. They explored practical responses to the pandemic, especially in complicated scenarios that have emerged as global concerns. The emergency decision matrix (DM) is an MCDM issue that revolves around various measures or structures with qualitative and measurable facets.

The significant negative impacts of urban coronavirus pandemic settings constitute a multifaceted disaster that is supposed to be evaluated with MCDM. Yang et al. (2020) emphasised that mask assortment issues arose during the coronavirus epidemic and selecting antiviral masks is essential given that mask supply is limited in the COVID-19 epidemic. High-quality masks are expensive or specifically utilised by frontliners. Such misinterpretation has led to indecorous and extreme purchase and usage of personal protective gear, increasing mask shortage. The usage and therapeutic resources of masks can be enhanced by assessing them according to reusability, eminence of material used and circumstances of individuals. MCDM aids in identifying the most recommendable virus-resistant masks according to demand and to the conditions of many individuals, thus maximising the application and confirming the importance of masks. Mahanta and Panda (2020) asserted that the selection of suitable face masks is challenging for most people in the absence of defined standards. They used MCDM to solve this problem. Sayan et al. (2020) pointed out that the precise and quick diagnosis of patients is an essential approach. In numerous diagnostic assessments, uncertainty in the identification of the most suitable process is high. The prioritisation of a test over another is a difficult decision, especially when various factors are considered, such as low cost, degree of sensitivity, high specificity, good usability and low falsity. Consequently, they used the MCDM technique in assessing the efficacy of seven COVID-19

diagnostic measurements and evaluated the effectiveness of analytic tests according to individual circumstances and the availability of resources in various nations.

Mohammed et al. (2020) study identified the broad application of an artificial intelligence (AI) model in coronavirus diagnosis. The model was specifically designed to help healthcare systems in selecting appropriate COVID-19 diagnostic mechanisms. However, similar to other technologies, AI has many shortcomings that limit its application. Mohammed et al. (2020) claimed that selecting an approach over another is an arduous task despite that various machine learning (ML) designs are available. Evaluating and standardising a COVID-19 ML are significant topics especially when numerous principles are entangled. Therefore, utilising the MCDM technique can be helpful in addressing problems. Abdel-Basst et al. (2020) stated that analysing COVID-19 through computed tomography (CT) is complex and faced with ambiguity given that the symptoms of the disease is similar to those of other epidemiologic lung diseases, including H1N1, H5N1, SARS and hantavirus infection. They found various problems, including multifaceted DM issues involving several conflicting criteria and used the MCDM technique in evaluating epidemiologic lung infections, including COVID-19, in unclear circumstances, conducting a crossover study given that they used the indicators and outcomes of CT imagery in assessment criterion format. They believe that their work can help technocrats track the elevation of COVID-19 by providing consistent metrics and results. O. Albahri and A. Zaidan et al. (2020) employed MCDM in detecting COVID-19. Three steps were used in classifying COVID-19 AI approaches to diagnose the virus. They started their investigation with pre-processing and collecting datasets and then explained the technique used in evaluating and benchmarking COVID-19 AI categorisation algorithms and categorical approaches. Four decisions matrices were provided as outcomes. MCDM was subsequently integrated to handle issues, and subjective and objective output

evaluation was explicitly conducted for additional verification. Garg et al. (2020) carried out a different diagnostic study and presented a technique for handling MCDM problems on the basis of operators. They used a COVID-19 case to prove the practicability and application of their proposed approach for selecting an appropriate laboratory diagnostic test. Yang et al. (2021) evaluated the significance of mask assortment in the coronavirus epidemic. They assessed the most available masks using MCDM techniques and scrutinised merits and demerits by comparing studies and conducting graphical interpretation.

Shirazi et al. (2020) examined patients who expressed frustration over hospital services in the context of COVID-19. In spite of resourceful medical capabilities, patients are frustrated because of the inapt apportionment of resources. Shirazi et al. (2020) asserted that prioritising patient service facets can maintain service quality. Hence, MCDM was integrated to solve decision-making issues. It facilitated the identification of specific satisfaction facets that should be prioritised in typical COVID-19 situations. This approach has been considered necessary for prosperity and survival in the current competitive disposition. Naeem et al. (2020) discussed various techniques to decrease COVID-19 rate and enhance treatment and used the modern version of the MCDM approach to identify the best treatment method for COVID-19. They focused on their proposed concept of the functional case. Another study assessed hospitals and their resources, focusing on the need for hospital preparedness (Ortiz-Barrios et al., 2020), which is the fundamental stage for those requiring healthcare attention during calamities and endemics. Many uncertainties regarding decisions concerning the hospital's capacity and readiness for the benefits it can offer in emergencies. Therefore, identifying hospitals and other healthcare facilities that seem to be unprepared is a good approach in disaster management. Ortiz-Barrios et al. (2020) argued

that the COVID-19 epidemic had strained healthcare resources. They stated that hospitals should be swift and reliable in terms of preparedness.

Consequently, MCDM was used in evaluating hospital adversity readiness. The best approach in case of scarce procedures for assessing hospital calamities in terms of readiness levels. Further research conducted by Wan et al. (2021) found that it is crucial for selecting appropriate hospitals in the event of COVID-19 breakout. In the coronavirus outbreak in Wuhan, China, hospital selection has been emphasised. The government responded by highlighting the significance of leaving no one unattended during the outbreak. The government of China ordered the design of makeshift hospitals in Wuhan to support the strained healthcare sector. The initiative generated significant DM problems regarding the selection of hospitals for the effective and quality treatment of patients with mild COVID-19 symptoms. Therefore, the MCDM was used as the best approach from the numerous probable substitutes.

Resource projects encompass an array of subjects, such as medical waste disposal, which is quite problematic. Manupati et al. (2021) described how most organisations in developing nations struggle to select optimum HCM (healthcare waste) disposal approaches for the competent treatment of medical wastes during and after the coronavirus pandemic. The selection of an optimal technique must consider fundamental and impalpable characteristics that can be portrayed as a complex DM challenge. Consequently, an approach for HCW disposal and assortment criteria that incorporated sociotechnical and fundamental factors was designed.

A different treatment appraisal research conducted by Zhang et al. (2020) found that people with COVID-19 are expected to experience fever, cough, dyspnoea, anoxia and other symptoms despite the administration of probable medication. Bharsakade et al. (2021) stated the significance of appreciating different features of significant waste disposal in the healthcare sector. The MCDM

technique was used in identifying wastes and their dimensions. They proposed a framework for assessing and confirming suppleness in the health care sector. Mishra et al. (2021) demonstrated that appropriate antiviral medical interventions to curb the moderate comorbidities of COVID-19 is complicated and unclear there is no defined treatment at the moment and other treatment paths include multiple viral-resistant suppositories. They used hesitant fuzzy sets (HFSs) in selecting five approaches and medications for treating mild comorbidities associated with COVID-19 and ensured that the proposed ideas were feasible and practical.

In the social subcategory, four studies emphasised the appraisal of societal perspective in the COVID-19 context. Baz et al. found out that the coronavirus affected several crucial sectors worldwide. It prompted analysis of socioeconomic factors that nations confront. In the stated social scopes, the outstanding issue is still undefined. MCDM was employed in organising issues and logically resolving uncertainties. Numerous preventive measures for combating COVID-19 have been defined. Multiple variations existed, especially between COVID-19 cases, and suitable procedures have not been identified.

Consequently, MCDM was used in defining the optimum preventive method. Ashraf and Abdullah (2020) pointed out that several organisations were facing DM problems in their emergency procedures because of catastrophic factors linked to the COVID-19 pandemic. They utilised the MCDM approach to resolve DM uncertainty in emergency operations. Jain et al. (2021) noted that employers relying on hand-held devices (HHDs) in their daily endeavours likely face risks of musculoskeletal issues. They state that an increasing number of people have been compelled to work from their households, and they are subjected to inconvenient postures. Musculoskeletal infections (MSIs) result from inappropriate postures in HHD operators. Jain et al. (2021) employed the MCDM in assessing MSI risks among HHD users. Another research explored COVID-19 risk

issues. The COVID-19 epidemic has affected the world since its onset in December 2019. The outbreak spread quickly in different forms and avenues because the virus is highly contagious (Ghorui et al., 2021). The authors identified cataloguing risk issues and ranked them in the context of spreading for the containment of the disease with MCDM techniques.

In the economic subcategory, 13 kinds of research were limited to four main subjects. The topics included supply chain, green economy, transport and environment. Grida et al. (2021) performed meta-analysis to solve COVID-19's interference and the associated outcomes of the pandemic. They contended that the coronavirus supply chain problem is associated with three factors. As stated by Grida et al., the factors included supply, demand and associated logistics. Various research works and publications have scrutinised preventative measures in the supply chain. In the same context, MCDM was applied to design substantive information directed in industrial enterprises, especially decision-making, to deal with uncertainties categorised as great decision subjects interconnected with three formerly defined supply chain techniques. Jamshidiantehrani et al. (2020) researched various encounters that restricted pharmacological operations in supply chain dexterity in the coronavirus menace. Specifically, delay in economic turnovers and the need for instant fiscal sources have been a focus of research. MCDM was utilised in increasing estimation accuracy, lowering the cost of production, improving resource application and creating standards for selecting suppliers and maximising production rate and flexibility.

Sharma et al. (2020), COVID-19 was described in terms of its effect on suppliers' operations in their ability to design systems that are responsive to future industrial problems and assertive. They used MCDM in capturing essential features that are useful in reconstructing enterprises and societies that can survive calamities by being flexible. Khurana et al. (2020) pointed out unexpected interferences with agricultural supply chains during the Coronavirus pandemic. Substantial hazards

remain concealed. MCDM techniques are usually used in prioritising hazards, including demand, finance-related hazards, logistics, infrastructural perils, management, operational issues and policy and regulation menaces with biological and environmental hazards. Ghosh et al. (2020) discussed discrepancies in the COVID-19 lockdown and proposed alternatives. They researched various indicators with MCDM methodologies and discovered, emphasised the effects of the pandemic lockdown on the environment, and assessed situations after lockdown. Moslem et al. (2020) argued that most nations suffer from pressure on transportation sustainability and face various environmental problems because of difficulty in identifying transportation alternatives. These issues were observed after restrictions on social distances were instigated to contain the spread of the virus. MCDM techniques were used in identifying effective strategies for urban environments. Apart from the supply chain, the green economy was considered. Sha et al. (2020) suggested that circumstances created by the coronavirus pandemic are barriers to achieving a green economy. They based their argument on curfew concerns that affected various firms developing optimum strategies for reducing carbon emissions. Businesses experienced difficulties in prioritising the type of waste for energy conversion. Therefore, MCDM, being suitable for waste–energy conversion, was established to eliminate vagueness. Yao et al. (2021) discussed green energy and claimed that the coronavirus imposed major health burden on global society, thereby derailing worldwide development. Various technocrats, such as environmental experts and governments, have faced difficulties in developing strategies and policies for green energy. The scholars used an MCDM methodology to analyse ecological regulations. Yao et al (2021) forecasted an alternative system, considering multiple environmental policies based on principal criteria and subcriteria.

Lam et al. (2021) point out that COVID-19 affected economic growth, directly affected government organisations and construction industries and forced industries to reconstruct and build

sophisticated infrastructures for healthcare, transportation, education and housing industries. MCDM was used given that the research did not fully assess construction companies' financial positions and growth, and the significance of fiscal proportions and the rating of initiatives in the construction sector was evaluated. Duan et al. (2021) discussed the effects of electric power grid investments during the pandemic. They found that socioeconomic growth in China is changing. Therefore, they deemed evaluating risks associated with the electric grid system essential to investment management and threat prevention. MCDM methodologies are useful in assessing risks associated to investments in Chinese electric power grid given changes in socioeconomic and regulations during the pandemic. Altuntas and Gok (2021) discussed the use of MCDM in the absence of scientific information, which is critical to the design of quarantine and isolation policies aimed at eliminating the destructive effects of COVID-19 on the hospitality sector. They recommended the systematic selection of quarantine preferences in an epidemic and stated that general strategies should not be appraised in the same manner as strategies used in the COVID-19 pandemic. They utilised the DEMATEL methodology to help government organisations alleviate problems caused by quarantine decisions on the hospitability sector because the pandemic disrupted many operations. The following study (Ecer & Pamucar, 2021) scrutinised how COVID-19 affected the healthcare sector, especially with the coronavirus pandemic-related decisions and predicaments already expressed in business and economy-related sectors.

Therefore, a review of the insurance industry was necessary. The rating of private healthcare insurance benefactors was considered useful to various agencies, customers' decisions and encounters as portrayed in the business and economic sectors. MCDM rated insurance firms by considering the healthcare services provided in Turkey during the onset of the coronavirus pandemic. Conclusively, the application of MCDM during the coronavirus endemic resolved the

problems posed by insurance assessment. Althaf and Bahhit (2021) focused on the necessity of electronic gadgets in society primarily because human communications became virtual after restrictions were imposed during the pandemic. Consequently, global health concerns and associated effects on climate change and the streaming of critical resources for manufacturing electric essentials became highly vulnerable. A multifaceted framework comprising TOPSIS ideas was used in evaluating supply chain disruptions and associated risks, especially in the electronic sector.

In the technological subcategory, three studies directed their efforts to evaluating the technology facet in the pandemic. Chauhan et al. (2020) explored the effects hazardous waste on the environment and general public healthcare. They pointed out that in the COVID-19 outbreak, efficient waste disposal mechanisms should be designed given that waste is a critical issue in human life. A policy for effectively disposing industrial and medical wastes should be formulated. MCDM is a good method for designing a waste management network comprising healthcare centres and facilities. Challenges in waste management were explored. Mardini et al. (2020) showed that digital technologies are crucial to daily life. COVID-19 is a recent disaster accompanied by multiple problems because of numerous strengths, challenges, likelihoods and risks. MCDM techniques were used in evaluating the essential domains of digital technology in the healthcare sector. The findings showed that health information frameworks and policies are significantly affected by health information systems, which are currently limited because of insufficient modern healthcare information. They claimed that digital divisions and economic intrusions impact healthcare information systems. The application of internet resources in healthcare information systems and technological elements affect the healthcare sector. Gong et al. (2021) stated that network tutoring has been globally embraced to facilitate teaching and learning

and protect the rights of learners. They offered insights into various online sources. Gong et al. (2021) considered appropriate websites for online tutoring and learning and their direct impact on educator and learner performance given that online learning requires quality control. Selecting e-learning platforms can be a critical MCDM issue requiring frequent expert evaluation in view of inherent human thoughts.

2.2.5.2 Development

The category based on development comprises two subcategories: service- and patient-based classes (Figure 2.3). A recent framework based on patient-faced focus was scrutinised via three major recapitulations specifically to tackle the pandemic. The first iteration is the diagnosis stage, which revolves around research efforts focused on the development of a decision enhancement system derived from an MCDM method for detecting the spread of a virus. The treatment stage complements the second iteration, which emphasises the development of an MCDM system for the provision of traditional interventions and handling patients in isolation and manifold posts. The third iteration is the vaccine phase, in which MCDM is used in the development of a framework that facilitates the distribution and allocation of vaccines. The frequency distributions of the subclasses that embrace MCDM as far as COVID-19 is concerned were portrayed.

Table 2. 2 Distribution frequencies of development category

References		First iteration-Detection phase	Second iteration-Treatment phase		Third iteration-Vaccination phase
			Hospital protocol single station	Hospital protocol multiple stations-based telemedicine	

(Requia et al., 2020)	✓				
(Ashraf et al., 2020)	✓				
(Ahmad et al., 2021)	✓				
(De Nardo et al., 2020)	✓				
(Abdulsalam et al., 2020)	✓				
(A. Albahri, J. R. Al-Obaidi, et al., 2020)		✓			
(Albahri & Hamid, 2020)		✓			
(O. Albahri, J. R. Al-Obaidi, et al., 2020)			✓		
(M.A. Alsalem, 2021)			✓		
(Mohammed; et al., 2021)				✓	
(Hezam et al., 2020)					✓
(Zidan, 2021)					✓
(Zaidan, 2021a)					✓
(Zaidan, 2021b)					✓
Percentages %	**35.71%**	**64.28%**			
		14%	**14%**	**7%**	**29%**

The table represents the distribution of research studies in terms of percentages for the development-based concept subcategories. Approximately 35.71% of the studies belonged to the service-based development subcategory, and patient-based subcategory accounted for 64.28% of development research. The patient-based development subcategory constituted 14% of the detection phase, 14% of the treatment phase and 29% of the vaccination phase.

In the service-based subcategory, the studies focused on the development and provision of services related to COVID-19 and focused on solutions for reducing the negative effects of COVID-19 in healthcare. Requia et al. (2020) proposed the use of MCDM in resolving issues related to bed capacity for patients with COVID-19 and allocating necessary support through policy intervention. Ashraf et al. (2020) focused on necessary support to emergency control for COVID-19. The difficulty in making a reliable decision about the use of MCDM in controlling the transmission and spread of COVID-19 during the pandemic prompted the researchers to consider MCDM a good method for addressing gaps. Focusing on the necessity of addressing COVID-19 through the administration of various treatment procedures, Ahmad et al. (2021) proposed that the Fuzzy Cloud-Based COVID-19 Diagnosis Assistant is the most reliable system for categorising patients as confirmed, suspected or probable cases of COVID-19 and assigning infected people to mild, moderate, severe or critical category. The tool provides necessary feedback and monitoring performance information and reduces the transmission rate of COVID-19.

The fourth set that focused on MCDM with services was characterised by 14 studies, three of which focused on patients. Hospital bed shortage during the pandemic was discussed by De Nardo et al. (2020). This issue not only affected admitted patients but also prevented hospitals from admitting more patients. The issue was highly prevalent in low- and middle-income settings. Hence, they concluded that prioritising access to care is necessary. They used MCDM to identify patients with non-critical COVID-19 discharged or referred to other treatment centres to pave way for patients with serious conditions. Abdulsalam et al. (2020) discussed telecommunication services and related problems in striking demands during the COVID-19 epidemic. They found that workers operating in their households were unable to meet all the needs of consumers. Home workstations are not

adequately equipped unlike standard office workstation, and the pandemic strained telecommunication services.

In the patient-based subclass, iterations of handling COVID-19 issues are explored. A. Albahri and J. R. Al-Obaidi et al. (2020) based their discussions on increasing COVID-19 cases. They claimed that healthcare centres confront problems, especially those regarding decisions and stated that medical centres depend on MCDM when identifying patients that should be prioritised and consider emergency cases to prevent further decline in health condition. Albahri and Hamid (2020) used a novel ramification design in handling asymptomatic COVID-19 cases based on a multilaboratory idea. They considered using MCDM in differentiating criteria according to importance and trade-off in COVID-19 cases and in prioritising patients and detecting a patient's health status, especially asymptomatic carriers.

Three studies focused on treatment iteration, two of which emphasised the development of a hospital guideline for single stations. Al-Obaidi et al. (2020) stated that patients recovering from the virus have antibodies that can fight COVID-19 infection. They recommended the used of these antibodies to boost the immunity of patients. The problem confronted in the study was to whom the antibodies should be given first given conflicts in multiple biological criteria. A rescue strategy for the transfusion of superlative convalescent plasma (CP) to critical patients while applying ML and MCDM was proposed. Alsalem (2021) discussed the utilisation of MCDM in tackling mesenchymal stem cells and proposed a transfusion strategy based on MCDM, which allows effective transfusion in chronic COVID-19 cases. The framework facilitated the allocation of patients to various emergency units by order of preference. The researchers highlighted the prevention of health deterioration in COVID-19 patients through the enhancement of their health status. Mohammed et al. (2021) discussed the raid transmission of the virus across the globe and

recommended CP transfusion to chronic COVID-19 cases to prevent the virus from spreading. They proposed a novel CP transfusion policy for protecting people from the coronavirus across centralised and devolved telemedicine health centres. From their perspective, the most significant objective was to perform CP transfusion effectively from legitimate and eligible donors to patients with chronic conditions with MCDM.

The vaccination phase was the focus of three studies, which discussed the development of mechanisms for distributing vaccines. Hezam et al. (2020) discussed coronavirus vaccines, emphasising the need for the government to set and recognise groups to be prioritised for vaccine administration. The writers explore MCDM methodologies that facilitate the classification of the people who are eligible to receive vaccines first. Zidan et al. (2021) used MCDM concepts in prioritising COVID-19 vaccine recipients. An improved vaccine distribution framework was proposed. An artificial record of 300 people who had received vaccines and various distribution techniques were used. Zaidan (2021a) utilised MCDM to prioritise vaccine recipients with a vigilant and strong MCDM technique. A fussy environment was used to handle uncertainties observed in numerous MCDM context issues. The final research by the same scholars (Zaidan, 2021b) integrated the fuzzy-weighty zero-inconsistency technique.

According to taxonomy diagram illustrated in Figure 2.2 and mentioned in Section 2.5, the patient-based subcategory starts with detection phase iteration followed by the second iteration treatment phase, which focused on hospital procedures in single and multiple stations, and vaccination phase iteration. To date, anti Sars-Cov-2 monoclonal antibodies (mAbs) have been used, but no study has explored their distribution with MCDM. Treatment for SARS-CoV-2 and how to shift from vaccine solutions to treatment therapy solutions have become major topics of interest in global research. Accordingly, this study three sequential questions.

2.3 Why seeking of SARS-CoV-2 treatment distribution is important?

At the onset of the COVID-19 epidemic, no targeted treatment was available to combat SARS-CoV-2. The immediate need to end this unprecedented phenomenon has led to many efforts to treat SARS-CoV-2. In addition to vaccines, mAbs presented a different dimension to feasible prevention and treatment approaches (Chigutsa et al., 2021). In view of progress in vaccine-derived immunity, neutralising mAb therapy can provide immediate and passive immunity to individuals and help decrease disease symptoms and progression (Dougan et al., 2021).

The ideal scenario is the prevention of SARS-CoV-2 infection through vaccination. However, in infected patients, the ideal intervention is to prevent the development of severe symptoms (Mornese Pinna et al., 2021). The mAb treatment is suitable for patients at a high risk and is thus one of the most promising treatments for mild-to-moderate SARS-CoV-2 infection (Dougan et al., 2021; Suárez-García, Perales-Fraile, González-García, Muñoz-Blanco, Manzano, Fabregate, Díez-Manglano, Aizpuru, Fernández, & García, 2021). Figure 2.4 shows the immune system response to the therapeutic combination of anti- SARS-CoV-2 mAbs during infection.

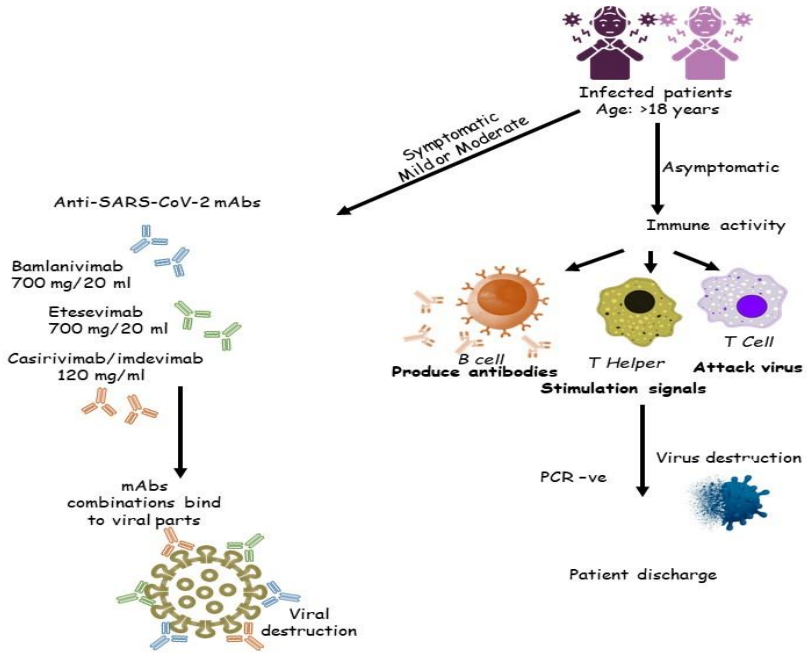

Figure 2. 4 Schematic illustrating the immune system response and therapeutic combination of anti-SARS-CoV-2 mAbs during infection

Etesevimab and bamlanivimab are mAb proteins synthesised in the laboratory and can simulate the immune system's ability to fight SARS-CoV-2 (HEALTH, 2021). These drugs are administered simultaneously and authorised for use after viral exposure (post-exposure prophylaxis [PEP]) but unsuitable for pre-exposure prophylaxis (PrEP) to SARS-CoV-2. Prophylaxis, or often termed preventive healthcare, consists of actions for disease prevention. The use of both mAb proteins in treating mild-to-moderate SARS-CoV-2 symptoms have been authorised, particularly in adults and paediatric patients (patients with at least 40 kg and aged 12 years and above) who have positive results in direct SARS-CoV-2 viral testing and are at high risk of getting severe SARS-CoV-2 symptoms (Aleem et al., 2021). Bamlanivimab monotherapy minimises the probability of SARS-CoV-2 risk compared with placebo (Cohen, 2021). Although only bamlanivimab administration

was assessed, the combination of two mAb proteins (i.e. bamlanivimab and etesevimab) is safer and more efficient for PEP than bamlanivimab alone.

SARS-CoV-2 treatments focus on reducing symptoms and preventing or delaying complications. If anti-SARS-CoV-2 mAbs cannot be developed and distributed properly, then situations could quickly worsen and considerably influence patients' quality of life and economic conditions in subsequent years (Bollyky et al., 2020). Any viable intervention for SARS-CoV-2 would initially be limited. The question of who should receive priority access is crucial. Therefore, the development and widespread distribution of SARS-CoV-2 medicinal treatments are significant (Bollyky et al., 2020). Fair distribution issues have been reported after frameworks for SARS-CoV-2 vaccine allocation have been presented and vaccine distribution among countries have been examined [13]. This perspective outlines how ethical standards should influence the distribution of SARS-CoV-2 medical treatments on the basis of recipient prioritisation across countries (Persad et al., 2020).

Medical treatment distribution is inseparable from distribution hospitals, also defined as 'hospital networks' (Lega, 2005) because the process must be coordinated and fair. A hospital network comprises various additional healthcare services and facilities and two or more hospitals in different locations (e.g. regions, states or countries). The headquarters of a hospital network is usually found in one of these locations served by network facilities (Association, 2014). Hospital networks and distribution hospitals were formed in the late 20th century to improve the efficiency of healthcare delivery and sharing of specialised medical services and specialists across these networks (Shalev & Shapiro, 2020). Management and control of healthcare services, patients' health records and use and reuse of health data among distribution hospitals help in overcoming

the limitations of medical services and motivating patients to receive treatments or assistance (Albahri et al., 2019). However, specific risks related to patient privacy were found in distribution hospitals. Privacy challenges are identified as main issues in the SARS-CoV-2 pandemic. The pandemic and the high infection frequency have compelled countries to re-examine data privacy, which has become a defining undercurrent when the global economy returns to its normal state (Azad et al., 2020). Within these contexts, patient data privacy and SARS-CoV-2 treatment availability in distribution hospitals are critical challenges that must be considered and evaluated.

2.4 What are the current distribution challenges for the SARS-CoV-2 treatment taken the Hospital Networks?

Two main challenges arose from SARS-CoV-2 treatment distribution. The first is addressing patient privacy challenge within distribution hospitals, and the second is prioritisation decision-making challenge for achieving fair distribution. Owing to the limitations of the available anti-SARS-CoV-2 mAbs, hospitals and medical authorities should prioritise their application for patients with high risk of clinical development (Chigutsa et al., 2021; Dispinseri et al., 2021).

2.4.1 Privacy challenge

Numerous studies were conducted at the onset of the SARS-CoV-2 epidemic to address the difficulty of protecting patients' privacy, and personal information can shared for SARS-CoV-2 treatment in hospital networks. In telehealth, data confidentiality and safety poses considerable concern. Various challenges, such as data safety and safeguarding patient confidentiality, have been identified as key factors for telehealth (Albahri A. S. et al., 2019). The risk of being exposed to con or data leakage is increasing as patients' health accounts increase at a rapid rate.

Furthermore, the vulnerability of some telehealth applications is posing concerns about privacy and security. The privacy of patient data is directly affected by the security queries of telehealth applications and telecommunication (Mohammed T. J. et al., 2021). According to Daggubati et al. (2020) and MEDICA (2020), inability to transfer patient data among medical institutions is due to privacy protection restrictions in medical big data. Furthermore, the confidentiality of patient data must be safeguarded against unauthorised use, and disclosure of personal patient information to third parties without patients' consent should be prevented. High-security and privacy methods will increase people's trust in telehealth services, and thus their willingness to use them. Two main issues were considered major concerns in privacy: data sharing and data independence issues.

2.4.1.1 Data Share Issue

During the COVID-19 pandemic, patient data are collected and shared across hospitals and clinical laboratories and used by data scientists and researchers developing and deploying strategies for preventing the virus from spreading. Patients, hospitals and medical institutions around the world are becoming increasingly concerned about the security and privacy of their data. Inability to share patient data in a centralised system with other parties is a significant problem because of data confidentiality (survey on security and privacy of federated learning [FL]; Viraaji Mothukuri, Reza M. Parizi, 2020). In particular, systems for sharing private patient data among hospitals and medical institutions must be secured. Thus, data sharing is considered one of the privacy issues that should be addressed.

2.4.1.2 Independence Issue

Data independence is a feature of a database management system that enables users to modify data definitions and structures without influencing hardware and software. This attribute allows multiple users to access and process the same data for different purposes regardless of how data are changed. Moreover, independence of data and process for each hospital is playing a vast role in medical data and decision-making. The more independent hospitals are, the lower the risk of sharing confidential data with external parties, increasing privacy and security levels. Given that users have their own local training data, data distribution has no single representation. I. Feki, S. Ammar and Y. Kessentini et al (2021) mentioned that local data in the healthcare domain remains private to each client and is never shared with any third party. Thus, data independence can be considered an important issue of privacy and security because of its significant influence on privacy in hospitals.

2.4.2 Prioritisation Challenge

Regarding the second challenge, we need to highlight issues that make the prioritisation of treatment recipients a challenging task and consider distribution hospitals. On this basis, the degree of importance of criteria affecting the distribution of treatments must be identified. The SARS-CoV-2 Treatment Guidelines Panel of the National Institutes of Health (NIH) recommended the use of anti-SARS-CoV-2 in treating mild-to-moderate SARS-CoV-2 symptoms and SARS-CoV-2 infection PEP in patients at a high risk of having severe SARS-CoV-2 (Chigutsa et al., 2021). Anti-SARS-CoV-2 mAbs are the most beneficial as PEP or treatment for people at a high risk of severe infection (Mornese Pinna et al., 2021). Fully vaccinated individuals and individuals with strong immunity have lower chances of showing severe SARS-CoV-2 symptoms than those who are

partially vaccinated or received a full vaccination dose but are not anticipated to generate significant immunological response to vaccines (Dispinseri et al., 2021; Hasan, 2021). Appropriate guidance on which individuals may benefit the most from a treatment is essential when treatment supply restrictions make it impossible to treat all eligible patients (HEALTH, 2021). The NIH has suggested prioritising SARS-CoV-2 treatment over SARS-CoV-2 infection PEP and prioritising anti-SARS-CoV-2 mAb treatment for unvaccinated or partially vaccinated people, vaccinated people, and vaccinated but immunocompromised people taking immunosuppressive drugs or who are 65 years old. Providers or hospitals should use clinical discretion when anti-SARS-CoV-2 mAbs for treatment or PEP in a particular context. Available anti-SARS-CoV-2 mAbs should be monitored for fair distribution (NIH, 2021). Numerous practical technical questions have been raised, including those regarding multiple-evaluation strategies, significant policies and data variations, which are associated with prioritisation challenges.

2.4.2.1 Concerns Related to the Multiple-Evaluation Criteria

Multi-evaluation strategy must be included in the ranking process for selecting eligible high-risk patients in different hospitals. A total of 15 high-risk criteria: age, hypertension, cardiovascular disease, heart diseases, chronic respiratory disease, obesity body mass index, chronic kidney disease, diabetes, immunosuppressive disease, immunosuppressive treatment, pregnancy, sickle cell disease, neurodevelopmental disorder and COVID-19 disease severity were used in determining the urgency of treatment for eligible SARS-COV-2 patients and can affect ranking processes. In ranking processes, various high-risk criteria should be considered in multicriterial distribution model because they entail the computation of high-risk strategic pointers. Owing to issues related to high-risk strategies, the assessment phase's high-risk policies will finally influence

the effectiveness of assortment methods. Therefore, assortment processes in association with risky strategies for intervention in treatment dissemination criteria should be thoroughly explored. A multifaceted characteristic DM can be used. Figure 2.5 depicts the respective set of manifold strategies for every dissemination criteria and its effect on the assortment procedure (Almahdi et al., 2019).

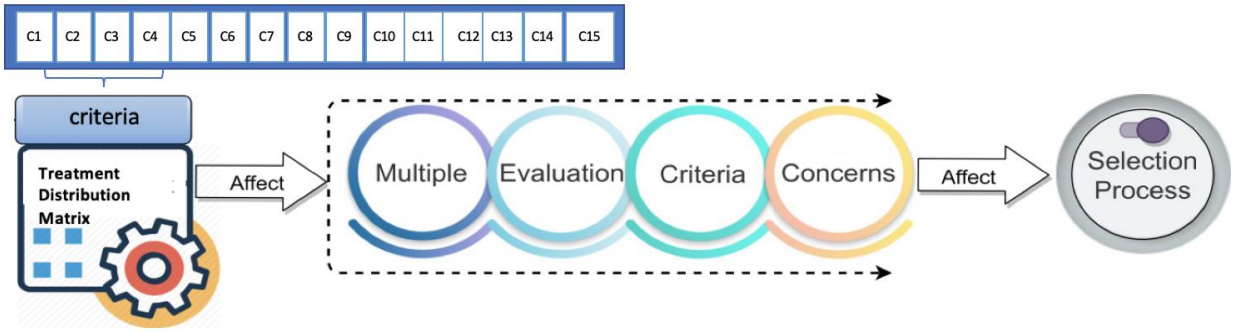

Figure 2. 5 Multi-criteria evaluation issues of the treatment distribution processes

2.4.2.2 Concerns Related to the Criteria of Importance

Demand for treatment dissemination methods is the basis of this study. Numerous strategies should be evaluated. Various weights are usually assigned to criteria subjectively by technocrats (Abdulkareem, Arbaiy, Zaidan, Zaidan, Albahri, Alsalem, Salih, et al., 2020; Aws Alaa Zaidan et al., 2015) or objectively through a fixed-weight process (A. Albahri, R. A. Hamid, et al., 2020). However, these approaches tend to increase the intricacy of the work and affect treatment distribution processes. The most suitable importance of 15 high-risk criteria can enhance the ranking process and assorting justified high-risk patients. Figure 2.6 shows how each set of high-risk criteria should be evaluated when determining the significance of a criterion in relation to

another one. This process is pertinent to solving challenges associated with the importance of criteria..

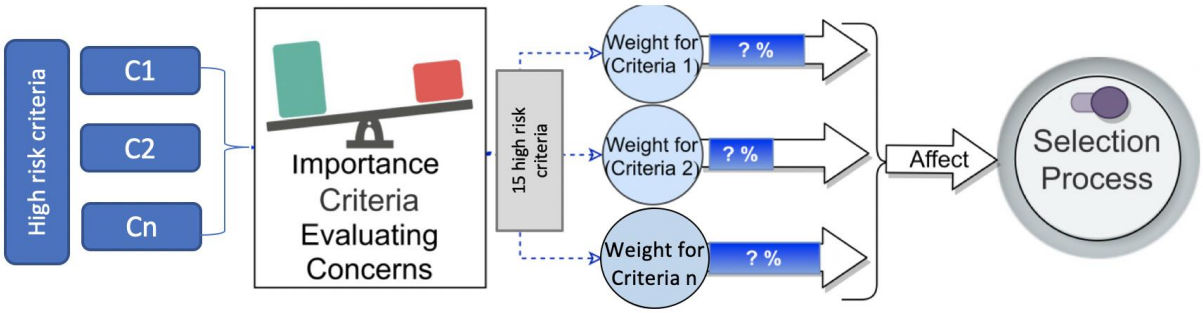

Figure 2. 6 Criteria Importance Issues of the Treatment Distribution Processes

The significance of the weights of DMs is differentiated depending on the subjective or objective method utilised in evaluation. For example, the 15 high-risk criteria in Section 2.4.2.1 varied.

2.4.2.3 Concerns Related to Data Variation

In the study, inconsistencies among various distribution techniques were found. Inconsistencies highlighted in the academic literature normally focused on the ranking of eligible high-risk patients (Chen et al., 2020; Nair et al., 2017; Raut et al., 2019; Raut et al., 2018). The examples of these data variations are shown in Figure 2.7. Inconsistencies can be regarded as unique incidents that offer precise arguments and examinations. For instance, a situation can occur as a goal extension illustration related to DM. In this context, an incident can occur when measures for maximising criteria impact the data of the alternatives (high, higher and highest levels) to enhance selection processes.

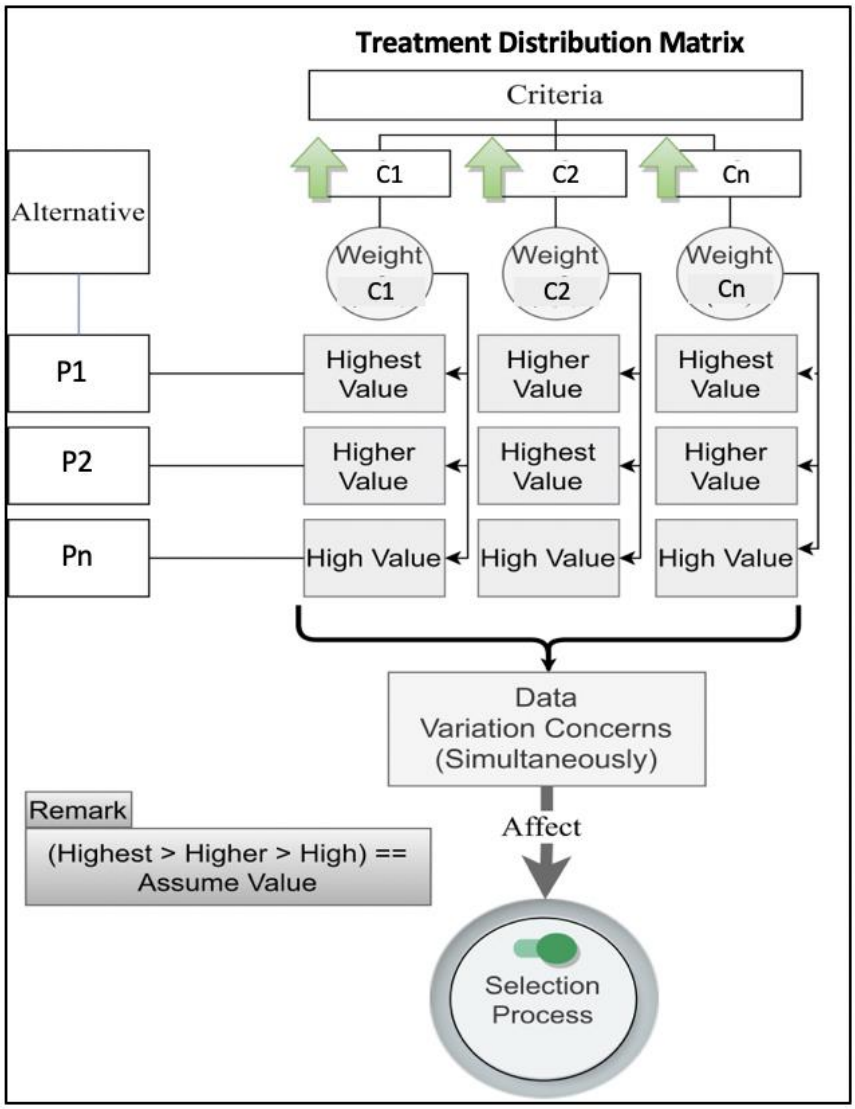

Figure 2. 7 Variations of issues in the distribution process

The assortment procedure entails the concurrent considerations of the multifaceted strategic matrices of treatment distribution methodology for eligible high-risk patients, in which various maximisation goal incidences are portrayed by creating a variation in great, higher and greatest levels that create diversity in information. Hence, asking and answering the third question are important.

2.5 The third question: 'How can be evaluating current SARS-CoV-2 treatment scenarios within distributed hospitals according to the above challenges?'

To determine the precise answer for this question, the discussion separately examines the above challenges. To answer the privacy challenge, this research argues that FL is considered an exact-fit approach that only applies distributed learning to fit the privacy data challenge.

2.5.1 Federated Learning (FL)

FL is a modern form of AI and based on devolved data and takes learning to the edge or on-device. It is a study topic that has been termed 'a new dawn in AI'. Its initial conception has not received global acceptance because of (unknown) security and privacy insinuation. FL ML approaches replicate a large array of distributed data (Bonawitz et al., 2019). The application of FL to the therapeutic field has broad prospect and may solve problems in privacy while sharing the data of patient in hospital networks. Several valuable studies have been performed recently in FL specifically in the medical domain to combat Covid-19. To systematically evaluate the effectiveness of FL in healthcare, Shyu conducted multiple studies to address concerns about medical data sharing and provided future study direction for the use of FL in Covid-19 treatment (Shyu et al., 2021).

2.5.2 Federated Learning for Medical COVID-19 Applications

The literature has limited attempts to contribute to FL in medical COVID-19 applications. Vaid et al. (2021) used FL in constructing the prediction models of mortality in SARS-COV-2 patients based on their e-health records (EHR) without aggregating all their data in a single centre. Similarly, R. Wang et al. (2021) adopted FL to develop a diagnostic model for SARS-COV-2 to

provide a robust model that can serve medical centres without sharing patient data. Therefore, federated fundamentals enable local hospitals to learn collaboratively without data sharing with centralised or medical central servers, specifically, patients' data located and processed in hospitals.

Feki et al. (2021), Kumar et al. (2021) and D. Yang et al. (2021) focused on the X-ray and CT scan image analysis for SARS-COV-2 diagnosis. They developed models with FL for training data locally without sharing patient data records and update global models with the parameters of training data accordingly for enhanced SARS-COV-2 detection. Pang et al. (2021) proposed an innovative collaborative model that allows numerous digital twin (DT) cities in the same region to swiftly communicate local plans and status. Particularly, FL main servers control the local updates of several contributors (DT cities) and produce a worldwide strategy based on numerous reiterations at varied DT cities until the model learns the connection among alternatives. As a result of this strategy, a 'global vision' of city crisis management can be gained by integrating information and the patterns of many DTs into a collaborative DT city paradigm. Meanwhile, it contributes to the improvement of each DT city by integrating data from other DT cities without infringing privacy regulations.

Ouyang et al. (2021) proposed a novel background for the primary warning of SARS-COV-2 through crowdsourcing and use of federated surveillance models that protect privacy and enable social participants without mutual trust to share verified surveillance resources and blend their surveillance solutions. A literature survey of studies on the use of FL in medical application is described in Table 2.3.

2.5.2.1 Literature survey for Federated Learning in Medical COVID-19 Applications

FL is a wide concept bringing the code to data rather than the data to the code and offers solutions to basic issues associated to data discretion, localisation and ownership. Federated fundamentals with ML have attracted considerable interest and have been used in many fields, especially in the medical sector. The frequency of their use has considerably increased after the outbreak of the SARS-COV-2 pandemic. Thus, patient data sharing and privacy have become main concerns. Table 2.3 lists the eight studies that explored the use of FL for COVID-19 applications.

Table 2. 3 Literature Survey for Federated Learning in Medical COVID-19 Applications

Author & Year	Contribution	Case Study	Federated Fundamental
Yang, Xu et al. (2020)	This study proposed a novel federated semi-supervised learning technique (with or without annotations) for effectively utilising available data in addressing variability in both data and annotations.	Chest computed tomography	Federated and semi-supervised learning as traditional ML
Akhil Vaid and Suraj K Jaladanki et al. (2021)	This study aimed to use federated learning technique to prevent local accumulation of raw clinical information across several institutions and forecast death in hospitalised COVID-19-positive	Electronic Health Records	Least absolute shrinkage and selection operator federated Multilayer perceptron federated as traditional ML

	patients within 7 days.		
Liwei Ouyang, Yong Yuan and Yumeng Cao et al. (2021)	The authors proposed a collaborative early warning style associated to blockchain and smart contracts for COVID-19, and the goal was crowdsourcing early warning errands to distributed stations in medical institutions, people and other social strata.	Early warning for COVID-19 based on blockchain and smart contracts	The strategy combines the monitoring results of two screening methods, medical federation screening based on federated learning and social association screening based on the learning markets method to alert new cases as traditional ML
Wang, Xu, Ma, Talha, Al-Rakhami and Ghoneim et al. (2021)	This study proposed a 5G-enabled auxiliary diagnosis architecture based on federated learning for many institutions and central cloud cooperation to enable the sharing of high generalisation performance diagnosis models	5G-enabled federated learning auxiliary diagnosis of COVID-19	COVID-19 severity classification Experiments were run on a central cloud and three edge cloud servers to ensure that the suggested architecture and model cognition technique were effective similar to traditional ML
Kumar, Khan, Zhang, Yang, Golilarz, Zakria, Ali, Shafiq	This study proposed a framework that collects a limited quantity of data from various sources (different hospitals) and uses	COVID-19 detection using CT imaging	Deep learning

and Wang et al. (2020)	blockchain-based federated learning to train a global deep learning model		
(Pang, Huang, Xie, Li and Cai et al. (2021)	This study proposed a framework that combines digital twins (DTs) of cities with federated learning to provide a novel collaborative paradigm that enables numerous city DTs to share local strategies and status quickly	City DTs to share local strategies and status quickly	Federated learning central server manages local updates from multiple collaborators (city DTs), generating a worldwide framework focused on manifold iterations at various city DT policies until the framework learns associations among different response stratagems and contamination trends, such as traditional ML
(Zhang, Zhou, Lu, Wang, Zhu, Sun, Wang, Lo, Wang, et la., 2021)	This study proposes a novel federated learning approach based on dynamic fusion for medical diagnostic imagery analysis to diagnose Coronavirus comorbidities.	COVID-19 Detection using Dynamic Fusion-based Federated Learning	DYNAMIC FUSION-BASED FEDERATED LEARNING as traditional ML
Feki, Ammar, Kessentini, and Muhammad et al. (2021)	This study proposed a federated learning system that allows several medical organisations to apply deep knowledge to scrutinise the virus from chest X-ray	Screening COVID-19 from chest X-ray images	Federated learning of a deep CNN model

	imagery while maintaining confidentiality.		

As shown in Table 2.3, eight articles focused on the use of FL in medical applications, such as COVID-19 detection using CT imaging, early warning for coronavirus based on blockchain and shrewd comparison and local strategy and status share of city DTs. Federated fundamentals well suited and widely used with ML models. Six of eight studies contributed to traditional ML, and the remaining studies contributed to deep learning that overcome the first obstacle of privacy (data sharing issue). However, no research explored prioritisation challenges. In other words, the second challenge cannot be addressed, which requires a precise decision-making approach to resolve the three prioritisation issues outlined. This situation is considered a research gap.

2.5.3 Point of view for Multicriteria decision making & Treatment Distribution

Apart from analysis, MCDM is regarded as a solution that assists experts in organising and solving any prioritisation issue (M. A. Alsalem et al., 2021). MCDM is defined as a decision theory extension covering any decision with multiple objectives and is a technique for evaluating options according to several contradictory criteria and for merging them into a single inclusive evaluation (M. A. Alsalem et al., 2021). Therefore, MCDM provides great benefits as a decision science support technique and has been used in the context of SARS-COV-2 along with a variety of applications. Identifying the prioritisation issue (second challenge) of SARS-COV-2 treatment recipients as an MCDM issue has been discussed in the literature. T. J. Mohammed et al. (2021) proposed an intelligent framework based on the MCDM context and successfully addressed patients' prioritisation issue in distribution hospital networks and issues in the transfusion of

efficient CP from donors to the most critical SARS-COV-2 patients as an early treatment (i.e. pre-vaccination stage). However, this framework relied on sharing donors' and patients' data in all hospitals (distribution hospitals) and combined them in a decision matrix for donors and in another decision matrix for SARS-COV-2 patients for prioritisation and matching. The privacy and sensitivity of patients' and donors' openly used data were ignored.

To date, no study has integrated the federated fundamental with MCDM techniques for SARS-COV-2 treatment. To bridge this gap, integration is essential to characterise the supply of anti-SARS-CoV-2 mAbs in distribution hospitals. Therefore, the formulation of a new federated fundamental concept called 'Federated-Decision Making Distributor (FDMD)' is necessary to overcoming challenges towards ensuring the privacy of health SARS-COV-2 data and prioritising anti-SARS-CoV-2 mAb recipients in distribution hospitals.

2.6 Theoretical Background for FDMD Fundamental Solution

FDMD enables hospitals to collaboratively learn to prioritise patients without data exchange or sharing with a centralised medical centre server. FDMD can distribute anti-SARS-CoV-2 mAb doses evenly among distribution hospitals and medical centre servers by utilising multiple decision matrices. In general, FDMD consists of two key sequence processes: a patients' prioritisation process that uses the hospital's local decision matrix (a unique decision matrix for each hospital). The global distribution transmission process ensures privacy protection and equitable distribution in all hospitals concurrently.

This process is implemented using representative data (abstract data) obtained from local decision matrices. Therefore, patients' privacy can be protected in distribution hospitals by introducing the

concept of FDMD. However, prioritisation processes still confront other challenging issues (i.e. multicriteria, data variation and criteria weighting) as mentioned above in Section 2.4.2. Owing to variations in multiple high-risk criteria, the prioritisation of eligible patients becomes complicated.

2.6.1 MCDM Methods

Several MCDM methods have been discussed and used to solve distinct issues in wide aspects. MCDM methods have been established on the basis of mathematical and human tactics. Table 2.4 provides the most frequently used MCDM mathematical approaches with different connotations.

Table 2. 4 MCDM mathematical approaches

Methods		Brief description
Simple Additive Weighting	SAW	The fundamental principle of SAW is extracting the weighted number of presentation rankings for substitution by considering other factors by utilising SAW steps (Chou et al., 2008; A. A. Zaidan et al., 2015). SAW comprises two fundamental steps: gauging the standards of all attributes for compatibility enhancement. The values of the all traits are added for each alternative (Chou et al., 2008).
Hierarchical Adaptive Weighting	HAW	In SAW, the value of each idea is rated over the highest criterion measure among all alternatives.
Weighted Sum Model	WSM	The WSM is a simple methodology appropriate for handling simple problems since it supports a one-dimensional complication. WSM permits comparison of alternatives designating scores and then utilising the scores in generating alternatives. The strategies are assigned weights based on the sternness; all weights should add up to 1. Every substitute is evaluated according to each attribute (Jablonsky, 2014; Singh, 2014)

Weighted Product Method	WPM	It resembles the WSM but multiplication is the major mathematical task in WPM, versus addition in WSM, (A. A. Zaidan et al., 2015). Comparison of alternatives is based on weights and ratios for every criterion (Aruldoss et al., 2013)
Multiplicative Exponential Weighting	MEW	Taking exponential of every strategy to the weight instead of multiplication of measures by weight.
The technique for order preference by similarity to ideal solution	TOPSIS	TOPSIS is a popular MCDM methodology that is broadly applied to multifaceted decision-making methodologies because of its clear sequence. TOPSIS is based on the criteria that the perfect substitute contains the highest traits and vice versa (Karahalios, 2017; Önüt & Soner, 2008).

TOPSIS is the most preferred method, which is based on the concept that an ideal alternative (patient) has the best level for all attributes and the negative ideal has all the worst attribute values. These methods clearly illustrate that MCDM techniques represent a wide area of research. TOPSIS is the most suitable for the FDMD concept given its nature with positive and negative ideals, facilitating the creation of many matrices distributed between local federated hospital clients and central servers. However, the classical version of TOPSIS has the following limitations:

i. Insensitivity to small values (T. Yang et al., 2020)
ii. Distortion of original information (Lin et al., 2021),
iii. Ranking of reversal flaws (Yu et al., 2020)
iv. Extremely small gaps amid positive and negative ideal ramifications (Ding et al., 2020; Wu et al., 2020; Zhao et al., 2020).

2.6.1.1 Technique order of preference by similarity to the ideal solution TOPSIS

Many improved versions of TOPSIS have been presented in the literature to overcome the flaws of classical TOPSIS (Deng et al., 2021; Lin et al., 2021; Liu et al., 2020; Lv et al., 2020; Singh et al., 2020; L. Wang et al., 2021; Wu et al., 2020; Zhang et al., 2021; Zhao et al., 2020). Tang and Fang (2018) developed classical TOPSIS to improve the positive and negative ideal solutions and introduced a closeness degree formula to prevent the possibility of rank reversal. FDMD is an iterative prioritisation in hospitals and considers the periodical admission or discharge of patients (i.e. increase or decrease in alternatives) at each hospital in a specific period and thus causes a rank reversal issue. Hence, the improved TOPSIS proposed by Tang and Fang (2018) applies the efficacy coefficient method to prevent potential rank reversal when absolute ideal solutions are used. To ensure patients' privacy during prioritisation, the adopted TOPSIS (Tang & Fang, 2018) has been used with the federated fundamental concept. The federated TOPSIS will be described in Chapter 3. In the FDMD sequence process, the importance of criteria has a vital role in the final results. However, Federated-TOPSIS is limited to criteria and requires an external method for weighting criteria. In MCDM, weights are designated to criteria objectively and subjectively (Wang & Lee, 2009). In objective weighting methods, the importance of criteria is computed on the basis of raw data. Changes in raw data affect the accuracy of weight values, and sharing of private data is necessary. Subjective weighting methods represent experts' cumulative knowledge and their opinions (Nigim et al., 2004). Many subjective weighting methods have been introduced in the literature (Table 2.5).

Table 2. 5 MCDM human Approaches

Methods	Brief description

Analytic Hierarchy Process	AHP	AHP portrays the innate thinking of human beings. It provides solutions to sophisticated issues by breaking down problems into a pyramid of easily interpreted subproblems with appropriate alternate decisions. It is a well-known MCDM approach that provides ratio gauges from paired assessments. It offers little variations in decisions given that human beings are consistent (Zaidan & Zaidan, 2017).
Analytic Network Process	ANP	It is denoted as a mathematical principle that tackles entire forms of dependencies methodically. It can be applied to various subjects and fields. It has multiple-criteria decision-making techniques that compare various substitutes for the selection of the best alternative. It permits the addition of pertinent ideas to a prevailing one, which might be concrete or intangible (Abdullateef et al., 2016).
Best-Worst-method	BWM	It is a comparative MCDM methodology which considers the greatest aspect to other aspects and all other features to the foulest feature (Nafari et al., 2017).
Fuzzy weighted with zero inconsistency	FWZIC	It computes the weight factors of a criterion with zero contradiction, irrespective of the criteria number

Table 2.5 shows the analytical hierarchy process (AHP; T. J. Mohammed et al., 2021) and best-worst methodology (BWM; Rezaei, 2015), which have a high rate of success in weighting criteria. However, the inconsistency in their weighing methods remains an unsolved issue (Pamučar et al., 2018). Contrary to that, the fuzzy weighted with zero inconsistency (FWZIC) method calculates the weight constants of criterion with zero discrepancy, irrespective of the number of criteria (M. Alsalem et al., 2021). The FWZIC method achieves zero discrepancy by precisely determining the weight values of each criterion. It can determine the importance of criteria in decision-making with the assistance of experts (M. Alsalem et al., 2021).

2.6.1.2 Fuzzy weighted with zero inconsistency (FWZIC)

The FWZIC methodology has four versions with distinct fuzzy forms and has six stages. The first three stages are alike regardless of fuzzy conditions applied, and last three stages need distinct mathematical processes based on fuzzy conditions. Analogous stages are explained amid forms, and variances are stated in the table from phase 4 to phase 6. However, the original version of FWZC adopts triangular fuzzy numbers (M. Alsalem et al., 2021) and thus shows a degree of vagueness and ambiguity. Consequently, many extensions of the FWZIC method are used with different fuzzy environments, such as trapezoidal fuzzy numbers (Krishnan et al., 2021), Pythagorean fuzzy set (A. Albahri et al., 2021), T-spherical fuzzy set (M. Alsalem et al., 2021) and q-rung Orthopair fuzzy sets (A. Albahri et al., 2021) to handle uncertainty and vagueness issues as a result of technocrats' feedback prejudice. Inspite of the fact that the uncertainty and vagueness issues have been improved in the previous versions of FWZIC, they remain an open issue. Therefore, the FWZIC method needs to be extended with a new fuzzy set to consider decision makers' uncertainty and vagueness. Various fuzzy set methods have been introduced in the literature, but the spherical fuzzy set (SFS) is the most complete conformation of them all (Kutlu Gündoğdu & Kahraman, 2019; Mathew et al., 2020). SFS is more efficient in addressing uncertainty in decision-making issues (Mathew et al., 2020; Onar et al., 2020; Rong et al., 2019). In addition, hesitant fuzzy set (HFS) method is the most frequently used method for maintaining vagueness.

2.6.1.2.1 Hesitant Fuzzy set (HFS)

The HFS is a robust tool for expressing unclear statistics in the development of (MADM) complications because it permits the association degree of a component to a convention expressed

by numerous alternative values (Xu & Zhang, 2013). Qian et al. (2013) successfully developed HFSs in a group decision-making strategy by using intuitionistic fuzzy sets. The generalised HFS is appropriate for scenarios in which DMs are conflicted between multiple possible memberships. Chen et al. (2013) connected an HFS to interval-valued HFS in which a component's degree of association to a specific convention is not clearly stipulated but represented by multiple probable interval measures. They then developed a strategy for classifying decision-making on the basis of interval-valued hesitant preference relationships to justify variances in individual DMs' views.

The present study proposed a novel weighting technique that employs FWZIC method with interval-valued spherical fuzzy and hesitant 2-tuple fuzzy environment and named IVSH2-FWZIC, which deals with uncertainty more efficiently and skilfully. The details will be described at Chapter 3. To test and apply the proposed FDMD, we needed to investigate and justify the data sets related to Covid-19 mAb treatment distribution.

2.7 Data Sets Related to the Covid-19 Studies

In order to test and apply the FDMD, there is a need to have a viewing for the data sets related the COVID-19 Studies. Up to the literature there are many COVID-19 studies followed 'Augmented data' if the infrastructure for the case study as application is not available. Accordingly; below table illustrates the previous studies that used augmented data. The table contains case study, number of experts participated in collecting data, number of criteria, procedure of evaluation (subjective or objective), partial or full augmented and justification of augmented. The reason of using the augmented data is to create artificial data for specific case study by modified copies of already existing data or newly created an amount of artificial data related to a specific case study.

Table 2. 6 Literature of augmented data related to COVID-19 case studies

Ref	Case study	Number of experts	Number of criteria	Procedure of evaluation (subjective or objective)	Partial or full augmented	Justification of augmented
(M. Alsalem et al., 2021)	COVID-19 vaccine dose	3	5	Subjective and objective	Partial: dataset of 300 / sample of first 20 covid-19 vaccine recipients	Data of vaccine dose recipients is not available
(O. Albahri et al., 2021)						
(A. Albahri et al., 2021)						
(T. J. Mohammed et al., 2021)	Convalescent-plasma-transfusion	3	5	Objective	Partial: 80 patients / 20 donors for each blood type	Data of Convalescent-plasma-transfusion is not available
(Alsalem et al., 2022)	Rescuing emergency cases of COVID-19 patients	3	Moderate= 4 Severe= 3 Critical= 3	Objective	Full	Data of patients with different emergency levels. is not available

Three study-works were carried out in five studies as aforementioned in the table. (M. Alsalem et al., 2021), (O. Albahri et al., 2021) and (A. Albahri et al., 2021) conducted research in COVID-19 vaccine dose, (T. J. Mohammed et al., 2021) conducted a case study in Plasma transfusion and (Alsalem et al., 2022) conducted research in emergency cases of COVID-19 patients. The number of participated experts in all studies was 3. Moreover, the number of criteria in both COVID-19 vaccine dose and plasma transfusion was 5 while the emergency cases of COVID-19 patients was 4 for moderate level, 3 for severe level and 3 for critical level. Additionally, the procedure of evaluation was subjective and objective in COVID-19 vaccine dose studies and objective only in

emergency cases of COVID-19 patients' study. A partial augmented data was used in both COVID-19 vaccine dose as 300 dataset of COVID-19 vaccine recipients augmented dataset and 80 datasets of patients for plasma transfusion case study, 20 donors for each blood type, however, full augmented dataset was used in emergency case study.

However, as discussed in above Table 2.6, the number of experts is the same in all studies in the augmented data used in different case studies. The number of criteria depends on the case study as well as the procedure of evaluation (subjective o/and objective). Moreover, the size of augmented data (partial or full) differs from case to case. According, to the justification of augmented data, there is no existing infrastructure to collect the data related to COVID-19 treatments. This study will follow the same pattern and all practical details will be explained in chapter 3.

2.8 Overview for Validation and Evaluation Procedures in Decision Science

According to the literature, validation and evaluation procedures in decision science will be discussed. The table in Section 2.11.1 shows the systematic ranking procedure used validating the ranks of alternatives. In Section 2.11.2, the sensitivity analysis procedure is discussed using a table. The weights of different criteria were then evaluated. In Section 2.11.3, a table was used in organising the evaluation procedure that used comparative data based on a benchmarking checklist, and studies were compared theoretically or practically with other studies.

2.8.1 Systematic Ranking Procedure

In the validation procedure, seven case studies used the orderly listing method to authenticate the ranks of alternatives. The table below includes case studies, total number of alternatives, number

of groups, sum of alternatives per each cluster and matrix-based data (raw, normalised or weighted data).

Table 2. 7 Literature of systematic ranking procedure in different case studies

Reference	Case study	Total number of alternatives	Number of groups	Number of alternatives per each group	Matrix based on raw, normalised or weighted data
M. Alsalem et al. (2021)	COVID-19 Vaccine Dose	150	6	25	Raw
O. Albahri et al. (2021)	COVID-19 vaccine dose	300	6	50	Raw
A. Albahri et al. (2021)	COVID-19 vaccine doses	300	6	50	Raw
T. J. Mohammed et al. (2021)	COVID-19 (plasma-transfusion)	80	4	20	Raw
Krishnan et al. (2021)	Smart e-tourism for tourism marketing	8	3	3, 3, 2	Raw & normalised
	Smart e-tourism for collaborative filtering	11	3	4, 4, 3	
	Smart e-tourism for content	18	3	6,6,6	
	Smart e-tourism for context	10	3	3,3,4	
	Smart e-tourism for hybrid models	18	3	6,6,6	
Hamid et al. (2021)	Telemedicine	500	3	166	Normalised or weighted data

Salih et al. (2021)	Network congestion control	6	2	3	-

Five case studies were conducted, focusing on COVID-19 vaccine dose (M. Alsalem et al., 2021; O. Albahri et al., 2021; A. Albahri et al., 2021), COVID-19 plasma transfusion (T. J. Mohammed et al., 2021), smart e-tourism applications with five subcases (Krishnan et al., 2021), telemedicine (Hamid et al., 2021) and network congestion control (Hamid et al., 2021). A total of 150 alternatives were used by M. Alsalem et al. (2021), 300 alternatives were used by O. Albahri et al. (2021) and A. Albahri et al. (2021), and 80 alternatives were used by T. J. Mohammed et al. (2021). M. Alsalem et al. (2021), O. Albahri et al. (2021) and A. Albahri et al. (2021) used six group. The number of alternatives per group was 25 in the study of M. Alsalem et al., 2021 and 50 in the studies of O. Albahri et al. (2021) and A. Albahri et al. (2021). In the study of T. J. Mohammed et al. (2021), the number of groups was four, and the number of alternative for each group was 20. The number of groups for each subcategory in the study of Krishnan et al. (2021) was three, and the alternatives in the groups were 3, 3, 2–4, 4, 3–6, 6 ,6–3, 3, 4, 6, 6 and 6 in number. In the study of Hamid et al. (2021), three groups were used, and each group had 166 alternatives. Salih et al. (2021) used two groups with three alternatives each. The matrix was based on raw data in the study of M. Alsalem et al. (2021), O. Albahri et al. (2021), A. Albahri et al. (2021) and T. J. Mohammed et al. (2021). In the study of Krishnan et al. (2021), the matrix was based on raw and normalised data. In the study of Hamid et al. (2021), the matrix was based on normalised data.

As discussed in above Table 2.7, the systematic ranking procedure is used in different case studies. Total number of alternatives, the number of groups and the number of alternatives per each group are different from case to case. the matrix can be raw, normalised or weighted data. This study will

employ the same pattern as explained aforementioned. The practical details will be discussed further in chapter 3.

2.8.2 Sensitivity Analysis Procedure

The sensitivity examination procedure was used in validating the weights of the criteria of the proposed framework when the weights were changing. The table below lists the case studies, weighting methods, fuzzy sets, number of scenarios, number of criteria, sensitivity type and correlation type.

Table 2. 8 Literature of sensitivity analysis assessment in different case studies

References	Case study	Weighting method	Fuzzy set	Number of scenarios	Number of criteria	Sensitivity type	Correlation type
M. Alsalem et al. (2021)	Prioritising COVID-19 vaccine dose recipients	T-SFWZIC	T-spherical Fuzzy	9	5	Elasticity coefficient (αc)	Spearman correlation coefficient (SCC)
O. Albahri et al. (2021)	COVID-19 vaccine dose recipients	PFWZIC	Pythagorean fuzzy	9	5	Elasticity coefficient (αc)	Spearman correlation coefficient (SCC)
A. Albahri et al. (2021)	Distribution case study of vaccine doses	ROFWZIC	q-rung orthopair Fuzzy	9	5	Elasticity coefficient (αc)	Spearman correlation coefficient (SCC)
Krishnan et al. (2021)	Smart electronic-tourism usage	IT2TR-FWZIC	IT2TR fuzzy	31	12	Elasticity coefficient (αc)	Spearman correlation coefficient (SCC)

Two case studies were conducted in the four published papers, namely, Covid-19 vaccine dose and smart e-tourism application. Four different weighting methods were used in the four studies: T-SFWZIC, PFWZIC, ROFWZIC and IT2TR-FWZIC. The studies were based on fuzzy sets: T-spherical fuzzy, Pythagorean fuzzy, q-rung orthopair fuzzy, IT2TR fuzzy. The first three studies (M. Alsalem et al., 2021; O. Albahri et al., 2021; A. Albahri et al., 2021) had nine scenarios of five criterion weight measures on ranking. The study of Krishnan et al. (2021) had 12 criterion weight measures on the standing results over 31 incidents. The sensitivity type used for all studies was elasticity coefficient (αc), which is used in calculating the comparative counterweights of other strategic weights to a criterion's greatest significant influence. The Spearman correlation coefficient (SCC) was applied in evaluation of the association between the outcomes of different situations.

As indicated in Table 2.8, sensitivity analysis procedure should be used in validating criterion weight. The weighting method, fuzzy set, number of scenarios and number of criteria vary by case, and no standard is available. Sensitivity type in all studies used the elasticity coefficient (αc), and the correlation type was SCC. The same pattern was used in the present study, and details are discussed in Chapter 3.

2.8.3 Comparative study based on Benchmarking checklist Procedure

In order to evaluate the proposed framework in studies, comparative study based on benchmarking checklist procedure should be followed. The literature in this section shows multiple studies that applied the comparative study. The table below consists of case studies, challenges and issues,

score points followed, comparative study (theory- or practice-based) and the number of benchmarking lists.

Table 2. 9 Literature of benchmarking checklist procedure in different case studies

References	Case study	Challenges and issues listed	Score points followed	Theory- or application- based	Number of benchmarking list
O. Albahri et al. (2021)	COVID-19 vaccine dose recipients	**Vaccine distribution problem:** ● Application revolving around three processes; ■ Identification of various dispersal techniques ■ Significant criteria ■ Variation in data ● Theory based ■ Fuzziness and inaccuracy.	-	Theoretical/practical	-
Alsalem et al. (2022)	Rescuing emergency cases of COVID-19 patients	**Two challenges aspects:** ● Varied hospital administration factors ranging from scalability to managing problems of prioritisation in patients and donors concurrently ● Technical factors that include lack of COVID-19 datasets and precise corresponding procedures considering all blood groups and types.	_	Theory	-
O. S. Albahri et al. (2020)	Helping doctors accelerate COVID-19 treatment	**Biologically, two challenges** ● Recuperating matters should satisfy preferred plasma standards and conform to countrywide health guidelines and	-	Theory	-

		recognised regular measures. ● Multiple-criteria decision-making issues should be considered when selecting the most appropriate CP and listing of COVID-19 patients.			
Krishnan et al. (2021)	Smart e-tourism applications	**Benchmarking challenge:** ● Application based and involves three factors; ■ Assessment criteria ■ Significance ■ Data variation ● Theory based ■ Fuzziness and inaccuracy in weighting	-	Theory	-
Hamid et al. (2021)	Telemedicine	Hybridised categorisation and prioritisation of patients with severe heart diseases (CHDs) can improve their health status by classifying them according to the severity of the infection.	▪ Classification scenario ▪ Prioritisation scenario	Application	▪ (6) Classification scenario aspects ▪ (10) For Prioritisation scenario

The table illustrates comparative study based on Benchmarking checklist in five studies. The table contains case studies, challenges and issues. The score points and benchmarking check lists are presented. The type of comparative study and number of benchmarking list in each study were discussed. The comparison analysis conducted by O. Albahri et al. (2021) was theory and practice based, whereas that conducted by Alsalem et al. (2022), O. S. Albahri et al. (2020) and Krishnan et al. (2021) were theory based. The comparison analysis by Hamid et al. (2021) was application

based. The score points followed in the telemedicine case study were classified into six scenario aspects and prioritisation with 10 scenarios. The issues and challenges in COVID-19 vaccine dose case study are vaccine distribution problem involving three issues in the application-based analysis. The factors included selecting various distribution measures, important criteria and data distinction. However, the theory-based studies were vague and imprecise. Alsalem et al. (2022) discussed two challenging factors for varied hospital administration features. They included scalability and administration factors for prioritising coronavirus patients and donors concurrently and for methodological facets, such as the absence of COVID-19 dataset, accessibility of patients and donors to a precise matching methodology by considering blood type. O. S. Albahri et al. (2020) reviewed two challenges. The first challenge was enabling recuperating patients to satisfy donor selection plasma standards and conform to national health guidelines and routine procedures. The second challenge was including MCDM issues in the assortment of most appropriate CP and the prioritisation of patients with COVID-19. The benchmarking challenges in the study of Krishnan et al. (2021) involved three issues: appraisal, criteria and significance, data variation and theory-based analysis contributed to vagueness and imprecision during weighting. Finally, the study by (Hamid et al., 2021), including issues in hybridised categorisation and listing patients with chronic heart diseases (CHDs) to save lives by sorting them in order of ailment adversity.

As indicated in Table 2.9, challenges with related issues differ among case studies, types of comparative study (application or theory) and number of benchmarking list aspects. The benchmarking checklist procedure was used in the present.

2.9 Chapter Summary

This chapter focuses on the literature appraisal which was performed to meet the study's objectives. The systematic literature review protocol was used in this study to achieve a conclusive interpretation of the research interests and enrich future study and research works with reliable information and statistics. In addition, the research study selection part comprises three subsequent steps: assortment of publications, scrutinising of titles and abstracts and full-text scanning. The defined attachment and omission criteria were used in the selection of the most relevant articles. A full taxonomy of results was performed to explain and interpret information on DM issues as far as COVID-19 is concerned, and details are presented in Section 2.2.5. A total of 55 studies focused on the DM issue and tackled the issue from the following standpoints: appraisal and development. Section 2.3 explains the importance of mAb treatment distribution and how ethical standards should influence the distribution of SARS-CoV-2 medical treatments on the basis of recipient prioritisation across countries. In Section 2.4, current distribution challenges for the SARS-CoV-2 treatment in hospital networks are described in detail, namely, privacy and prioritisation challenges. Section 2.5 provides detailed answer to the third question 'How can be evaluating current SARS-CoV-2 treatment scenarios within distributed hospitals according to the above challenges?'. FL for medical application was explored in eight studies (Table 2.3). No research on the prioritisation challenge has been conducted, prompting a precise policymaking tactic to resolve the three prioritisation issues outlined in Section 2.4.2. This finding is considered a research gap. Point of view for MCDM and treatment distribution is provided in Section 2.5.3. No research has attempted to integrate the federated fundamental into MCDM techniques for SARS-COV-2 treatment. This finding is considered a theoretical gap. Section 2.6 provides the theoretical background for FDMD fundamental solution. FDMD consists of two key sequence processes:

prioritisation process and distribution transmission process, which ensures privacy protection and equitable distribution across all hospitals concurrently. Many COVID-19 studies used ‘augmented data’ when the infrastructure for the case study as an application was unavailable. Details are provided in Section 2.7. In Section 2.8, literature review for validation and evaluation procedure for FDMD Solution is discussed, particularly the systematic ranking procedure, sensitivity analysis procedure and comparative study on the basis of benchmarking checklist procedure.

CHAPTER 3: METHODOLOGY

3.1 Introduction

This chapter introduces an overview description of the key phases followed to develop a treatment distribution methodology for Anti-SARS-CoV-2 Monoclonal Antibody for Eligible High-Risk Patients from different hospitals based on Novel (FDMD) Federated Decision-Making distributer. An overview of the methodology structure of FDMD is described under methodology section 3.2. The methodology is divided into two sections, each of which achieves certain research objectives that are mentioned in chapter 1. In this chapter, section 3.2.1 presents the first section that is Formulated MCDM theory under federated fundamental and section 3.2.2 presents the second section that is Federated-Decision Making Distributor (FDMD). In section 3.3 procedures of validation and evacuation are presented. Finally, section 3.4 summarizes this chapter.

3.2 Methodology

In these contexts, an FDMD scenario consists of two main phases: local decision matrix to generate the local vector and global dissemination to aggregate the iterated local vectors as a unified vector. This demonstrates the fact that with the help of FDMD, the hospitals can benefit from the other hospitals' data without sending their privacy-sensitive personal data to a medical central server and ensure fairly anti-SARS-CoV-2 mAbs distribution based on simultaneous prioritisation within distribution hospitals. In the FDMD sequences process, the FDMD central federated server provided the criteria setting (i.e. the criteria set, the weighted coefficients value using the newly formulated IVSH2-FWZIC, and the evaluation procedure), the Dynamic Decision Matrix (DDM) developed at each local machine, a local ideal vector of the data from each local decision matrix is computed using the proposed F-TOPSIS that represents the max and min parameters, then after

the obtained local vectors are participated in the medical centre and disseminate again as a unified vector to hospitals through global distribution transmission step. Upon receiving the federated unified vector in all distribution hospitals, each LM uses its own data for the local prioritisation dependent on the federated unified vector and the provided criteria weight. Then, these LM send back their patients' index and scores to the FDMD medical central server for global aggregation. This process is repeated various rounds until the desired global ranking are achieved the required threshold. In this regard, This FDMD of treatment is implemented through synchronised dialog communication between two parts, the central federated server-side (the treatment provider) and the hospital as a local machine (treatment receiver). For more descriptions about the FDMD methodology, see Section 3.2.2. Thus, this study aims to offer a novel FDMD framework for developing complex distribution and prioritising issues in the context of SARS-COV-2 treatment, as well as for supporting medical privacy rules in distribution hospitals. In this study, we describe the resulting high-level FDMD design, sketch and overcome the above challenges and discuss their solutions, and touch upon a novel federated-decision making monoclonal antibody treatment distributor for eligible high-risk SARS-COV-2 patients.

In this section, the methodology of integrating federated fundamental in the context of MCDM is presented in two sub-sections as presented in figure (3.1); in the first section, the formulated of MCDM theory under federated concept are demonstrated followed two sequences processes, first the formulation of new IVSH2-FWZIC weighting method and second proposed of Federated TOPSIS (F-TOPSIS). In the second sub-section, the proposed Federated-Decision Making Distributor (FDMD) is presented.

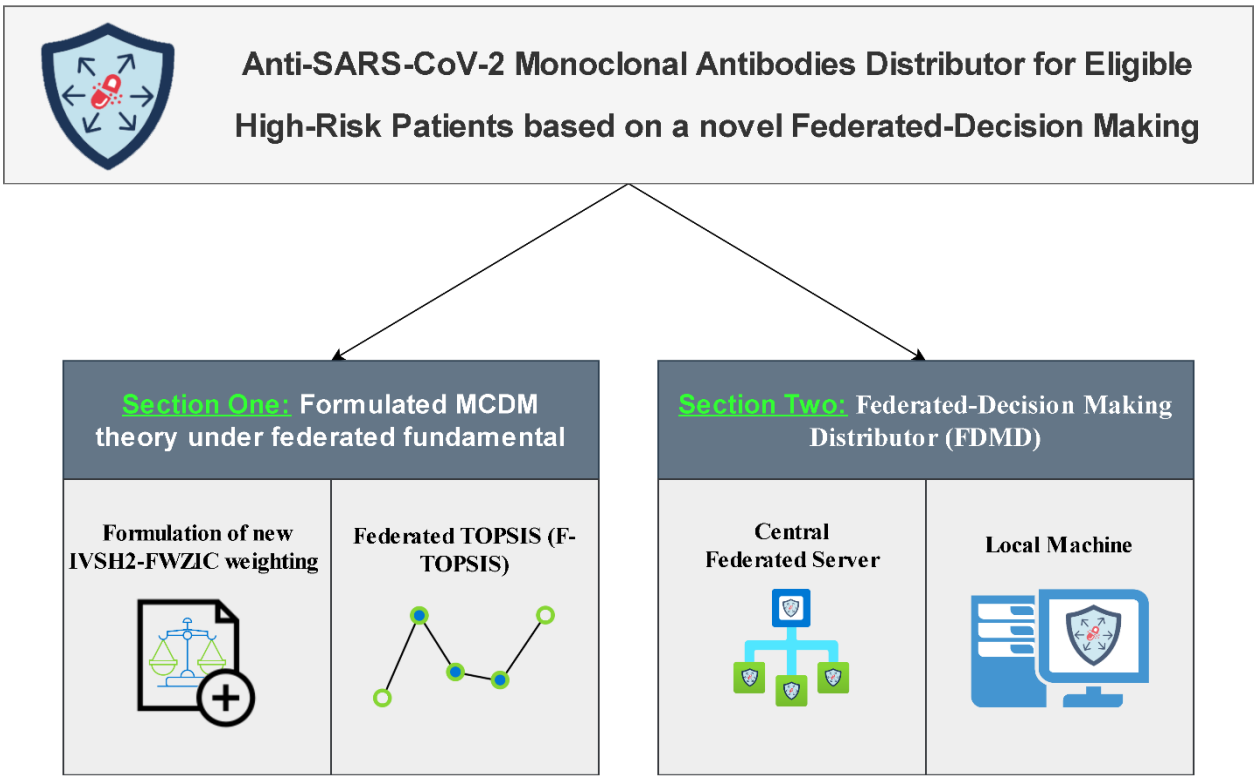

Figure 3. 1 An overview of the methodology structure of FDMD

3.2.1 Formulated MCDM theory under federated fundamental

The formulation of MCDM theory with the federated concept is presented in this section. The new formulation of the weighting method is discussed in addition to the proposed federated-TOPSIS, as below:

3.2.1.1 Formulation of IVSH2-FWZIC Weighting Method

The formulation of the IVSH2-FWZIC method proposed with a new fuzzy environment as an extension of original FWZIC (R. Mohammed et al., 2021), The IVSH2-FWZIC method consists of five phases for determining the high-risk criteria weight. (See Algorithm 1). The five phases are illustrated in detail below.

Phase 1: Criteria Definition

The same panel of experts reviewed and evaluated the selected high-risk criteria, as detailed of the criteria definition in the following Section 3.2.2.1.1.

Phase 2: Structured expert judgment (SEJ)

Domain specialists (researchers and doctors) are identified and chosen to assess the importance of the high-risk criteria defined in the first phase. Doctors/researchers having experience with anti-SARS-CoV-2 mAbs distribution criteria (high-risk criteria) are included in the target population. Five steps are required in this process:

i. **Experts' identification**: an expert is someone who has specialised knowledge in a certain field. To be called an 'expert on a given subject,' one must be recognised by others as having a thorough understanding of the topic in question, whether in their current or previous work. These individuals are sometimes referred to as 'domain' experts in the literature. All authors and co-authors of publications that have listed anti-SARS-CoV-2 mAbs distribution criteria were analysed bibliometrically as a basis for the expert selection approach used in the current study.

ii. **Experts' selection:** the individuals who would take part in the experiment were chosen after determining the group of experts. Generally speaking, the most experts possible given the resources available should be taken into account. Three experts were selected in this study. It was decided to reach out to all potential experts identified through email to see if there was any interest on their part and if they saw themselves as a good fit for the panel. After listing all the candidate experts, three experts worked to form the expert judging panel.

iii. **Assessment form development:** the design of an assessment form is an essential step because it serves as a means of obtaining consensus among experts. Before finalising the evaluation form in the current study, the questionnaire was tested for its validity and reliability. The form was examined by the three experts, who had been chosen in the prior step.

iv. **Degree of importance definition:** 5-point Likert scale was utilised to assess the significance/importance degree of each criterion by all the three experts.

v. Linguistic scale to numerical scale conversion: The data collected (linguistic scale) from each expert by the designed form cannot be employed for further analysis unless they are translated into their equivalent numerical scale (Table 3.1).

Table 3. 1 Linguistic scale and their equivalent numerical scale

Numerical scale	Linguistic scale
1	Not important
2	Slight important
3	Moderately important
4	Important
5	Very important

Phase 3: Building the Expert Decision Matrix (EDM)

The preceding phase outlines the process of selecting experts and expressing their preferences. In this phase, the EDM is built. The EDM's main components are the high-risk criteria of and the experts, as shown in Table 3.2.

Table 3. 2 EDM

Experts	C1	C2	…	Cn
E1	Im (E1/C1)	Im (E1/C2)	…	Im (E1/Cn)
E2	Im (E2/C1)	Im (E2/C2)	…	Im (E2/Cn)
E3	Im (E3/C1)	Im (E3/C2)	…	Im (E3/Cn)
...	…	…	…	…
Em	Im (En/C1)	Im (En/C2)	…	Im (Em/Cn)

**Im refer to the importance degree.

Crossovers are undertaken between all high-risk criteria and experts, as shown in Table 3.2. Each selective expert (Ei) crosses with Each criterion (Cj), where the experts have assigned the appropriate importance degree to all high-risk criteria. The EDM serves as the foundation for the proposed method's more analysis, which are demonstrated in the following subsections.

Phase 4: IVSH2 membership function Application

IVSH2's membership function and the defuzzification technique are performed on the EDM data, resulting in the data being turned into an IVSH2 EDM to improve the data's precision and simplicity of use in subsequent analysis. The problem is imprecise and ambiguous in MCDM; thus, it is challenging to assign an exact preference to a certain criterion. The use of vague numbers rather than precise numbers (crisp) is a benefit of the fuzzy method since it addresses the issue of imprecise and ambigsub-double-struck. The IVSH2 membership function is shown in Equations (1), and the following mathematical operations and defuzzification equation are defined by (Khan et al., 2021).

$$\mathbb{Z} = \{\langle g, M_{\mathbb{Z}}(g), L_{\mathbb{Z}}(g), K_{\mathbb{Z}}(g)\rangle \mid g \in \mathbb{R}\}$$

$$M_{\mathbb{Z}}(g) = \{\kappa \mid \kappa \in [0,1]\}, L_{\mathbb{Z}}(g) = \{\delta \mid \delta \in [0,1]\} \text{ and } K_{\mathbb{Z}}(g) = \{\partial \mid \partial \in [0,1]\}$$

$$0 \leq (\kappa^{+})^2 + (\delta^{+})^2 + (\partial^{+})^2 \leq 1, \text{ for all } g \in \mathbb{R} \quad (1)$$

$$\kappa^{+} = \bigcup_{\kappa \in M_{\mathbb{Z}}(g)} max\{\kappa\}, \delta^{+} = \bigcup_{\delta \in L_{\mathbb{Z}}(g)} max\{\delta\}, \text{ and } \partial^{+} = \bigcup_{\partial \in K_{\mathbb{Z}}(g)} max\{\partial\}$$

The applied IVSH2aggregation operation can be seen in Equation (2), (Khan et al., 2021).

$$WA_{SHF}^{(A)}(\mathbb{Z}_1, \mathbb{Z}_2, \ldots \mathbb{Z}_n) = \bigcup_{(k_s,\delta_g,\partial_g)\in(M_s,L_g,K_g)} \left\{ \sqrt{1 - \prod_{g=1}^{n} (1 - x_g^2)} \ , \prod_{g=1}^{n} (\delta_g) \ , \prod_{g=1}^{n} (\partial_g) \right\} \tag{2}$$

The division operation is performed using Equation (3), (Ashraf & Abdullah, 2020b).

$$\begin{aligned} &\tilde{A}_s \oslash \tilde{B}_s \\ &= \bigcup_{(k_\varepsilon,\delta_g,\partial_g)\in(M_g,L_\varepsilon,K_g)} \left\{ \left(\frac{(\mathrm{k}_1^2(2-\mathrm{k}_2^2)}{1-(1-\mathrm{k}_1^2)\cdot(1-\mu_2^2)} \right)^{\frac{1}{2}}, \frac{(\delta_1^2-\delta_2^2)^{\frac{1}{2}}}{(1-\delta_1^2\cdot\delta_2^2)^{\frac{1}{2}}}, \frac{(\partial_1^2-\partial_2^2)^{\frac{1}{2}}}{(1-\partial_1^2\cdot\partial_2^2)^{\frac{1}{2}}} \right\}, if \frac{\mu_2^2}{\mu_1^2} \\ &\geq \frac{1-\pi_2^2}{1-\pi_1^2}\frac{1+\pi_1^2}{1+\pi_2^2} \geq 1 \end{aligned} \tag{3}$$

Equation (4) depicts the equation of IVSH2 division on crisp values (Khan et al., 2021). Table 3.3 shows the linguistic scale with their equivalent IVSH2 fuzzy numbers.

$$\frac{\mathbb{Z}_1}{\lambda} = \bigcup_{(k_\varepsilon,\delta_g,\partial_g)\in(M_g,L_\varepsilon,K_g)} \left\{ \sqrt{1-(1-\kappa_1^2)^\lambda, (\delta_1)^\lambda, (\partial_1)^\lambda} \right\} \tag{4}$$

Equation (5) defines defuzzied (crisp) value of the IVSH2 fuzzy number (Khan et al., 2021) as following:

$$Sc(\mathbb{Z}_g) = \frac{2 + \sum_{g=1}^{n} x_g - \sum_{g=1}^{n} \delta_g - \sum_{g=1}^{n} \partial_g}{3} \quad (5)$$

Table 3. 3 Linguistic scale and their equivalent IVSH2 fuzzy numbers (Khan et al., 2021).

Linguistic scale	IVSH2								
	M			L			K		
	k_1	k_2	k_3	δ_1	δ_2	δ_3	∂_1	∂_2	∂_3
Not important	0.25	0.2	0.15	0.9	0.85	0.8	0.05	0.1	0.15
Low important	0.4	0.35	0.3	0.75	0.7	0.65	0.2	0.25	0.3
Medium importance	0.6	0.55	0.45	0.6	0.55	0.45	0.35	0.4	0.45
Important	0.75	0.7	0.65	0.4	0.35	0.3	0.2	0.25	0.3
Very important	0.9	0.85	0.8	0.25	0.2	0.15	0.05	0.1	0.15

According to Table 3.3, all linguistic terms are translated to IVSH2, where the fuzzy number serves as the variable assigned by each expert to define the importance degree of the criteria.

Phase 5: Determination of the final values of the high-risk criteria's weight coefficients

This phase calculates the final weight values of the high-risk criteria $(w1, w2, \ldots, wn)^T$ using the fuzzification data from the previous phase.

a) The fuzzification data ratio is calculated using equations (2) and (3); these equations are applied with IVSH2, the symbolic form of the process is shown in Table 3.4 and Equation (6).

Table 3. 4 IVSH2 EDM

Criteria/ Experts	$\widetilde{C1}$	$\widetilde{C2}$	…	$\widetilde{Cn}$
E1	$\frac{\mathrm{Im}(\widetilde{E1/C1})}{\sum_{j=1}^{n} \mathrm{Im}(\widetilde{E1/C_{1j}})}$	$\frac{\mathrm{Im}(\widetilde{E1/C1})}{\sum_{j=1}^{n} \mathrm{Im}(\widetilde{E1/C_{1j}})}$	…	$\frac{\mathrm{Im}(\widetilde{E1/C1})}{\sum_{j=1}^{n} \mathrm{Im}(\widetilde{E1/C_{1j}})}$

E2	$\frac{\mathrm{Im}(\widetilde{E2/C1})}{\sum_{j=1}^{n}\mathrm{Im}(\widetilde{E2/C_{2j}})}$	$\frac{\mathrm{Im}(\widetilde{E2/C2})}{\sum_{j=1}^{n}\mathrm{Im}(E2/C_{2j})}$	…	$\frac{\mathrm{Im}(\widetilde{E2/Cn})}{\sum_{j=1}^{n}\mathrm{Im}(E2/C_{2j})}$
…	…	…	…	…
Em	$\frac{\mathrm{Im}(\widetilde{Em/C1})}{\sum_{j=1}^{n}\mathrm{Im}(\widetilde{Em/Cm_j})}$	$\frac{\mathrm{Im}(\widetilde{Em/C2})}{\sum_{j=1}^{n}\mathrm{Im}(\widetilde{Em/C_{mj}})}$	…	$\frac{\mathrm{Im}(\widetilde{Em/Cn})}{\sum_{j=1}^{n}\mathrm{Im}(\widetilde{Em/C_{mn}})}$

$$\frac{Im(\widetilde{E1/C1})}{\sum_{j=1}^{n} Im(\widetilde{E1/C_{1j}})} \quad (6)$$

where $Im(\widetilde{E1/C1})$ refer to the fuzzy number of *Im(E1/C1).*

b) The mean values are calculated to obtain the final fuzzy values for the high-risk criteria's weight coefficients $(\widetilde{w1}, \widetilde{w2}, \ldots, \widetilde{wn})^T$. The IVSH2 EDM is utilised to compute the final weight values for high-risk criteria via equation (4),where Equation (7) represents the symbolic form of the process.

$$\widetilde{W}_{j=} \left(\sum_{i=1}^{m} \frac{Im(\widetilde{E_{ij}/C_{ij}})}{\sum_{j=1}^{n} Im(\widetilde{E_{ij}/C_{ij}})}\right)/m\ ), \text{ where } i = 1,2,3,..m \text{ and } j = 1,2,3,..n\,. \quad (7)$$

c) To determine the final weight, defuzzification is performed using Equation (5). Weight should be assigned to each criterion by summing the weight values of all the criteria for rescaling purposes.

Algorithm 1: Weighting the Criteria using IVSH2-FWZIC

Phase 1: Define the criteria:

identify $C[i]$ *// C represent the defined high-risk criteria*

Phase 2: SEJ

Define E[i] *// E represent the potential experts who have been nominated.*

Define EF, Im *// establishing and building the assessment form with the degree of importance (Im) for the criterion.*

m ← length (E)

For i in {1..m}

if E(i) is true then E(i) ← EF(i) *// The assessment form of the high-risk criteria is given to each expert who promised to participate in the study.*

endif

endfor

Phase 3: Building EDM

Initialize $EDM[i,j] \leftarrow E \uplus C$ *// A crossover between the identified experts and the high-risk criteria is performed in this step to construct the EDM.*

J ← length (C)

m ← length (E)

For j in {1..J}

For i in {1..m}

$\mathrm{EDM}\,[i,j] \leftarrow \mathrm{Im}\left(E_{ij}/C_{ij}\right)$ *// The collected data (degree of importance) from all experts for each criterion is assigned in EDM.*

endfor

endfor

Phase 4: IVSH2 fuzzy membership function application:

For j in {1..J}

For i in {1..m}

$\tilde{EDM}[i,j] \leftarrow EDM[i,j]$ *// The linguistic scale of the EDM is transformed into an IVSH2 EDM ($\tilde{EDM}$) by using IVSH2 fuzzy as shown in Equation (1) and Table 3.3*

endfor

endfor

The EDM's linguistic scale is converted to an IVSH2 EDM using an IVSH2 fuzzy numbers like in Equation (1) and as shown in Table 3.3.

Phase 5: Calculate the final weights for all criteria:

Phase 5.a: Find ratio value

For j in {1..J}

For i in {1..m}

$$\tilde{E}_{ij} : \tilde{C}_{ij} = \frac{\mathrm{Im}\left(\tilde{E}_{ij}/\tilde{C}_{ij}\right)}{\sum_{j=1}^{n} \mathrm{Im}\left(\tilde{E}_{ij}/\tilde{C}_{ij}\right)}$$ *//The fuzzification data ratio is obtained using Equations (2) and (3), which are expressed in Equation (6)*

endfor

endfor

Phase 5.b: Find the final fuzzy weight:

For j in {1..J}

For i in {1..m} //The mean values are calculated to obtain the final weight's fuzzy values using

$\tilde{w}_j = \sum_{i=1}^{m} \tilde{E}_{ij} : \tilde{C}_{ij}/m$ Equation (4) in a manner similar to that described in Equation (7).

$w[j] \leftarrow (2 + \sum_{g=1}^{n} x_g - \sum_{g=1}^{n} \delta_g - \sum_{g=1}^{n} \partial_g) / 3$ *// Using Equation (5), a defuzzification is performed to determine the final weights.*

Endfor

Endfor

3.2.1.2 Proposed of Federated TOPSIS (F-TOPSIS)

In this section, the proposed F-TOPSIS is introduced; this includes an overlapping between the concept of federated fundamental and MCDM context to come out with federated prioritisation method that can guarantee the accuracy of the final decision and data privacy protection over the distribution process between the federated central server (CFS) and local machine (LM). The main contribution of this proposed method, F-TOPSIS is the unification of the positive and negative ideal vectors that compute at server side and provided to all LMs, with the preliminary settings. While each LM used it for the local prioritisation process and sent back to the server for combining and computing the global prioritisation ranks for each alternative (i.e. patients) over the LM networking. This sequence synchronised process of F-TOPSIS that implemented between CFS, and LM consist of eight steps as below:

Step 1: Proposed the Dynamic Decision Matrix (DDM) locally

At each LM, the DDM is constructed based on crossover the high-risk criteria and eligible treatment patients as demonstrated in Table (3.5) using Equation (8).

Table 3. 5 DDM matrix

Alternatives	C1	C2	-	-	Cm

A1	C1/A1	C2/A1	-	-	Cm/A1
A2	C1/A2	C2/A2	-	-	Cm/A2
A3	C1/A3	C2/A3	-	-	Cm/A3
.	-	-	-	-	-
.	-	-	-	-	-
An	C1/An	C2/An	-	-	Cm/An

$a^k{}_{ij} where\ i = 1 \ldots n, j = 1 \ldots m\ and\ k = 1 \ldots K$

K: represent the number of the local machine

n: represent the number of alternatives

m: represent the number of criteria (8)

Step 2: Allocation of DDM values locally

In this step, the evaluation of each alternative related to each criterion is allocated following the evaluation procedure that was set up before, as mentioned in phase one, using Equation (9).

$a^k = a^k{}_{ij}\ , where\ i = 1 \ldots n, j = 1 \ldots m\ and\ k = 1 \ldots K$

K: represent the number of the local hospital

n: represent the number of patients

m: represent the number of criteria (9)

Step 3: Unified the local positive and negative vectors at CFS

In the third step, the positive and negative ideal vectors are determined for each registered LM and sent to the CFS to be unified as federated positive and negative ideal values using equations (10 and 11), (Tang & Fang, 2018) the equation generalised for all $a^{k}{}_{j}^{+}$ and $a^{k}{}_{j}^{-}$ for all LM.

$$\begin{cases} a^{k}{}_{j}^{+} = \left\{ \underset{1\le i\le n}{max}\, a^{k}{}_{ij} \mid j \in j^{+}, \underset{1\le i\le n}{min}\, a^{k}{}_{ij} \mid j \in j^{-} \right\} \\ a^{k}{}_{j}^{-} = \left\{ \underset{1\le i\le n}{min}\, a^{k}{}_{ij} \mid j \in j^{+}, \underset{1\le i\le n}{max}\, a^{k}{}_{ij} \mid j \in j^{-} \right\} \end{cases} \quad (10)$$

$$\begin{cases} a^{g}{}_{j}^{+} = \left\{ \underset{1\le k\le K}{max}\, a^{k}{}_{j}^{+} \mid j \in j^{+}, \underset{1\le k\le K}{min}\, a^{k}{}_{j}^{+} \mid j \in j^{-} \right\} \\ a^{g}{}_{j}^{-} = \left\{ \underset{1\le k\le K}{min}\, a^{k}{}_{j}^{-} \mid j \in j^{+}, \underset{1\le k\le K}{max}\, a^{k}{}_{j}^{-} \mid j \in j^{-} \right\} \end{cases} \quad (11)$$

the equation (11) generalised the $a^{k}{}_{j}^{+}$ and $a^{k}{}_{j}^{-}$ for all LMs in federate negative and positive ideal vectors. Where $a^{g}{}_{j}^{+}$ is max value over all local max values, and $a^{g}{}_{j}^{-}$ is min value over all local min values

Step 4: Normalisation.

At step three the evaluated decision matrix at each local machine is normalised using Equation (12), (Tang & Fang, 2018) based on the federated positive and negative ideal values and β interval value that sent by CFS.

$$b^k{}_{ij} = \frac{a^k{}_{ij} - a^{g^+}_j}{a^{g^+}_j - a^{g^-}_j} \times \beta + (1-\beta), \text{ where } \quad 0 < \beta < 1 \text{ and } k = 1, \dots, K \tag{12}$$

Step 5: Application of external weight values

In step four, the provided weight of each criterion as mentioned in phase one is applied on the normalised decision matrix at each LM, using Equation (13), (Tang & Fang, 2018).

$$y^k{}_{ij} = b^k{}_{ij} \cdot \omega_j, where \quad i = 1, \dots, m; j = 1, \dots, n \tag{13}$$

Step 6: Closeness determination

In this step, the positive and negative ideal solutions are defined using Equation (14), (Tang & Fang, 2018) at LM.

$$y^* = [1,1, \dots, 1]^T_n, \qquad y_* = (0,0, \dots, 0)^T_n \tag{14}$$

Step 7: Ranking the alternatives

In this step, the ranking of alternatives computes locally at LM and combine and sort globally at server side. At LM the local score at each alternative compute using the thesis from each alternative y_i to positive ideal solution y* using equation (15), (Tang & Fang, 2018).

$$Pr^k\left(y^k{}_{ij}\right) = \frac{\sum_{j=1}^n y_j^* y^k{}_{ij}}{\sqrt{\sum_{j=1}^n \left(y_j^*\right)^2}} \tag{15}$$

Finally, the patient rank will set $X = \{x1, x2, \ldots, xm\}$ according to the value of $Pr^k\left(y^k{}_{ij}\right)$ ($i \in M$).

$$Pr = \bigcup_{k=1..K} Pr^k \tag{16}$$

Then the global rank is ordered the alternative $X = \{x^1, x^2, \ldots, x^k\}$ according to the value of Pr.

3.2.2 Federated-Decision Making Distributor (FDMD)

The formulation of the proposed novel FDMD to treat the high-risk COVID19 patients based on anti-SARS-CoV-2 mAbs is architected from two sides. The CFS side (the treatment provider) and LM side (hospital). The process at *the* CFS *side consists of five phases*. The first phase is the preliminary setting; in this phase, the high-risk criteria of COVID19 patients are identified then weighted using a new formulate weighting method named (IVSH2-FWZIC) method; in addition, the evaluation procedure of these criteria are determined in this phase. The second phase is the federation of the positive and negative ideal vectors. The local positive and negative ideals vectors from all local machines are unified in this phase. The confirmation of dose availability is triggered in phase three to all hospitals once the treatment dose is available. Phase four is the prioritisation of the patients; the received scores of each indexed patient from all hospitals are sorted and prioritised according to the available amount of treatment. The last phase (the fifth phase) is matching the patient eligibility for treatment distribution and alerting each hospital accordingly. The process at the LM side (hospital) consists of four phases that synchronised with the CFS side in this proposed methodology. The first phase is the criteria settings, and all registered hospitals

are provided with the criteria settings from the CFS. The high-risk criteria influencing the eligibility of SARS-COV-2 treatment distribution and its important weight with evaluation procedure are provided in this phase. In the second phase, the proposed dynamic decision matrix at each hospital is constructed based on the intersection between high-risk criteria of COVID19 patients and the eligible treatment recipients. This is followed by the patient's evaluation phase, is performed in six stages. In stage one, the provided evaluation procedure is implemented, the dataset augmentation is to be utilised in the proposed DDM in this study. The local positive and negative ideal vectors are determined in stage two. In the stage three, the evaluation DDM is normalised, while the weighted normalised DDM is computed in stage four. In stage five, the distance and closeness to the ideal solutions are calculated. The patient evaluation phase ends up when the patient's score and rank are computed. Finally, each hospital sends the patients' score with their index to the CFS side as a response to the acknowledgment of dose availability. The following sections go in detail information about each phase. Figure 3.2 summarizes the FDMD architecture of anti-SARS-CoV-2 mAbs on the eligible patients.

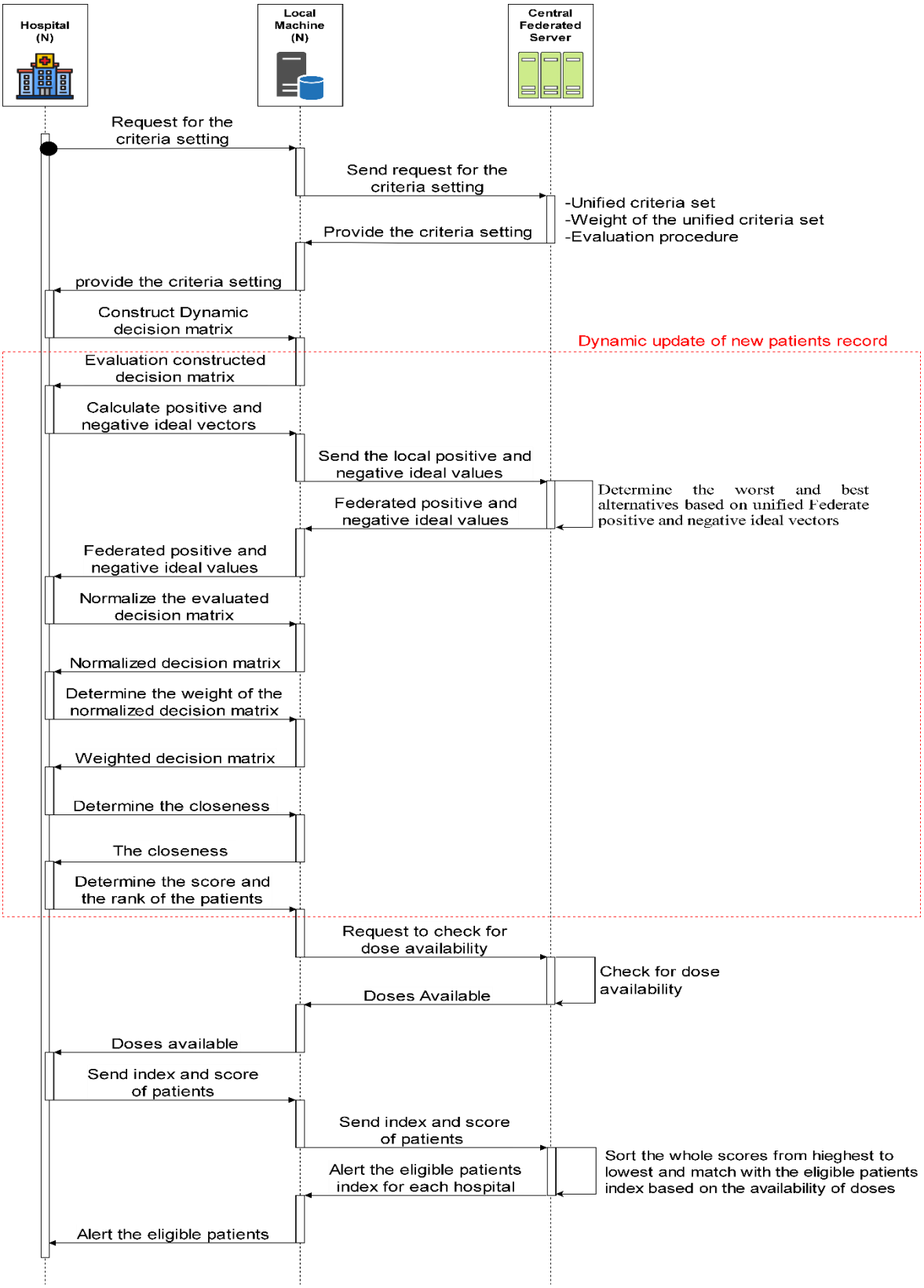
Hospital (N)
Local Machine (N)
Central Federated Server
Request for the criteria setting
Send request for the criteria setting
-Unified criteria set
-Weight of the unified criteria set
-Evaluation procedure
Provide the criteria setting
provide the criteria setting
Construct Dynamic decision matrix
Dynamic update of new patients record
Evaluation constructed decision matrix
Calculate positive and negative ideal vectors
Send the local positive and negative ideal values
Determine the worst and best alternatives based on unified Federate positive and negative ideal vectors
Federated positive and negative ideal values
Federated positive and negative ideal values
Normalize the evaluated decision matrix
Normalized decision matrix
Determine the weight of the normalized decision matrix
Weighted decision matrix
Determine the closeness
The closeness
Determine the score and the rank of the patients
Request to check for dose availability
Check for dose availability
Doses Available
Doses available
Send index and score of patients
Send index and score of patients
Sort the whole scores from hieghest to lowest and match with the eligible patients index based on the availability of doses
Alert the eligible patients index for each hospital
Alert the eligible patients

Figure 3. 2 FDMD flow diagram of anti-SARS-CoV-2 mAbs

3.2.2.1 Central Federated Sever

The process of evaluation at CFS consist of five main phases, the first phase is the preliminary settings, and this phase in return is a composite of three stages included criteria identification, a new formulation of the IVSH2-FWZIC method to compute the weight coefficients of the identified criteria, and evaluation procedure determination. This phase is followed by positive and negative ideal vectors federation and confirmation of treatment available in phases two and three, respectively. Phase four is the prioritisation of patients using F-TOPSIS. Lastly, matching the patient eligibility for treatment distribution based on doses availability in the fifth phase (See algorithm 2).

3.2.2.1.1 Phase one: Preliminary settings

In this phase, the preliminary setting is established. The output of this phase is the criteria settings to be sent to all registered hospitals. This consists of three stages:

Stage One: Identify the criteria set

The presentation and investigation of the evaluation criteria are the first step in the procedure. A deep analysis and collection have been conducted in this study based on the literature to identify the 15 high-risk criteria used to determine the urgency of a patient in the process of treatment distribution to the eligible SARS-COV-2 patients, which are:

Age (C1): The risk rises for individuals in their 50s and climbs in the 60s, 70s, and 80s. Individuals aged 85 and above are the most prone to get seriously sick. Other criteria can also make individuals

have severe symptoms with SARS-COV-2 , such as having certain underlying medical issues in elderly individuals (Brooke & Jackson, 2020).

Hypertension (C2): SARS-COV-2 surveillance data from throughout the world indicate that patients with high blood pressure are at an increased risk of SARS-COV-2 infections and medical problems. Additionally, data from both China and the United States indicate that hypertension is the most frequently shared underlying condition among people hospitalised with SARS-COV-2 infections (Ran et al., 2020).

Cardiovascular disease (C3): SARS-COV-2 exerts numerous impacts on the cardiovascular system, increasing morbidity in patients with pre-existing cardiovascular disease and causing dysfunction and myocardial injury (Clerkin et al., 2020).

Heart diseases (C4): the heart diseases such as coronary artery disease, heart failure, cardiomyopathies, and hypertension (perhaps high blood pressure) can increase individuals' risk of having severe symptoms from SARS-COV-2 (Abbasi, 2021).

Chronic respiratory disease (C5): Individuals with chronic respiratory diseases, especially chronic obstructive pulmonary disease, are at a greater risk of infection with SARS-COV-2 due to their diminished underlying lung reserve and elevated expression of the angiotensin-converting enzyme 2 (ACE-2) receptor in the small airways (Leung et al., 2020).

Obesity body mass index (C6): Obesity is a prevalent, severe, and costly chronic disease. Obesity raises a person's risk of developing a variety of other serious chronic diseases and increases the risk of getting severe symptoms from SARS-COV-2. Obesity is associated with lower lung capacity and reserve, poor immune function, and can exacerbate the difficulty of ventilation (Kompaniyets et al., 2021)

Chronic kidney disease (C7): Numerous studies have demonstrated an increased incidence of SARS-COV-2 disease among patients on dialysis or undergoing kidney transplantation, as well as a poor prognosis for SARS-COV-2 disease in these patients. SARS-COV-2 infection is highly connected with the dissemination of the infection in the community, although its lethality is associated with the underlying kidney disease and comorbidities. SARS-COV-2 -related mortality was approximately tenfold that of COVID19 patients who did not have the chronic renal disease (Gibertoni et al., 2021).

Diabetes (C8): SARS-COV-2 can cause more serious problems in diabetics. When infected with any virus, diabetics are more prone to suffer from more severe symptoms and complications. People with diabetes are more likely to be infected; rather, if they do, the condition is considerably more severe and appears to advance more rapidly (Hartmann-Boyce et al., 2020).

Immunosuppressive disease (C9): Immunosuppression is associated with a more severe SARS-COV-2 course, including an increased risk of in-hospital death or ICU admission, and many in-hospital complications (thromboembolic disease, ADRS, heart failure, bacterial pneumonia, myocarditis, and multiorgan failure) (Suárez-García, Perales-Fraile, González-García, Muñoz-Blanco, Manzano, Fabregate, Díez-Manglano, Aizpuru, Fernández, García, et al., 2021).

Receiving immunosuppressive treatment (C10): Patients with immune suppression (e.g. transplant recipients, cancer, or immunosuppressive treatments) may have a worse prognosis with SARS-COV-2. Immunosuppressed individuals hospitalised with SARS-COV-2 have a greater risk of death and various other in-hospital complications than non-immune suppressed patients (Suárez-García, Perales-Fraile, González-García, Muñoz-Blanco, Manzano, Fabregate, Díez-Manglano, Aizpuru, Fernández, García, et al., 2021).

Pregnant (C11): Pregnant and recently pregnant women are more prone than non-pregnant women to develop severe illness from SARS-COV-2. According to published reports, pregnant women responded more slowly to the SARS-COV-2 vaccine (Gray et al., 2021).

Sickle cell disease (C12): Patients with sickle cell disease are more likely to have a high incidence of numerous comorbidities, which can increase an individual's risk of severe illness and death from SARS-COV-2 (Singh et al., 2021).

Neurodevelopmental disorder (C13): Individuals with neurodevelopmental disorders disabilities who also have pre-existing medical issues may face serious sickness. Certain individuals who have a neurodevelopmental disorder may have difficulty accessing information, implementing or comprehending preventative actions, and communicating sickness symptoms (Rizzo et al., 2021).

Medical-related technological dependence (C14): Individuals who are dependent on medical technology for reasons other than SARS-COV-2, such as tracheostomy or positive pressure ventilation, may experience serious SARS-COV-2 symptoms. This case is considered a high-risk criterion for severe SARS-COV-2 infection in adolescents (FDA, 2021).

COVID-19 disease severity (C15): The virus causes mild to moderate respiratory sickness in the majority of individuals who contract it and recover without having special treatment. However, some will develop life-threatening illnesses and require medical intervention. Elderly and individuals with underlying medical diseases such as diabetes, cardiovascular disease, cancer, or chronic respiratory disease are at an increased risk of developing serious symptoms of COVID-19 (Di et al., 2020).

Stage Two: Determination of criteria weight using a new formulation of the IVSH2-FWZIC weighting method

In this stage, the importance of high-risk criteria set for SARS-COV-2 patients is computed using the formulation of the IVSH2-FWZIC method procedure as presented in section 3.2.1.1

Stage Three: Evaluation Procedure:

The evaluation procedure in this study is divided into two categories. The C1 and C15 (age and SARS-CoV-2 disease severity) are fitted to the categorical data, where age is separated into three categories: 18-55, 55-65, and 65 and above. Whereas SARS-CoV-2 disease is separated into two categories, Mild and Moderate, the remaining criteria C2 - C14 (hypertension, cardiovascular disease, heart disease, chronic respiratory disease, obesity body mass index, chronic kidney disease, diabetes, immunosuppressive disease, receiving immunosuppressive treatment, pregnant, sickle cell disease, neurodevelopmental disorder, and medical-related technological dependence) are conformed to logical (Boolean) value to indicate if the patient is diagnosed with these criteria or not (i.e. yes/no).

3.2.2.1.2 Phase Two: Federation of the positive and negative ideal vectors

The unification of positive and negative ideal vectors over all hospitals is computed in this stage to use for the normalisation process at each hospital. As mentioned in section 3.2.1.2

3.2.2.1.3 Phase Three: Confirmation of treatment availability

In phase three, the confirmation of treatment availability will send as a response to all registered hospitals once the treatment dose is available.

3.2.2.1.4 Phase Four: Prioritisation of the patients

With the availability of dose confirmation, the server receives back from each hospital the index and score of the patients. The CFS combines and sorts the whole scores from highest to lowest and match with the eligible patient's index based on the availability of doses using the united project Equation (16) presented in section 3.2.1.2

3.2.2.1.5 Phase Five: Matching the patient eligibility for treatment distribution

At last, the alert sends to each hospital that matches with the eligible patients' index based on the availability of doses. The priority distribution of treatment followed the amount of dose and the highest needs over all hospitals; each hospital received a different amount of doses based on their patient order in the global rank. The process of matching and distribution is modelled mathematically and presented in equation (17).

For hospital 1

$$a_{1,j\in m1} = \begin{cases} 1 & r_{i\in m} \leq TD \\ 0 & otherwise \end{cases}$$

For hospital 2

(17)

$$a_{2,j\in m2} = \begin{cases} 1 & r_{i\in m} \leq TD \\ 0 & otherwise \end{cases}$$

For hospital 3

$$a_{3,j\in m1} = \begin{cases} 1 & r_{i\in m} \leq TD \\ 0 & otherwise \end{cases}$$

.

.

.

For hospital k

$$a_{k,j\in mk} = \begin{cases} 1 & r_{i\in m} \leq TD \\ 0 & otherwise \end{cases}$$

Where a =1 mean assign dose for the patient and a =0 mean not assign dose for the patient and;

$m1$: a group of patients in hospital 1

$m2$: a group of patients in hospital 2

$m3$: a group of patients in hospital 3

m: group of patients in Server where $m = m1 + m2 + m3$+…. +mk

r: rank of patients in server

k: number of hospitals

a_1: binary variable for assign dose for patients

a_2: binary variable for assign dose for patients

a_3: binary variable for assign dose for patients

TD: Treatment Dose available

Algorithm 2: Central Federated Server

Step 1: Preliminary Setting:

Step 1.1: Input Criteria

identify $C[i]$ // *C represent the identified high-risk criteria*

Step 1.2: Compute Criteria weight

$w[j] \leftarrow$ **IVSH2-FWZIC** ($C[i]$) // *Use the IVSH2-FWZIC to compute the weight of criteria*

Step 1.3: Define Evaluation Procedure:

$C[i] \leftarrow v$ // *the value (v) of each criterion defined in this step*

Step 2: Unify ideal vectors:

Define K // *K is the set of all registered local machines in this case the hospitals*

k $\leftarrow$ length (K)

For i in $\{1..k\}$

$Fp = max(max(pos(i))$; // Fp *Federated positive ideal vector and* Fn *Federated negative ideal vector compute over all local positive and negative ideal vectors, referring to equation (11)*

$Fn = min(min(neg(i))$;

Endfor

Step 3: Confirm Dose availability

ACK message to K // Once dose be available, an acknowledge message (ACK) send to all LMs (K)

Step 3: Prioritise the alternatives

Step 3.1: Combine the alternatives

For i in $\{1..k\}$

For j in $\{1..m\}$

$GSC(i,j) \leftarrow GSC(i,j) \cup LSC(i)$; // *the Local Score (LSC) for each alternative index (a) per local machine (k) is combined in GSC, referring to equation (16)*

endfor

endfor

Step 3.2: Sort the alternatives

```
For i = 1 to n - 1                          // sorts the whole scores from highest to lowest and match with alternatives index
    Max = i
    For j = i+1 to n
     if GSC(j) > GSC(Max) then
Max = j;
     endif
     if indexMax != i  then
     swap GSC[Max] and GSC[i]
     endif
    endfor
endfor
```

Step 4: Matching the alternatives

```
For i = 1 to K
  For j = 1 to m
    if j <= D then
     I_GSC(i,j) ← 1;
    else
     I_GSC(i,j) ← 0;
  Endfor
endfor
For i = 1 to K
  For j = 1 to m
    If I_GSC(i,j) = 1 then
    H_P(i,j) ← TD
   endfor
   GH_P(i) ← H_P(i,j)..H_P(i,m)
Endfor
```

// Reserve the highest global ranks (i.e. the most eligible patients) based on the available doses (D) and send an alert to local machine (K) with the indication of the Group of eligible patient index (GH_P) for receiving treatment dose (TD), referring to equation (17).

3.2.2.2 Local Machine Side

The process of evaluation at the hospital side consists of four main phases, which are criteria setting, proposed dynamic decision-making matrix, patients' evaluation, lastly sending the index and score of patients. The subsequent subsections will discuss each phase in detail, along with the associated mathematical expressions. (See algorithm 3). On the basis of the proposed F-TOPSIS as mentioned in section 3.2.1.2

3.2.2.2.1 Phase one: Criteria setting

In this phase, each registered hospital is provided by CFS with criteria settings. This included three main settings: first, the unified of 15 criteria set; second, the important weight of each criterion; and the procedure of evaluation.

3.2.2.2.2 Phase Two: Proposed DDM

The proposed DDM (a^k) per hospital (k) is constructed based on the intersection of the high-risk unified criteria of the SARS-COV-2 patients from phase one with the admitted patients as alternatives. The DDM is presented in Table 3.6. As explained in Section 3.2.1.2

Table 3. 6 DDM used in SARS-COV-2 patients' evaluation

Patients	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
P1	C1/P1	C2/P1	C3/P1	C4/P1	C5/P1	C6/P1	C7/P1	C8/P1	C9/P1	C10/P1	C11/P1	C12/P1	C13/P1	C14/P1	C15/P1
P2	C1/P2	C2/P2	C3/P2	C4/P2	C5/P2	C6/P2	C7/P2	C8/P2	C9/P2	C10/P2	C11/P2	C12/P2	C13/P2	C14/P2	C15/P2
P3	C1/P3	C2/P3	C3/P3	C4/P3	C5/P3	C6/P3	C7/P3	C8/P3	C9/P3	C10/P3	C11/P3	C12/P3	C13/P3	C14/P3	C15/P3
.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pn	C1/Pn	C2/Pn	C3/Pn	C4/Pn	C5/Pn	C6/Pn	C7/Pn	C8/Pn	C9/Pn	C10/Pn	C11/Pn	C12/Pn	C13/Pn	C14/Pn	C15/Pn

The proposed DDM is constructed based on the crossover between the unified criteria (C1 (age), C2 (Hypertension), C3 (Cardiovascular disease), C4 (Heart disease), C5 (Chronic respiratory disease), C6 (Obesity Body Mass Index), C7 (Chronic Kidney disease), C8 (Diabetes), C9 (Immunosuppressive disease), C10 (Receiving immunosuppressive treatment), C11 (Pregnant), C12 (Sickle cell disease), C13 (Neurodevelopmental disorder), C14 (Medical-related technological dependence), C15 (COVID-19 disease severity) and the SARS-COV-2 admitted patients at each hospital separately. The value of each criterion of all patients is defined according to the provided evaluation procedure as mentioned earlier. This procedure will be presented in detail in the following phase.

3.2.2.2.3 Phase Three: Patient evaluation phase:

In this phase, patient scoring per hospital is presented, and iteration is dynamically updated with the newly admitted patients with each cycle of dose availability. This phase is composite of six stages:

Stage one: Evaluation of the Constructed DDM:

In this stage, each patient's evaluation in relation to each criterion is allocated following the evaluation procedure set up before, as mentioned in phase one. In this phase, 49,152 cases of SARS-COV-2 patients with a mild and moderate level of emergency were generated. For proof of concept, 16 cases from each hospital were presented through the methodology processing phases. However, generalisation and inclusion of more than 49,152 cases are conceivable; insights from the produced cases typically satisfy the stated methodology's concepts, from which the findings can then meet the desired goals. Based on the fifteen criteria, MATLAB was used to produce the augmented dataset of the 49,152 cases based on the exception-handling model (Appendix A.7). As a proof of concept, generating the most appropriate probabilities for the identified alternatives and criteria can assist in achieving the study objective and overcoming the mentioned problems. Following that, this study considered certain assumptions concerning SARS-COV-2 patient alternatives. Additionally, the rule-based control scheme was based on experts' opinions who offered detailed descriptions of the criteria. Following the generation of the dataset, a panel of three experts subjectively assessed it (i.e. knowledge-driven outcomes) to maximise the data's authenticity and the reliability of the data to cover the majority of recipients' conditions. The panel of the three experts were selected and identified from related study field (i.e. immunology, molecular biology, medical biotechnology, biomedical engineering, and clinical microbiology).

Stage Two: Determination of the positive and negative ideal vectors

In the second stage, the positive and negative ideal vectors are determined for each registered hospital, followed by the proposed F-TOPSIS as mentioned in section 3.2.1.2

Stage Three: Normalising the evaluated DDM.

At stage three, the evaluated decision matrix at each local machine (hospital) is normalised based on the federated positive and negative ideal values and β interval values sent by CFS. as explained in Section 3.2.1.2

Stage Four: Weighted normalised DDM

In stage four, the provided weight of each criterion as mentioned in phase one was applied on the normalised decision matrix at each hospital, using Equation (14), (Tang & Fang, 2018). as explained in Section 3.2.1.2

Stage Five: Determination of ideal solutions

In this stage, the closeness to positive and negative ideal solutions for all patients at LM are determined, as explained in Section 3.2.1.2

Stage Six: Patient's score and ranking determination

In this stage, the local score at each hospital will compute using the project from each alternative as presented in section 3.2.1.2

3.2.2.2.4 Phase Four: Sending index and score of patients

All local machines (i.e. registered hospitals) send the patients' index and score to the CFS after the hospitals' request of dose availability confirmation is acknowledged by the last. This ensures that the patient medical record (data) is kept private and federated locally inside the hospital and isolated from the global prioritisation process of treatment distribution.

Algorithm 3: Local machine side

Step 1: Input the criteria setting:

$C[i] \leftarrow C$ *// assign the set of unified criteria that provided by CFS*

$w[j] \leftarrow w$ *// assign the weight of each criterion that provided by CFS*

$C[i] \leftarrow v$ *// assign the procedure of evaluation for each criterion based on defined evaluation procedure from CFE*

Step 2: Build DDM

Define P[i] *// P is the set of the admitted SARS-COV-2 patients*

Initialise $DDM[i,j] \leftarrow \mathrm{P} \uplus C$ *// A crossover between the admitted SARS-COV-2 patients and the high-risk criteria is conducted to build the DDM matrix, refereeing to Table (3.6)*

J $\leftarrow$ length (C)

p $\leftarrow$ length (P)

Step 3: Patient evaluation:

Step 3.1: Evaluate the Constructed DDM

For i in {1..p} *// applying the evaluation of each patient in related to each criterion is allocated following the evaluation procedure, referring to equation (9).*

For j in {1..j}

ED$^{\mathrm{DM}}[i,j] \leftarrow v(P_{ij}/C_{ij})$

endfor

endfor

Step 3.2: The positive and negative ideal vectors determination

p $\leftarrow$ length (P) *// K is the set of all registered local machines in this case the hospitals*

For i in $\{1..p\}$

$Lp = max(max(i));$

$Ln = min(min\ (i));$

Endfor

// L^p Local positive ideal vector and L^n Federated negative ideal vectors, referring to equation (10)

Step 3.3: Normalise the EDDM:

For i in {1..p}

For j in {1..j}

$$N\_EDDM(i,j) = \frac{EDDM(i,j) - Fp(j)}{Fp - Fn} * \beta + (1-\beta)$$

//The normalisation of EDDM is computed using the Fp, Fn and β that determined at CFS refereeing to equation (12)

endfor

endfor

Step 3.4: Weight the Normalised EDDM:

For i in {1..p}

For j in {1..J}

$$WN\_DDM(i,j) = w[j] * N\_EDDM(i,j)$$

//The weighted normalised EDDM (WN_DDM) compute refereeing to equation (13)

endfor

endfor

Step 3.5: Determine distances and closeness:

For j in {1..p}

For i in {1..J}

// define the positive and negative ideal solution refereeing to equation (14)

$$y^*(j) \leftarrow WN\_DDM(i,j)$$

$$y_*(j) \leftarrow WN\_DDM(i,j)$$

endfor

endfor

Step 3.6: Compute the patients score and rank:

For j in {1..p}

For i in {1..J}

// the local score at each LM compute, referring to equation (15)

$$PS(i,j) = \frac{y^*(j) * WN\_DDM(i,j)}{Sqrt(power(Sum(\ y^*(j)))}$$

endfor

endfor

Step 4: Send the patients' index and score:

For i in {1..p}

// send the patients' index and score to CFS

CFS $\leftarrow PS(i,j)\ and\ indexPS(i,j)$

endfor

3.3 Validation and Evaluation procedures

The results of the prioritisation of eligible treatment patients based on IVSH2-FWZIC are tested and evaluated using three assessment processes. Two main procedures will be used to validate the results of FDMD methodology, namely, sensitivity analysis assessment and systematic analysis assessment. In Section 3.3.1, sensitivity analysis assessment will be used to investigate the effect of altering the weight values for 15 high-risk criteria on the ranking results across nine scenarios. The second assessment will be explained in Section 3.3.2 will be used to examine whether or not eligible patients per DDM for each group are subjected to systematic ranking. However, in term of evaluation procedure methods of comparative analysis assessment will be applied between the FDMD and available MCDM is explained in section 3.3.3.

3.3.1 Procedure of Sensitivity analysis

Sensitivity analysis is one of validation assessment that would be applied in this study.Multicriteria models' results can be significantly influenced by the weights assigned to the different criteria. Thus, examining the impact of changing the weights of the high-risk criteria on the proposed method's results is a reasonable step toward determining the method's robustness and the produced results. Therefore, this section of the study conducts the procedure of sensitivity analysis of patient ranks to changes in criteria weights that will be applied and the results will be presented in chapter 4. Sensitivity analysis begins with the identification of the most important criterion as determined by the IVSH2-FWZIC method. After that, Equation (18) was used to produce nine scenarios using the relative weights of criteria to investigate the impact of adjusting these weights Pamucar et al.

(2020). Moreover, the elasticity coefficient (α_c) will be used to calculate the relative change of each criterion over the most essential one and the upper and lower bounds for adjusting the most important criterion weight were identified. Finally, the ranks produced by adjusting the criteria weights in the created scenarios were compared to the rank generated by the IVSH2-FWZIC.

$$w_c = (1 - w_s) \times (w_c^o / W_c^0) = w_c^o - \Delta x \alpha_c, \tag{18}$$

Where w_s is the most important criteria. w_c^o is the weight values calculated by the IVSH2-FWZIC method. W_c^0 is the summation of weight generated by IVSH2-FWZIC. Δx is the alterations range applied to the weights of the high-risk distribution criteria, which are the upper and lower bounds of the most important criteria. In addition, the Spearman correlation coefficient (SCC) will be used to perform a statistical analysis of the correlations between the nine scenarios and the rank results of IVSH2-FWZIC for the local machine. Results will be discussed in (Section 4.8.1).

3.3.2 Procedure of Systematic ranking assessment

In the second assessment (objective assessment), the prioritised patients at LM and CFS will be separated into different groups based on their prioritising sequence to assess the prioritisation results of patients who are eligible for treatment. Many researchers (Abdulkareem, Arbaiy, Zaidan, Zaidan, Albahri, Alsalem, & Salih, 2020; Abdulkareem et al., 2021; O. Albahri et al., 2021; Kalid et al., 2018; Khatari et al., 2021; Zughoul et al., 2021) have carried out similar assessment to evaluate their MCDM methods in the literature. The patient prioritisation results are validated by separating the patient into different groups and conducting a validation process. Each group

contained several patients. Within each group, the patients' number varies according to the overall number of patients at the LM and CFS. Notably, (Abdulkareem, Arbaiy, Zaidan, Zaidan, Albahri, Alsalem, & Salih, 2020; K. Mohammed et al., 2020) indicated that the number of groups or patients used in the evaluation has no effect on the evaluation results. However, the last groups should have the greatest number of patients. The grouping of eligible patients for treatment can be validated in the following steps:

i. All weighted or normalised matrix are aggregated to produce a unified weighted or normalised matrix.
ii. The eligible treatment patients within the unified weighted or normalised matrix are ordered based on the prioritisation results.
iii. After sorting, the eligible patients for treatment were separated into three groups.
iv. Following that, the means are computed for each group to ensure that the patients were subject to a systematic order (Equation 19).

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \tag{19}$$

The comparisons were conducted based on the resulting mean of each group. The 1st group in the LM and CFS must receive the highest mean value to make sure that the ranking results were systematically ranked. The 2nd group's mean must then be equal or greater than to that of the 3rd group and equal or less than to that of the 1st group. The same strategy must be followed for the remaining groups, with each group having a mean value equal or greater than to that of the next

group but equal or less than to that of the previous group. The results of this assessment are presented in subsections for LM (Section 4.8.2.1) and CFS (Section 4.8.2.2).

3.3.3 Procedure of comparison analysis

In term of evaluation assessment, the robustness of the proposed methodology (FDMD) will be presented in section 4.3 in compared to the available MCDM method (T. J. Mohammed et al., 2021). The two main concerns of treatment distribution for patients with SARS-CoV-2 over hospitals networking will be discussed. These two main challenges will be used as benchmark checklist of achievement comparison from two aspects. First the application aspect in the medical field, more specific the available method or procedure in handling SARS-COV-2 treatment distribution issues over the hospital networking in compared to the proposed one (FDMD), and second the theoretical aspects, in term of the privacy and prioritisation challenges. The benchmarking check list will be presented in Table 4.10.

3.4 Conclusion

This chapter focuses on the research methodology employed to achieve the study objectives. Two main sections in the methodology presented the applied steps for the novel FDMD, namely, Formulated (MCDM) theory under federated fundamental and (FDMD) Federated decision making distributor, respectively. In the first section 3.2.1, the new formulation of the weighting method consisted of five phases and all steps are discussed in section 3.2.1.1 as well as the proposed federated-TOPSIS consists of seven steps that mentioned in details in section 3.2.1.2. Moreover, in the second section 3.2.2 the formulation of the proposed novel FDMD to treat the high-risk COVID19 patients based on anti-SARS-CoV-2 mAbs is architected from two sides. The central

federated server (CFS) side that considered as treatment provider is consisted of five phases, namely, preliminary settings, federation of the positive and negative ideal vectors, confirmation of treatment availability, prioritisation of the patients and Matching the patient eligibility for treatment distribution, respectively. However, the local machine (LM) which is the hospital side is consisted four phases, the first phase is criteria setting, the second phase is proposed DDM, the third phase is patient evaluation phase and finally the fourth phase is sending index and score of patients. The summarizes the FDMD architecture of anti-SARS-CoV-2 mAbs on the eligible patients is illustrated in figure 3.2 and the detailed information about the phases presented in section 3.2.2.1 and section 3.2.2.2. Lastly, three procedures for evaluation and validation are applied in this chapter, namely, procedure of sensitivity analysis, procedure of systematic ranking assessment and procedure of comparison analysis and detailed information are explained in section 3.3.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction

This chapter reports the findings of evaluating the eligible treatment patients to formulate a mechanism for treatment distribution. The section 4.2 reports the IVSH2-FWZIC results to determine the criteria importance degree. Basically, the experts' preferences are transformed by mathematical computations to illustrate the overall high-risk criteria weights. The data augmentation results are reported in Section 4.3, followed by the DDM for the eligible treatment patients (Section 4.4). Section 4.5 presents the results of the positive and negative ideal vectors in the LM and CFS. Section 4.6 presents the results of the eligible treatment patient's score and ranking at LM using F-TOPSIS method. The patients' prioritisation results in the CFS are described in Section 4.7. The results of the prioritisation of eligible treatment patients based on IVSH2-FWZIC are tested and evaluated in section 4.8 using three assessment processes.

4.2 Results of High-Risk Criteria Weighting By Using IVSH2-FWZIC

This section discusses the weight impacts of the high-risk criteria using the IVSH2-FWZIC method outlined in Section 3.2.2.1. Based on the IVSH2-FWZIC's concept, the methods can be implemented in five steps. There is no inconsistency of the weighted criteria generated by IVSH2-FWZIC. Identifying the criteria (i.e. the fifteen high-risk criteria, Section 3.2.2.1.1) is the first phase of IVSH2-FWZIC's methodology. After that, the data are collected from each expert, as outlined in phase 2. Three domain experts have contributed their insight in assessing the degree of importance of all the high-risk criteria that have been collected through the designed assessment form. Then, as indicated in Table 3.1, the expert's preferences are transformed from the linguistic

terms into their equivalent numerical scale. Accordingly, the EDM is built based on Table 3.2 as explained in the third phase and shown in Table A1 in the Appendix. After that, the IVSH2 membership function is applied to convert all the precise numbers (crisp) of the EDM into the equivalent fuzzy numbers (Table A2 in the Appendix) as detailed in phase 4. The fuzzification process's result of the EDM is presented in Table A3 (Appendix). In phase 5a, the ratio values of the fifteen high-risk criteria are determined using Equations (2) and (3). To determine the final fuzzy weight (phase 5b), the mean of the experts' preferences for all the criteria is computed using Equation (4). In the end, the final weights for all the high-risk criteria are determined using Equation (5), as explained in phase 5c. The overall results of phase 5 are stated in Table A3 in the Appendix. The final weights of all high-risk criteria are listed in Table 4.1, from highest to lowest.

Table 4. 1 Criteria weighting result using IVSH2-FWZIC

Criteria	Weights
C1 = Age	0.1001
C15 = Covid-19 disease severity	0.0972
C9 = Immunosuppressive disease	0.0972
C5 = Chronic respiratory disease	0.0950
C10 = Receiving immunosuppressive treatment	0.0932
C3 = Cardiovascular disease	0.0903
C4 = Heart diseases	0.0903
C14 = Medical-related technological dependence	0.0861
C12 = Sickle cell disease	0.0849
C2 = Hypertension	0.0369
C7 = Chronic Kidney disease	0.0323
C8 = Diabetes	0.0323
C11 = Pregnant	0.0314
C6 = Obesity Body Mass Index	0.0194
C13 = Neurodevelopmental disorder	0.0137

The weighting results of fifteen high-risk criteria based on the extended IVSH2-FWZIC are shown in Table 4.1 The greatest importance weight (0.1001) was assigned to age (C1), followed by Covid-

19 disease severity (C15) and immunosuppressive disease (C9) with the same level of importance (0.0972). Chronic respiratory disease (C5) and receiving immunosuppressive treatment (C10) have slightly close weight values at (0.0950) and (0.0932), respectively. Cardiovascular disease (C3) and heart diseases (C4) have the same level of importance with a weight value of 0.0903. Medical-related technological dependence (C14) and sickle cell disease (C12) have relatively close weights to each other at 0.0861and 0.0849, respectively. Hypertension (C2) received the importance weight of 0.0369, however chronic kidney disease (C7) and diabetes (C8) received the same importance weight of 0.0323. Pregnant (C11) received the importance weight of 0.0314, whereas obesity Body Mass Index (C6) and neurodevelopmental disorder (C13) have close weight values at 0.0194 and 0.0137, respectively. The weight results of the proposed IVSH2-FWZIC demonstrate that the age criterion has a significant effect on the distribution of monoclonal antibody therapy with respect to the other criteria. The final prioritisation results for the eligible treatment patients can be accomplished, as to be described in Section 4.6. To prioritise the eligible treatment patients, weight values are required.

4.3 Data Augmentation Results

As discussed in Section 3.2.2.2.3, MATLAB was used to generate a dataset of 49,152 eligible treatment patients in the augmentation procedure. However, 48 cases from the eligible treatment patients' dataset are selected randomly in the present study, sixteen eligible patients with SARS-CoV-2 for each hospital, with the assistance of specialists. Tables 4.2 and A4 (Appendix) show sixteen samples of the selected cases for each hospital.

Table 4. 2 Samples of 16 eligible treatment patients' cases of the augmented dataset (hospital 1)

hospital 1															
Patients	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	**C12**	**C13**	**C14**	**C15**
P138	1	No	No	No	No	No	Yes	No	No	No	Yes	No	No	Yes	2
P4286	1	Yes	No	No	No	No	Yes	No	Yes	Yes	Yes	Yes	No	Yes	2
P6800	1	Yes	Yes	No	Yes	No	Yes	No	No	No	Yes	Yes	Yes	Yes	2
P6987	1	Yes	Yes	No	Yes	Yes	No	Yes	No	No	Yes	No	Yes	No	1
P17004	3	No	No	No	Yes	No	No	Yes	Yes	No	Yes	No	Yes	Yes	1
P17192	3	No	No	No	Yes	Yes	No	No	Yes	No	No	Yes	Yes	Yes	2
P22552	3	Yes	Yes	No	No	No	No	No	No	Yes	No	Yes	Yes	Yes	1
P7112	1	Yes	Yes	No	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	1
P20649	3	Yes	No	No	No	No	Yes	No	Yes	No	Yes	No	No	No	2
P24539	3	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes	No	1
P11109	2	No	Yes	No	Yes	Yes	No	Yes	Yes	No	No	Yes	No	No	1
P14106	2	Yes	No	Yes	Yes	Yes	No	No	No	Yes	Yes	No	No	Yes	2
P14372	2	Yes	Yes	No	No	No	No	No	Yes	No	No	No	Yes	Yes	1
P16066	2	Yes	Yes	Yes	Yes	No	Yes	Yes	No	No	No	No	No	Yes	2
P19639	3	No	Yes	Yes	No	No	Yes	No	Yes	Yes	No	Yes	Yes	No	1
P19761	3	No	Yes	Yes	No	Yes	No	No	Yes	Yes	No	No	No	No	1

The MATLAB model provided all conceivable patient scenarios, which can be extremely valuable for future studies, where the researchers in this domain can explore the various populations of the eligible treatment patients. Furthermore, the dataset contains a large number of noteworthy cases (alternatives/patients with different high-risk criteria) that can be tested in the distribution mechanisms. It is worth mentioning that the samples selected from the augmented dataset of eligible treatment patients will be applied to the proposed DDM as to will be explained in the following Section.

4.4 The results of evaluation constructed DDM

The evaluation results of the eligible treatment patients DDM are presented based on the intersection between the selected eligible treatment patients from each hospital (i.e. hospital 1,

hospital 2, and hospital 3) and the identified high-risk criteria (Table 3.6). The DDM is applied to the selected eligible treatment patients' cases of the augmented dataset (Section 4.3), where each value in the DDM indicated the evaluation of eligible treatment patients considering the high-risk criteria. The completed evaluation result of the eligible treatment patients' DDM is presented in Table 4.3.

Table 4. 3 The evaluation results of the eligible treatment patients DDM

	Hospital 1														
Patients	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	**C12**	**C13**	**C14**	**C15**
H1_P1	1	0	0	0	0	0	1	0	0	0	1	0	0	1	1
H1_P2	1	1	0	0	0	0	1	0	1	1	1	1	0	1	1
H1_P3	1	1	1	0	1	0	1	0	0	0	1	1	1	1	1
H1_P4	1	1	1	0	1	1	0	1	0	0	1	0	1	0	2
H1_P5	3	0	0	0	1	0	0	1	1	0	1	0	1	1	2
H1_P6	3	0	0	0	1	1	0	0	1	0	0	1	1	1	1
H1_P7	3	1	1	0	0	0	0	0	0	1	0	1	1	1	2
H1_P8	1	1	1	0	1	1	1	1	0	0	0	1	1	1	2
H1_P9	3	1	0	0	0	0	1	0	1	0	1	0	0	0	1
H1_P10	3	1	1	1	1	1	1	1	0	1	1	0	1	0	2
H1_P11	2	0	1	0	1	1	0	1	1	0	0	1	0	0	2
H1_P12	2	1	0	1	1	1	0	0	0	1	1	0	0	1	1
H1_P13	2	1	1	0	0	0	0	0	1	0	0	0	1	1	2
H1_P14	2	1	1	1	1	0	1	1	0	0	0	0	0	1	1
H1_P15	3	0	1	1	0	0	1	0	1	1	0	1	1	0	2
H1_P16	3	0	1	1	0	1	0	0	1	1	0	0	0	0	2

The first criterion (C1) in Table 4.3 represents the eligible treatment patients' age, which is divided into three categories ranging from one to three (i.e. 18-55, 55-65, and 65 and above, respectively), as detailed in Section 3.2.2.1.1. In addition, the zero and one in all other criteria except C15 (i.e. Covid-19 disease severity) represented the existence or absence of the criterion in the patient. However, the one and two in C15 represented Covid-19 disease severity (i.e. Mild or Moderate). For example, the age criterion of alternative H1_P7 is three, which represents the patients aged 65

and beyond. Furthermore, this patient is not affected by heart disease (C4), chronic respiratory disease (C5), obesity body mass index (C6), chronic kidney disease (C7), diabetes (C8), immunosuppressive disease (C9), and pregnant (C11). In contrast, the patient has hypertension (C2), cardiovascular disease (C3), sickle cell disease (C12), neurodevelopmental disorder (C13), was medical-related technological dependence (C14), and received immunosuppressive treatment (C10). Finally, the patient's last criterion C15 revealed that the severity of Covid-19 disease is moderate. On the other hand, other patients have different specifications for these criteria, making the distribution substantially more complicated, as indicated in chapter 1. As to be shown in the next sections, the novel MCDM method is capable of solving this challenge and providing a prioritising a mechanism for prioritising distribution progress.

4.5 The Positive and Negative Ideal Vector Results

This section explains the positive and negative ideal vector results of the LM (i.e. hospital 1, hospital 2, and hospital 3) and CFS. As detailed in Section 3.2.1.2, Equation 10 is used to calculate the local positive and negative ideal vectors for all the criteria at each hospital. Then, these vectors were submitted to the CFS, which unified them to calculate the federated positive and negative ideal vectors for each criterion using Equation 11. In the three selected hospitals, the positive ideal vector of the age criterion (C1) is three, representing the patients aged 65 and beyond. Whilst the negative ideal vector of the C1 is one, which represents the patients aged 18 to 55. For all other criteria except Covid-19 disease severity (C15), the positive ideal vector is one, which represents the eligible treatment patients who positively have these issues (e.g. obesity body mass index). However, the negative ideal vector for the same group of the criteria is zero, which represents the patients who do not have these issues. Finally, the positive ideal vector of the Covid-19 disease

severity criterion (C15) is two, which represents the moderate severity of the infection, while the negative ideal vector of the C15 is one, which represents mild severity infection. The positive and negative ideal vector results in the LM and CFS for all the selected criteria are shown in Table 4.4.

Table 4. 4 The Positive and Negative Ideal Vector results

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
Positive ideal hospital 1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	2
Negative ideal hospital 1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Positive ideal hospital 2	3	1	1	1	1	1	1	1	1	1	1	1	1	1	2
Negative ideal hospital 2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Positive ideal hospital 3	3	1	1	1	1	1	1	1	1	1	1	1	1	1	2
Negative ideal hospital 3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Federated positive ideal	**3**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**2**
Federated negative ideal	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**

As detailed in section 3.2.1.2, the positive and negative ideal vector results of each hospital are unified in the CFS to determine the federated positive and negative ideal vectors. As can be observed, the federated results of the positive and negative ideal vectors are consistent with those from the three hospitals. The CFS sent back the unified positive and negative ideal vectors to each hospital to prioritise the eligible treatment patients (section 4.6).

4.6 The Results of Patient's prioritisation at LM using F-TOPSIS

In this section, the results and discussions of the treatment distribution for high-risk SARS-COV-2 patients are reported. Where the most eligible patients to receive the treatment are prioritised. The generated weights of the evaluation criteria (Section 4.2) and the federate positive and negative ideal vectors (Section 4.5) are used for prioritising eligible patients based on the DDM (Table 4.3). Table A5 (appendix) shows the normalised matrices calculated based on the federated positive and

negative ideal vectors using Equations (12). Then, these matrices are utilised to calculate the weighted matrices using Equations (13), and the results of this step are presented in Table A6 in the appendix. After that, the scores of each alternative (the eligible treatment patients) are determined using Equations (15). Finally, the patient's rank is determined by the score value, where the highest score value refers to the highest-ranked patient. Overall ranking results of the eligible treatment patients at each hospital are presented in Table 4.5. In the present study, β values were set to 0.2, 0.4, 0.6, and 0.8 to examine the increase of the discrimination degree of alternatives (Tang & Fang, 2018).

Table 4. 5 The score and ranking results of the eligible treatment patient at the LM ($\beta = 0.2$)

Hospital 1			Hospital 2			Hospital 3		
Patients	**Scores**	**Ranking Results**	**Patients**	**Scores**	**Ranking Results**	**Patients**	**Scores**	**Ranking Results**
H1_P6	0.2668	1	**H2_P9**	0.2798	1	**H3_P9**	0.2794	1
H1_P15	0.2666	2	**H2_P4**	0.2725	2	**H3_P6**	0.2720	2
H1_P14	0.2650	3	**H2_P14**	0.2645	3	**H3_P14**	0.2702	3
H1_P12	0.2649	4	**H2_P8**	0.2624	4	**H3_P5**	0.2646	4
H1_P10	0.2639	5	**H2_P3**	0.2596	5	**H3_P10**	0.2636	5
H1_P2	0.2615	6	**H2_P5**	0.2596	6	**H3_P12**	0.2632	6
H1_P16	0.2610	7	**H2_P10**	0.2585	7	**H3_P8**	0.2628	7
H1_P3	0.2610	8	**H2_P13**	0.2583	8	**H3_P15**	0.2623	8
H1_P7	0.2597	9	**H2_P16**	0.2582	9	**H3_P13**	0.2587	9
H1_P11	0.2578	10	**H2_P2**	0.2577	10	**H3_P3**	0.2568	10
H1_P5	0.2563	11	**H2_P12**	0.2546	11	**H3_P2**	0.2555	11
H1_P8	0.2547	12	**H2_P1**	0.2544	12	**H3_P16**	0.2550	12
H1_P9	0.2523	13	**H2_P7**	0.2510	13	**H3_P1**	0.2545	13
H1_P13	0.2518	14	**H2_P6**	0.2495	14	**H3_P7**	0.2540	14
H1_P4	0.2445	15	**H2_P15**	0.2422	15	**H3_P4**	0.2516	15
H1_P1	0.2429	16	**H2_P11**	0.2375	16	**H3_P11**	0.2495	16

Table 4.5 present the ranking and scoring results of the three hospitals for $\beta = 0.2$. At hospital 1, the first ranked (highest rank) patient is H1_P6, who got the greatest score value of 0.2668.

H1_P6's criteria specifications are related to C1, C5, C6, C9, C12, C13, C14, and C15 (i.e. age, chronic respiratory disease, obesity body mass index, immunosuppressive disease, sickle cell disease, neurodevelopmental disorder, medical-related technological dependence, and covid-19 disease severity, respectively). Although H1_P6 has the highest criteria (C1, C5, and C9), where the weight of the age, chronic respiratory disease, and obesity body mass index criteria played significant influence in the process of decision-making and highly prioritised the patient. Thus, the rest of the criteria appeared to be varied in terms of significance. H1_P3, got the midst rank result (rank = 8), who acquired a score of (0.2610). The criteria specifications of H1_P3 are related to C2, C3, C5, C7, C11, C12, C13, and C14 (i.e. hypertension, cardiovascular disease, chronic respiratory disease, chronic kidney disease, pregnant, sickle cell disease, neurodevelopmental disorder, and medical-related technological dependence, respectively). This alternative received a satisfactory ranking result, and the specifications for the high-risk criteria are significant on average, thus granting the middle ranking priority. The lowest-ranked patient was H1_P1, who received a score value of (0.2429). The H1_P1' specifications criteria are related to C7, C11, and C14 (i.e. chronic kidney disease, pregnant, and medical-related technological dependence, respectively). Two of the three criteria have low importance levels, which explains why this patient (H1_P1) has a lower chance to receive the treatment.

At hospital 2, the patient with the highest ranking (rank = 1) is H2_P9, who received the highest score (0.2798). The criteria specifications of H2_P9 are related to C1, C2, C3, C4, C7, C9, C10, C11, C12, C14, and C15 (i.e. age, hypertension, cardiovascular disease, heart disease, chronic kidney disease, immunosuppressive disease, receiving immunosuppressive treatment, pregnant, sickle cell disease, medical-related technological dependence, and covid-19 disease severity, respectively). The midway ranking result (rank 8) received by H2_P13, who got a score value of

(0.2583). H2_P13's criteria specifications are related to C1, C2, C3, C6, C7, C11, C12, C14, and C15 (i.e. age, hypertension, cardiovascular disease, obesity body mass index, chronic kidney disease, pregnant, sickle cell disease, medical-related technological dependence, covid-19 disease severity, respectively). Despite the fact that this patient has an age criterion, however, the patient is aged from 55-65. The lowest ranked patient at hospital two was received by H2_P11, who had a score value of (0.2375). The H2_P9 criteria specifications are related to C2, C6, C7, C8, and C12 (i.e. hypertension, obesity body mass index, chronic kidney disease, diabetes, chronic respiratory disease, respectively).

Finally, the greater ranked patient at hospital 3 is H3_P9, who received a score of 0.2794. The criteria specifications of H3_P9 are related to C1, C2, C3, C4, C6, C8, C9, C10, C12, C14, and C15 (i.e. age, hypertension, cardiovascular disease, heart disease, obesity body mass index, diabetes, immunosuppressive disease, receiving immunosuppressive treatment, sickle cell disease, medical-related technological dependence, covid-19 disease severity, respectively). The H3_P15 patient is ranked in the middle of the results and has a score of (0.2623). H3_P15's criteria specifications are related to C1, C3, C5, C6, C9, C10, and C11 (i.e. age, cardiovascular disease, chronic respiratory disease, obesity body mass index, immunosuppressive disease, receiving immunosuppressive treatment, pregnant, respectively). The patient with the lowest ranking was H3_P11, who received a score of (0.2495). The criteria specifications of H3_P11 are related to C2, C3, C5, C8, and C10 (i.e. hypertension, cardiovascular disease, chronic respiratory disease, diabetes, and receiving immunosuppressive treatment)

Moreover, the experimental part that has done on a set of β values (i.e. 0.2, 0.4, 0.6, and 0.8) successfully increases the discrimination degree of alternatives. For instance, the scores differences

between H1_P6 and H1_P15 are 0.000155, 0.000309, 0.000464 and 0.000619 when $\beta = 0,2$, $\beta = 0.4$, $\beta = 0.6$ and $\beta = 0.8$, respectively. These results revealed that the degree of discrimination grows as the value of β increases. Table A.6 in the appendix presents the overall ranking results at the LM when β =0.4, 0.6, and 0.8.

Furthermore, the ranking results of the patients significantly are affected by each criterion weight (i.e. high-risk criterion). For example, the patient H1_P3 from hospital 1 has 8 criteria, which are hypertension (w = 0.0369), cardiovascular disease (w = 0.0903), chronic respiratory disease (w = 0.0950), chronic kidney disease (w = 0.0323), pregnant (w = 0.0314), sickle cell disease (w = 0.0849), neurodevelopmental disorder (w = 0.0137), and medical-related technological dependence (w = 0.0861). The patient H1_P4 from hospital 1 also has eight high-risk criteria, but with a few distinctions: hypertension (w = 0.0369), cardiovascular disease (w = 0.0903), Chronic respiratory disease (w = 0.0950), obesity Body Mass Index (w = 0.0194), Diabetes (w = 0.0323), pregnant (w = 0.0314), Neurodevelopmental disorder (w = 0.0137), Covid-19 disease severity (w = 0.0972). Although both patients have the same number of criteria, H1_P3 got highest rank (rank = 8) than H1_P3 (rank = 15). Thus, identifying the criteria importance is a necessary step to properly select and rank patients with highest risk criteria.

4.7 The prioritisation results of the eligible patients in the CFS

After the LM (i.e. hospitals) received a confirmation of the doses availability from the CFS, the LM sent the indexes and scores for all eligible treatment patients at each hospital to the CFS. These scores are unified (Equation 16) and sorted from the highest to the lowest as explained in section 3.2.2.1.4 and matched with the eligible patients' index based on the availability of doses. Table 4.6

shows the final sorted scores along with the eligible patients' index at the CFS when β =0.2. Let's assume that the CFS has seven doses of treatment available and the total number of patients from three hospitals at the CFS is 48 patients. Therefore, the treatment is assigned to the first seven prioritised patients in the CFS.

Table 4. 6 The results of the prioritised patients at the CFS

CFS											
Patients	**Scores**	**Ranking Results**	**Patients**	**Scores**	**Ranking Results**	**Patients**	**Scores**	**Ranking Results**	**Patients**	**Scores**	**Ranking Results**
H2_P9	0.2798	1	**H3_P10**	0.2636	13	**H2_P10**	0.2585	25	**H2_P1**	0.2544	37
H3_P9	0.2794	2	**H3_P12**	0.2632	14	**H2_P13**	0.2583	26	**H3_P7**	0.2540	38
H2_P4	0.2725	3	**H3_P8**	0.2628	15	**H2_P16**	0.2582	27	**H1_P9**	0.2523	39
H3_P6	0.2720	4	**H2_P8**	0.2624	16	**H1_P11**	0.2578	28	**H1_P13**	0.2518	40
H3_P14	0.2702	5	**H3_P15**	0.2623	17	**H2_P2**	0.2577	29	**H3_P4**	0.2516	41
H1_P6	0.2668	6	**H1_P2**	0.2615	18	**H3_P3**	0.2568	30	**H2_P7**	0.2510	42
H1_P15	0.2666	7	**H1_P16**	0.2610	19	**H1_P5**	0.2563	31	**H2_P6**	0.2495	43
H1_P14	0.2650	8	**H1_P3**	0.2610	20	**H3_P2**	0.2555	32	**H3_P11**	0.2495	44
H1_P12	0.2649	9	**H1_P7**	0.2597	21	**H3_P16**	0.2550	33	**H1_P4**	0.2445	45
H3_P5	0.2646	10	**H2_P3**	0.2596	22	**H1_P8**	0.2547	34	**H1_P1**	0.2429	46
H2_P14	0.2645	11	**H2_P5**	0.2596	23	**H2_P12**	0.2546	35	**H2_P15**	0.2422	47
H1_P10	0.2639	12	**H3_P13**	0.2587	24	**H3_P1**	0.2545	36	**H2_P11**	0.2375	48

At the CFS, there are three counters of the prioritised patients assigned to each hospital with respect to the available doses (i.e. seven doses), where the first counter represents the patients' number from hospital 1, the second counter represents the patients' number from hospital 2, and the third counter represents the patients' number from hospital 3. Therefore, the CFS sent an alert to hospital 1 to start treating the eligible patients (i.e. H1_P6 and H1_P15), hospital 2 to start treating H2_P9 and H2_P4, and hospital 3 to start treating H3_P9, H3_P6, and H3_P14.Those patients represent the top two most eligible patients at hospitals 1 and 2, as well as the top three most eligible patients

at hospital 3 (see Table 4.5). Table A.7 in the appendix presents the overall unified scores and ranks at the CFS when β =0.4, 0.6, and 0.8.

4.8 Validation and Evaluation the results

The results of the prioritisation of eligible treatment patients based on IVSH2-FWZIC are tested and evaluated in this section using three assessment processes. In term of validation, sensitivity analysis procedure and systematic ranking procedure are applied as mentioned in sections 3.3.1 and 3.3.2, respectively. The outcomes of sensitivity analysis for LM side and CFS side are done (Section 4.8.1) to investigate the effect of altering the weight values for 15 high-risk criteria on the ranking results across 9 scenarios. The second assessment is conducted (Section 4.8.2) to examine whether or not eligible patients per DDM for each group are subjected to systematic ranking. However, in term of evaluation, a comparative analysis procedure is made between the FDMD and available MCDM methods as mentioned in Section 3.3.3.

4.8.1 Sensitivity analysis results

According to section 3.3.1, the procedures of sensitivity analysis are applied and the result is presented in this section. The age (w = 0.1001) was the most important criterion (i.e. Table 4.1) among fifteen high-risk criteria. On this basis, the calculation of the relative weights of each criterion was done using Equation (18), yielding nine scenarios for adjusting the criteria weights . Table 4.7 presents the results of calculating the α_c for all the fifteen criteria. The limit values of the age criterion were $-0.1001 \leq \Delta x \leq 0.8999$.

Table 4. 7 High-risk criteria weights of the eligible treatment patients in nine scenarios for sensitivity analysis

Criteria	IVSH2-FWZIC	S1	S2	S3	S4	S5	S6	S7	S8	S9	α_c
C1	0.1001	0	0.125	0.25	0.375	0.5	0.625	0.75	0.875	0.9999	0.1113
C2	0.0369	0.041	0.0358	0.0307	0.0256	0.0205	0.0154	0.0102	0.0051	0	0.041
C3	0.0903	0.1003	0.0878	0.0752	0.0627	0.0502	0.0376	0.0251	0.0125	0	0.1003
C4	0.0903	0.1003	0.0878	0.0752	0.0627	0.0502	0.0376	0.0251	0.0125	0	0.1003
C5	0.095	0.1055	0.0924	0.0792	0.066	0.0528	0.0396	0.0264	0.0132	0	0.1055
C6	0.0194	0.0215	0.0188	0.0161	0.0135	0.0108	0.0081	0.0054	0.0027	0	0.0215
C7	0.0323	0.0359	0.0314	0.0269	0.0224	0.0179	0.0135	0.009	0.0045	0	0.0359
C8	0.0323	0.0359	0.0314	0.0269	0.0224	0.0179	0.0135	0.009	0.0045	0	0.0359
C9	0.0972	0.108	0.0945	0.081	0.0675	0.054	0.0405	0.027	0.0135	0	0.108
C10	0.0932	0.1035	0.0906	0.0776	0.0647	0.0518	0.0388	0.0259	0.0129	0	0.1035
C11	0.0314	0.0349	0.0305	0.0261	0.0218	0.0174	0.0131	0.0087	0.0044	0	0.0349
C12	0.0849	0.0943	0.0825	0.0708	0.059	0.0472	0.0354	0.0236	0.0118	0	0.0943
C13	0.0137	0.0153	0.0134	0.0114	0.0095	0.0076	0.0057	0.0038	0.0019	0	0.0153
C14	0.0861	0.0956	0.0837	0.0717	0.0598	0.0478	0.0359	0.0239	0.012	0	0.0956
C15	0.0972	0.108	0.0945	0.081	0.0675	0.054	0.0405	0.027	0.0135	0	0.108

The defined interval ranges were divided into nine sequences, each of which resulted in the creation of nine scenarios and the generation of new weight values, as illustrated in Table 4.7. The following sub-sections show the sensitivity analysis results of LM and CFS.

4.8.1.1 The results of Sensitivity analysis for the LM

This subsection discusses the sensitivity analysis of the ranking results for each hospital, as detailed in Section 4.8. The produced weights were utilised to assess the sensitivity of the prioritised eligible treatment patients. The purpose of this process is to ascertain the effect of altering the weight values on the final prioritising results in each of the nine scenarios. Figures A.1–A.3 in the Appendix demonstrate the changing impacts of the criteria weights on the ranks of eligible treatment patients.

Definitely, the weights assigned to high-risk criteria have a significant effect on the individual ranking of eligible treatment patients in some scenarios. The prioritisation of the eligible treatment patients based on IVSH2-FWZIC method demonstrates its effectiveness in the majority of the nine scenarios.

The ranks of the 16 eligible treatment patients per hospital were compared. For hospital 1, H1_P6 remained first in 7 scenarios (S2-S8) but dropped to the fifth and second rank in S1 and S9, respectively. H1_P15 only dropped to the sixth rank in S1 and had the same ranking results (rank = 2) as IVSH2-FWZIC in the remaining scenarios. H1_P11 remained stable in S3-S9, raised to the ninth rank in the first scenario, and dropped in the second scenario to the eleventh rank. H1_P8 remained stable in one scenario (S9) but dropped in seven scenarios (S2-S8), in the second scenario dropped to the thirteen rank and fourteen rank in S3-S8 while raised only in S1 to the eighth rank. Whereas H1_P13 raised in eight scenarios to the thirteen and eleventh ranks in S1 and S3-S9, respectively. Both H1_P4 and H1_P1 had the same ranking results (fifteen and sixteen, respectively) as IVSH2-FWZIC in all scenarios. All other patients in hospital 1 relatively changed their ranks, as shown in Figure A.1 in the Appendix.

For hospital 2, H2_P9 kept in the highest rank (rank = 1) in all scenarios. H2_P4 and H2_P5 retained the second and sixth ranks in the first and second scenarios, respectively, but dropped to seventh and eighth ranks in S3-S9, respectively. Both H2_P13 and H2_P6 remained stable in two scenarios and relatively changed in the rest scenarios. Where H2_P13 had the same rank as IVSH2-FWZIC in S2 and S9 and dropped to the tenth rank in the remaining scenarios. Whilst H2_P6 raised to the sixth and fifth ranks in S3-S8 and S9, respectively, and remained stable in S1 and S2. H2_P14, H2_P8, H2_P10, H2_P2, and H2_P7 had the same ranking results as IVSH2-FWZIC in one scenario only, and the rest scenario relatively changed. H2_P15 and H2_P11 maintained the

fifteen and sixteen ranks in S1-S8 and swapped their positions in S9. All other patients in hospital 2 relatively changed their ranks as illustrated in Figure A.2 in the Appendix.

For hospital 3, H3_P9 maintained the top position in all scenarios. H3_P6 and H3_P14 remained stable in S1, swapped their position in S2, and had the sixth and second rank in S3-S9, respectively. Both H3_P11 and H3_P13 had the same ranks as IVSH2-FWZIC in S2-S8, while H3_P11 raised to fourteen and fifteenth rank in S1 and S9, respectively, and H3_P13 dropped to the eleventh rank in S1and raised to eighth rank in S9. H3_P1remained stable in S1 only and dropped to the fourteenth and fifteenth rank in S2 and S3-S9, respectively. H3_P4 and H3_P16 retained their rank (fifteen and twelfth, respectively) in two scenarios only, where H3_P4 raised to tenth rank in S3-9 and H3_P16 dropped to thirteen and fourteen ranks in S2 and S3-8, respectively. All other patients in hospital 3 changed their ranks significantly, as demonstrated in Figure A.3 in the Appendix.

4.8.1.1.1 The results of Spearman correlation coefficient (SCC)

The Spearman correlation coefficient (SCC) was used to perform a statistical analysis of the correlations between the nine scenarios and the rank results of IVSH2-FWZIC [2] for the local machine. In general, the results indicated a high correlation between IVSH2-FWZIC and the nine scenarios, as illustrated in Figures A.4–A.6 in the Appendix.

The obtained correlation analysis results for the ranking of patients in hospital 1is shown in Figure A.4 (Appendix), which proved the high correlation (0.7-1.0) in eight over nine scenarios (S1-S8), whereas the remaining scenario (S9) had the SCC value of 0.6, with a mean value of 0.727 for all scenarios. The correlation analysis results of patients ranking in hospital 2 are shown in Figure A.5 in the appendix. In S1 and S2, SCC values were strong 0.9 in both scenarios, while the SCC value was 0.6 in the rest scenarios, with a mean value of 0.702 for all scenarios. Finally, Figure A.6

(Appendix) presents the correlation analysis result between IVSH2-FWZIC and the nine scenarios for hospital 3. Similar SCC values (0.9) were received in the first two scenarios; also, the SCC values were identical (0.7) in the remaining scenarios, with a mean value of 0.742 for all scenarios.

4.8.1.2 The results of Sensitivity analysis for the CFS

This subsection describes the findings of a sensitivity analysis conducted on the CFS, in which the highest seven out of 48 monoclonal antibody therapy patients were selected to explore the altering impact of the weights on the final prioritising results. Figure 4.1 shows the effects of changing the criteria weights on the ranks of eligible treatment patients in the CFS. Altering the weight had no impact on ranking the highest patient (i.e. H2_P9) in all scenarios. H2_P9 aged 65 and beyond (C1), and had hypertension (C2), cardiovascular disease (C3), heart disease (C4), chronic kidney disease (C7), immunosuppressive disease (C9), and sickle cell disease (C12), received immunosuppressive treatment (C10), was pregnant (C11), was medical-related technological dependence (C14), and had moderate severity of Covid-19 disease (C15). Whereas the highest second patient (i.e. H3_P9) kept the second rank in S1-S8 and raised to the first rank in S9. Where H3_P9 also aged 65 and beyond (C1), and had hypertension (C2), cardiovascular disease (C3), heart disease (C4), obesity body mass index (C6), diabetes (C8), immunosuppressive disease (C9), and sickle cell disease (C12), received immunosuppressive treatment (C10), and was medical-related technological dependence (C14). H2_P4 had consistent ranks during the weight change in the first and second scenarios, however, the ranks jumped down to the nineteenth rank in S3 to S9. H3_P6, H3_P14, H1_P6 and H1_P15 remained stable in one scenario but completely changed in the rest eight scenarios.

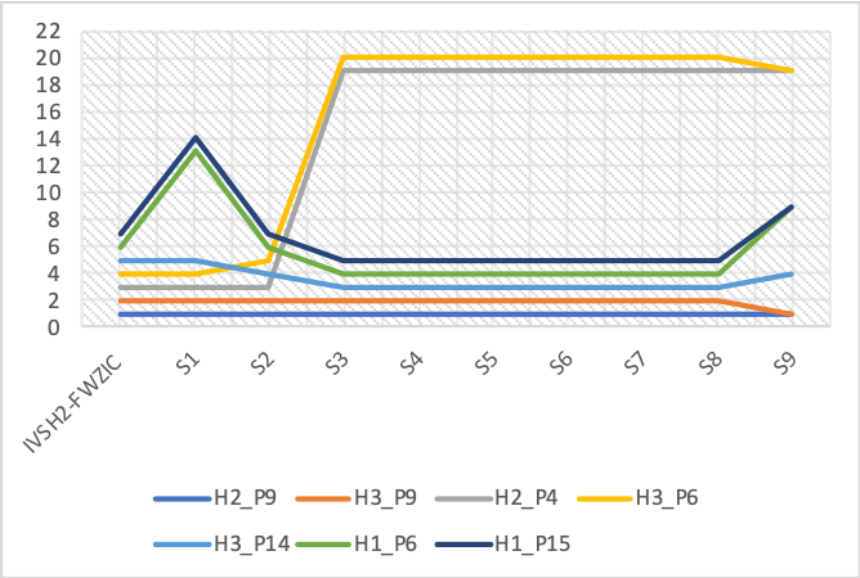

Figure 4. 1: Sensitivity analysis of the eligible treatment patients' ranking in the nine scenarios (CFS)

These results revealed that the criteria' weights play a key role in assigning the final ranking results. For instance, the Covid-19 disease severity (C15) and immunosuppressive disease (C9) criteria have the second and third highest weight using IVSH2-FWZIC (i.e. Table 4.1) however these two criteria significantly dropped in S3-S9. Consequently, the ranks greatly changed as can be clearly seen in the ranks of H2_P4 patient jumped down from third to nineteenth in S3-S9 (Figure 4.1). The SCC was calculated in the final part of this subsection to determine the relationship between the nine scenarios and the IVSH2-FWZIC rank results in the CFS as shown in Figure 4.2.

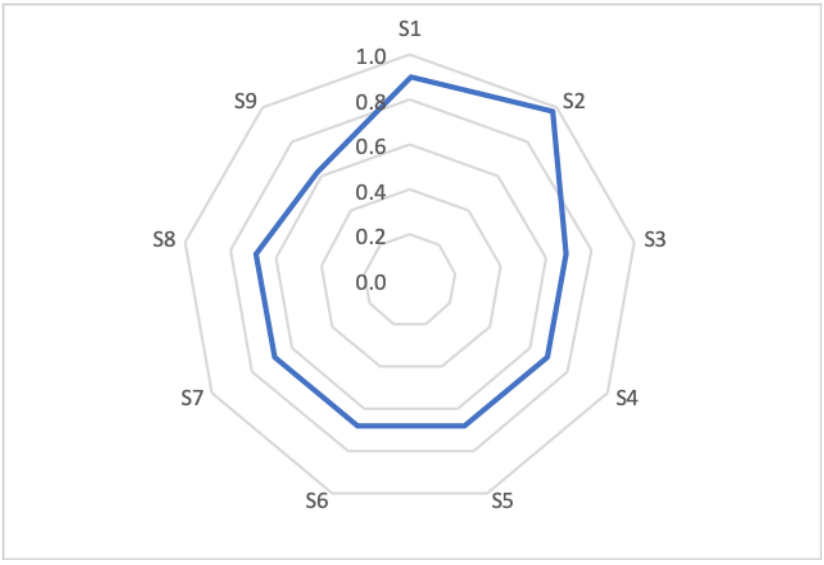

Figure 4. 2 Ranks correlation of the nine scenarios for all 48 eligible treatment patients

As illustrated in Figure 4.2, S2 had the highest SCC value of 0.1, followed by S1 with SCC value of 0.9. Whereas S3-S8 had identical SCC value of 0.7, and the remaining scenario (S9) had SCC value of 0.6, with a mean value of 0.737 for all scenarios.

4.8.2 The results of Systematic ranking assessment

As mentioned in Section 3.3.2, the prioritised patients at LM and CFS were separated into different groups based on their prioritising sequence to assess the prioritisation results of patients who are eligible for treatment. The details of the results for LM and CFS will be presenting in the following subsections.

4.8.2.1 The systematic ranking results for the LM

This section presents the systematic ranking assessment results of the three hospitals. Where the final rankings of the prioritised patients within each hospital are divided into three groups. All groups are distributed in a systematic manner, since the start of the 2nd group's ranking results

coincides with the end of the 1st group's ranking results, and the same holds true for the remaining groups. For the three hospitals, the 1st and 2nd groups include 5 patients, and 3rd group include 6 patients. The results of this assessment for patient's prioritisation at each hospital are shown in Table 4.8.

Table 4. 8 Validation of prioritisation results of the eligible treatment patients at the LM

	Hospital 1	
Groups	**Patients**	**Mean**
1st Group	H1_P6, H1_P15, H1_P14, H1_P12, H1_P10	0.917
2nd Group	H1_P2, H1_P16, H1_P3, H1_P7, H1_P11	0.897
3rd Group	H1_P5, H1_P8, H1_P9, H1_P13, H1_P4, H1_P1	0.886
	Hospital 2	
Groups	**Patients**	**Mean**
1st Group	H2_P9, H2_P4, H2_P14, H2_P8, H2_P3	0.921
2nd Group	H2_P5, H2_P10, H2_P13, H2_P16, H2_P2	0.905
3rd Group	H2_P12, H2_P1, H2_P7, H2_P6, H2_P15, H2_P11	0.878
	Hospital 3	
Groups	**Patients**	**Mean**
1st Group	H3_P9, H3_P6, H3_P14, H3_P5, H3_P10	0.927
2nd Group	H3_P12, H3_P8, H3_P15, H3_P13, H3_P3	0.908
3rd Group	H3_P2, H3_P16, H3_P1, H3_P7, H3_P4, H3_P11	0.877

In Table 4.8 the assessment results are shown for each group per hospital. According to the comparisons, the 1st group obtained the highest mean, which is the best across all hospitals in terms of ranking results. Thus, the 1st group has the most eligible patients among all hospitals in terms of rankings. The findings show that the F-TOPSIS method used to prioritise patients follows a systematic ranking.

4.8.2.2 The systematic ranking results for the CFS

Same objective assessment has been performed to evaluate the first seven ranking results of the eligible treatment patients at the CFS. The ranking results of the prioritised patients are split into three groups. The 1st and 2nd groups each have two patients, whereas the 3rd group contains three patients. Table 4.9 presents the assessment results for patient's prioritisation at CFS.

Table 4. 9 Validation of prioritisation results of the eligible treatment patients at the CFS

Group	Patients	Mean
1st Group	H2_P9, H3_P9	0.947
2nd Group	H2_P4, H3_P6	0.920
3rd Group	H3_P14, H1_P6, H1_P15	0.916

In comparison to the second and third groups, the 1st group has the best and greatest mean value (0.947) as shown in Table 4.9. Meanwhile, the 2nd group's mean (0.920) is greater than the 3rd group's (0.916). This finding reveals that the prioritisation results of eligible treatment patients are robustness and consistent.

4.8.3 The results of Comparison analysis assessment

According to Section 3.3.3, the procedure of comparison analysis is applied and the results is presented in this section. The (FDMD) methodology is compared to the existing (MCDM) method (T. J. Mohammed et al., 2021). The two main challenges of distributing treatment for SARS-CoV-2 patients over hospital networks are explored. These two main challenges were used as a checklist for comparing achievement in two aspects. First the application aspect in the medical field, more specific the available method or procedure in handling SARS-COV-2 treatment distribution issues

over the hospital networking in compared to the proposed one (FDMD), and second the theoretical aspects, in term of the privacy and prioritisation challenges as presented in Table 4.10.

Table 4. 10 Comparison analysis between proposed FDMD and Previous Study

Methodologies	Benchmarking check list								%
	Privacy challenge		Prioritisation Challenge						
			Weighting issue			Ranking issue			
	Data Share Issue	Independence Issue	Weighting Process	inconsistency	Vagueness	Reversal rank	Multi-criteria Issue	Data Variation Issue	
FDMD	✓	✓	✓	✓	✓	✓	✓	✓	100%
MCDM (Available) (T. J. Mohammed et al., 2021)	×	×	✓	×	×	×	✓	✓	37.5%

Table (4.10) demonstrated the achievement percentage of the discussed benchmark checklist, which clearly depict the superiority of FDMD (i.e. 8/8; 100% achievement) over the available MCDM method (i.e. 3/8; 37.5% achievement) (T. J. Mohammed et al. (2021).

From ***Application aspect in the medical field,*** although the available method proposed a protocol for the transfusion of efficient convalescent plasma (CP) distribution as a pre-vaccination treatment. Yet, this solution wasn't good enough to save patients' life or reduce the speed of SARS-COV-2 infection transmission. However, it was the best available solution for the pre-vaccination period. In contrast, this study through the proposed FDMD focused on the distribution of anti-

SARS-CoV-2 mAbs for eligible patients as a recommended medicine for curing the SARS-COV-2 patient in mild or moderate infection level.

In the theoretical aspect, from one side, the proposed FDMD overcome *privacy challenge*, that ignored totally by the available method (T. J. Mohammed et al., 2021). The integration of federated fundamental in the proposed FDMD kept the patients' data private and not shared over the network during the computation process, in addition, each hospital can independently process their data patients which in return gives equal opportunity for all hospitals in receiving the anti-SARS-CoV-2 mAbs for their own patients without overriding an individual hospital data over others. From the other side, FDMD, handled the prioritisation challenge more efficiently and effectively in compared to the available method (T. J. Mohammed et al., 2021).

The (T. J. Mohammed et al., 2021), used an integration framework between AHP as weighting method to compute the importance of the criteria and classical TOPSIS as ranking method to order the alternatives during the process of prioritisation and matching between the donors and patients to overcome the multicriteria and data variation issues. Although these two methods are considered as well-known methods in the context of MCDM in handling these issues, AHP and classical TOPSIS had been theoretically criticised because of the inconsistency issue in the AHP method, which increases dramatically when the number of criteria exceeds nine (Pamučar et al., 2018) and the rank reversal issue of the classical TOPSIS (Tang & Fang, 2018), which commonly occurs as a consequence of adding or removing alternative (i.e. admit or discharge patient). By contrast, the proposed FDMD introduced IVSH2-FWZIC as a new formulated weighting method which computes the importance of weight criteria with zero inconsistency and provides high-accuracy outcomes due to the adoption of IVSH2 fuzzy environment that override vagueness and ambiguity. Finally, the proposed F-TOPSIS that was used in the sequencing process of FDMD succeed not

only in handling the multicriteria and data variation issues and employing the federation fundamental, but it solves the reversal ranking in an efficient way. Overall, in the basis of above comparison scenario with previous work proved the effectiveness of the proposed FDMD.

4.9 Conclusion

This chapter presented the results of FDMD methodology following the validation and the evaluation procedures that mentioned in chapter 3. The results of high-risk criteria weighting by using IVSH2-FWZIC is discussed in section 4.2. The dataset used in this study contains a large number of important cases (alternative/patients with different high-risk criteria), the augmentation results were presented in details in section 4.3. The evaluation results of the eligible treatment patients DDM were presented based on the intersection between the selected eligible treatment patients from three hospitals as mentioned in section 4.4. Section 4.5 explained the positive and negative ideal vector results of the LM (i.e. hospital 1, hospital 2, and hospital 3) and CFS. The discussion of the treatment distribution for high-risk SARS-COV-2 patients is reported in section 4.6. The prioritisation results of the eligible patients in the CFS side were presented in section 4.7. Finally validation and evaluation results of FDMD methodology is discussed in section 4.8. in term of validation, sensitivity analysis and systematic ranking procedures are applied, however, in evaluation two main challenges were used as a checklist for comparing achievement in two aspects, namely, the application aspect and the theoretical aspects as mention in section 4.8.3.

CHAPTER 5: CONCLUSION AND FUTURE STUDY

5.1 Introduction

This chapter highlights the contributions, implications, limitations and future works. Section 5.2 discusses the research contribution, and Section 5.3 reports the implications. Section 5.4 presents the research limitations, and Section 5.5 provides recommendations for future work. Finally, the conclusion is presented in Section 5.6.

5.2 Contribution to the body of knowledge

The presented study can support the medical and industrial community by providing a novel FDMD methodology that privately prioritise alternatives (i.e. patients) without sharing their data. As shown in Figure 5.1, the main contribution of our study and novelty mapping are presented. This research belongs to multidisciplinary research and includes the transfer of knowledge from expert systems and healthcare services for the development of an FDMD methodology that can address challenges and related issues. Figure 5.1 presents the main contribution of our study and novelty mapping.

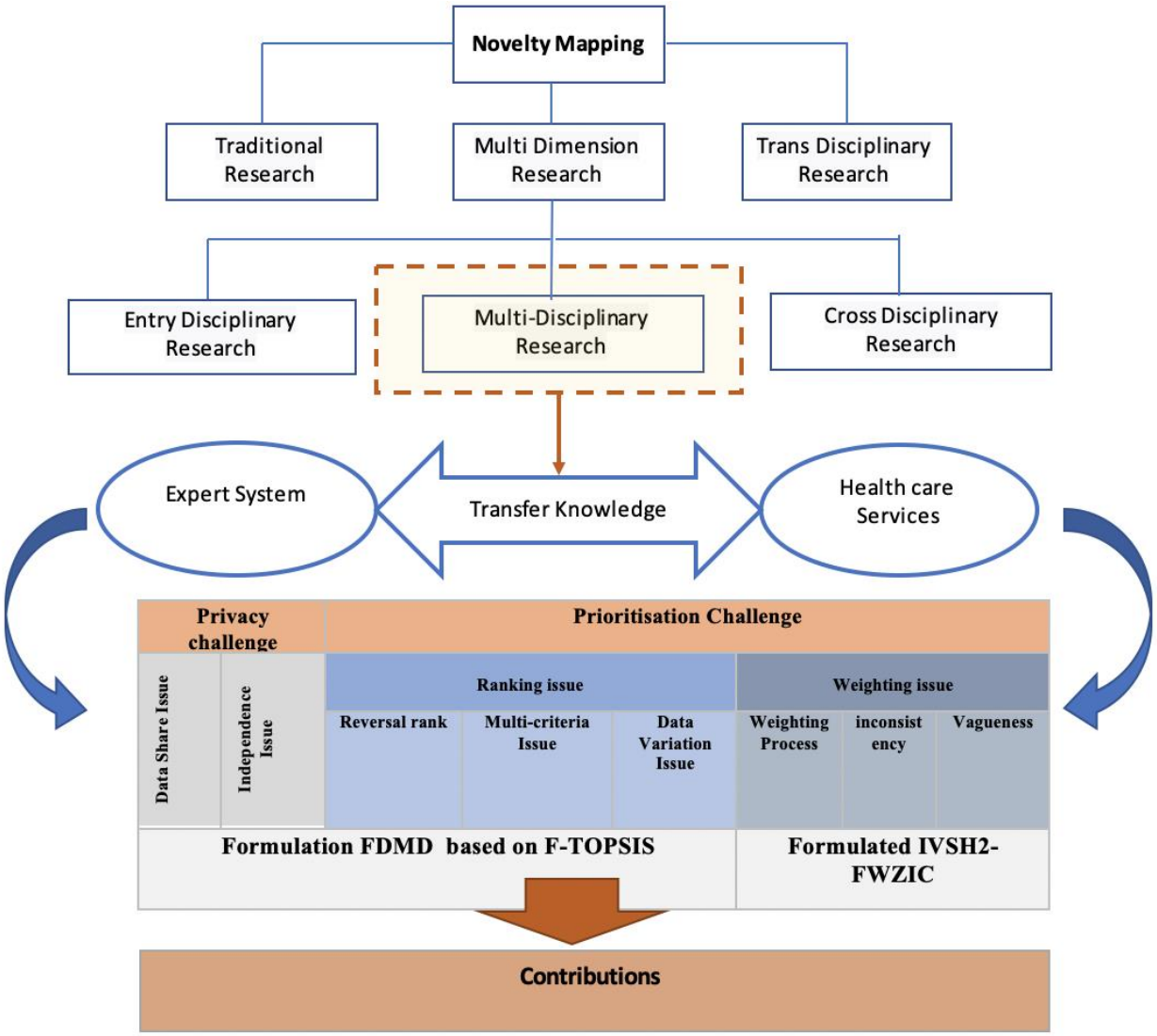

Figure 5. 1:Novelty mapping and research contributions

The study contributions can be summarised in the following points:

i. This study fills the gap of anti-SARS-CoV-2 monoclonal antibody distribution among most eligible patients in hospital networks without sharing patient data records.

ii. A dynamic decision matrix is formulated on the basis of the crossover of ‘patient’ and ‘15 multiple high-risk evaluation criteria of patient level in mild and moderate cases.

iii. A novel MCDM weighting method called IVSH2-FWZIC is proposed to determine the importance of criteria that overcome the vagueness and ambiguity issue.

iv. A novel form of the MCDM method is established on the basis of federated fundamental called F-TOPSIS to prioritise the most eligible patients under federated environments after a synchronise sequence process between LM and CFS.

v. A novel FDMD methodology is developed for the federated prioritisation of the most eligible high-risk SARS-COV-2 patients to overcome the two predefined challenges.

5.3 Limitation of the research

The proposed FDMD has some limitations:

i. The evaluation procedure of the high-risk criteria for SARS-COV-2 patients were adopted and presented under two categorial scales.

ii. The IVSH2-FWZIC was formulated with a single aggregation operator and single defuzzification method.

iii. The process of FDMD consider the actual time rather than the real-time process. The new iteration starts after the most recent computation of local prioritisation patient score is completed and sent to CFS, and new admission patients need to wait after the first batch receives treatment.

iv. The study was conducted only on patients with weights of at least 40 kg and aged 12 years and above, and thus patients aged 12 years or younger should be tested to ensure the capability of the proposed framework.

v. The FDMD was implemented on the augmented data of 49,152 cases of patients with SARS-CoV-2 with mild and moderate symptoms, and no real data were available.

5.4 Future Work

Several future directions can be explored as follows:

i. The evaluation criteria of the high-risk SARS-COV-2 patients might be assessed by using various Likert scales (e.g. 5, 7 and 11 scales).

ii. IVSH2-FWZIC can be formulated with other aggregation operators and defuzzification techniques. Other fuzzy types with FWZIC, such as Fermatean fuzzy set and fractional orthotriple fuzzy set, can be used in investigating the uncertainty restriction in other fuzzy sets.

iii. The proposed FDMD can be used for the prioritisation of any systems in which prioritising or benchmarking alternatives present data privacy issues, particularly in military operations, strategic information systems, bank systems, marketing strategies and organ donation and transplantation.

iv. Integration into other MCDM ranking methods such as VIKOR or FDOSM can be performed in the investigation and comparison of results.

v. The evaluation procedure can allocate different representing method for the values of the evaluation criteria.

vi. Different normalisation methods can be implemented and tested.

vii. More investigation is needed on MCDM industrial application based federated such as organ donation.

5.5 Research Conclusion

This study has bridged the existed research gap by solving issues in the distribution of limited SARS-COV-2 treatment (i.e. anti-SARS-CoV-2 mAbs) to the most eligible SARS-COV-2 patients

through prioritisation, which is subjected to multiple evaluation criteria. The evaluation of the importance of criteria and data variation in distribution hospitals networking considers the privacy of personal data records. A combination of federated fundamental and MCDM concept is proposed in this research, which works with the two sides of processing steps in CFS and LM (i.e. hospital). This study proposed a novel FDMD distributor and an MCDM method called F-TOPSIS, which not only was found efficient in prioritising patients but also was found to implement prioritisation independently at LM. The scores were combined and sorted for the global prioritisation at the CFS side, and these steps were performed without sharing patient data. In the proposed F-TOPSIS, the importance of criteria must be weighted and computed externally. To accomplish this step, a new version of FWZIC was formulated under an IVSH2 fuzzy environment and used in calculating the criteria weight without inconsistency and handling vagueness, hesitancy and uncertainty.

The processing steps at VFS and LM were synchronised in successive phases in an experimental test, in which an augmented dataset of 49,152 was used. The preliminary setting phase at CFS was performed, followed by the determination of the local positive and negative ideal vectors at each LM. These vectors were unified to federated positive and negative ideal vectors at CFS and sent to all LMs. The LMs independently computed the scores and ranked the patients. Finally, all LMs sent the patients' indices and scores to the CFS after dose availability was confirmed, and CFS in turn combined, sorted and matched the most eligible patients according to the available amount of dose and alerted the hospitals. The systematic ranking and sensitivity analysis of the CFS and LMs confirmed the strength of the proposed method, and the comparison analysis demonstrated the efficiency of the proposed FDMD in comparison with available methods.

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APPENDIX

Table A. 1 Expert's preferences of fifteen high-risk criteria in numerical scale

Criteria / Expert	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
E1	5	4	4	4	5	2	3	3	4	4	2	2	2	2	5
E2	5	3	3	3	3	4	3	3	5	4	3	2	3	3	4
E3	5	4	5	5	5	3	4	4	5	5	4	5	3	5	5

Table A. 2 IVSH2-EDM

Expert / Criteria		E1	E2	E3	Expert / Criteria		E1	E2	E3	Expert / Criteria		E1	E2	E3
		0.9	0.9	0.9			0.4	0.75	0.6			0.4	0.6	0.75
	M	0.85	0.85	0.85		M	0.35	0.7	0.55		M	0.35	0.55	0.7
		0.8	0.8	0.8			0.3	0.65	0.45			0.3	0.45	0.65
		0.25	0.25	0.25			0.75	0.4	0.6			0.75	0.6	0.4
C1	L	0.2	0.2	0.2	C6	L	0.7	0.35	0.55	C11	L	0.7	0.55	0.35
		0.15	0.15	0.15			0.65	0.3	0.45			0.65	0.45	0.3
		0.05	0.05	0.05			0.2	0.2	0.35			0.2	0.35	0.2
	K	0.1	0.1	0.1		K	0.25	0.25	0.4		K	0.25	0.4	0.25
		0.15	0.15	0.15			0.3	0.3	0.45			0.3	0.45	0.3
		0.75	0.6	0.75			0.6	0.6	0.75			0.4	0.4	0.9
	M	0.7	0.55	0.7		M	0.55	0.55	0.7		M	0.35	0.35	0.85
		0.65	0.45	0.65			0.45	0.45	0.65			0.3	0.3	0.8
		0.4	0.6	0.4			0.6	0.6	0.4			0.75	0.75	0.25
C2	L	0.35	0.55	0.35	C7	L	0.55	0.55	0.35	C12	L	0.7	0.7	0.2
		0.3	0.45	0.3			0.45	0.45	0.3			0.65	0.65	0.15
		0.2	0.35	0.2			0.35	0.35	0.2			0.2	0.2	0.05
	K	0.25	0.4	0.25		K	0.4	0.4	0.25		K	0.25	0.25	0.1
		0.3	0.45	0.3			0.45	0.45	0.3			0.3	0.3	0.15
		0.75	0.6	0.9			0.6	0.6	0.75			0.4	0.6	0.6
	M	0.7	0.55	0.85		M	0.55	0.55	0.7		M	0.35	0.55	0.55
		0.65	0.45	0.8			0.45	0.45	0.65			0.3	0.45	0.45
		0.4	0.6	0.25			0.6	0.6	0.4			0.75	0.6	0.6
C3	L	0.35	0.55	0.2	C8	L	0.55	0.55	0.35	C13	L	0.7	0.55	0.55
		0.3	0.45	0.15			0.45	0.45	0.3			0.65	0.45	0.45
		0.2	0.35	0.05			0.35	0.35	0.2			0.2	0.35	0.35
	K	0.25	0.4	0.1		K	0.4	0.4	0.25		K	0.25	0.4	0.4
		0.3	0.45	0.15			0.45	0.45	0.3			0.3	0.45	0.45
C4	M	0.75	0.6	0.9	C9	M	0.75	0.9	0.9	C14	M	0.4	0.6	0.9

		0.7	0.55	0.85			0.7	0.85	0.85			0.35	0.55	0.85
		0.65	0.45	0.8			0.65	0.8	0.8			0.3	0.45	0.8
		0.4	0.6	0.25			0.4	0.25	0.25			0.75	0.6	0.25
	L	0.35	0.55	0.2		L	0.35	0.2	0.2		L	0.7	0.55	0.2
		0.3	0.45	0.15			0.3	0.15	0.15			0.65	0.45	0.15
		0.2	0.35	0.05			0.2	0.05	0.05			0.2	0.35	0.05
	K	0.25	0.4	0.1		K	0.25	0.1	0.1		K	0.25	0.4	0.1
		0.3	0.45	0.15			0.3	0.15	0.15			0.3	0.45	0.15
		0.9	0.6	0.9			0.75	0.75	0.9			0.9	0.75	0.9
	M	0.85	0.55	0.85		M	0.7	0.7	0.85		M	0.85	0.7	0.85
		0.8	0.45	0.8			0.65	0.65	0.8			0.8	0.65	0.8
		0.25	0.6	0.25			0.4	0.4	0.25			0.25	0.4	0.25
C5	L	0.2	0.55	0.2	C10	L	0.35	0.35	0.2	C15	L	0.2	0.35	0.2
		0.15	0.45	0.15			0.3	0.3	0.15			0.15	0.3	0.15
		0.05	0.35	0.05			0.2	0.2	0.05			0.05	0.2	0.05
	K	0.1	0.4	0.1		K	0.25	0.25	0.1		K	0.1	0.25	0.1
		0.15	0.45	0.15			0.3	0.3	0.15			0.15	0.3	0.15

Table A. 3 Fuzzification, data ratio and final weights results of the 15 high-risk criteria

Expert / Criteria		E1	E2	E3	$\tilde{w}$	Def. of $\tilde{w}$	Final weight
C1		0.9000	0.9000	0.9000	0.9000		
	M	1.0000	0.0000	1.0000	1.0000		
		0.0000	0.0000	0.0000	0.0000		
		0.2500	0.2500	0.2500	0.2500		
	L	0.0000	0.0000	0.0000	0.0000	1.2000	0.1001
		0.0000	0.0000	0.0000	0.0000		
		0.0500	0.0500	0.0500	0.0500		
	K	0.0000	0.0000	0.0000	0.0000		
		0.0000	0.0000	0.0000	0.0000		
C2		0.7500	0.6000	0.7500	0.7095		
	M	0.8517	0.7695	0.8517	0.5916		
		0.0000	0.0000	0.0000	0.0000		
		0.4000	0.6000	0.4000	0.4579		
	L	0.2601	0.3385	0.2601	0.6383	0.4419	0.0369
		0.0000	0.0000	0.0000	0.0000		
		0.2000	0.3500	0.2000	0.2410		
	K	0.2601	0.3385	0.2601	0.6383		
		0.0000	0.0000	0.0000	0.0000		
C3		0.7500	0.6000	0.9000	0.7899		
	M	0.8517	0.7695	1.0000	1.0000	1.0822	0.0903
		0.0000	0.0000	0.0000	0.0000		

		0.4000	0.6000	0.2500	0.3915		
	L	0.2601	0.3385	0.0000	0.0000		
		0.0000	0.0000	0.0000	0.0000		
		0.2000	0.3500	0.0500	0.1518		
	K	0.2601	0.3385	0.0000	0.0000		
		0.0000	0.0000	0.0000	0.0000		
C4		0.7500	0.6000	0.9000	0.7899		
	M	0.8517	0.7695	1.0000	1.0000		
		0.0000	0.0000	0.0000	0.0000		
		0.4000	0.6000	0.2500	0.3915		
	L	0.2601	0.3385	0.0000	0.0000	1.0822	0.0903
		0.0000	0.0000	0.0000	0.0000		
		0.2000	0.3500	0.0500	0.1518		
	K	0.2601	0.3385	0.0000	0.0000		
		0.0000	0.0000	0.0000	0.0000		
C5		0.9000	0.6000	0.9000	0.8457		
	M	1.0000	0.7695	1.0000	1.0000		
		0.0000	0.0000	0.0000	0.0000		
		0.2500	0.6000	0.2500	0.3347		
	L	0.0000	0.3385	0.0000	0.0000	1.1384	0.0950
		0.0000	0.0000	0.0000	0.0000		
		0.0500	0.3500	0.0500	0.0956		
	K	0.0000	0.3385	0.0000	0.0000		
		0.0000	0.0000	0.0000	0.0000		
C6		0.4000	0.7500	0.6000	0.6187		
	M	0.4267	1.0000	0.6215	0.3876		
		0.0000	0.0000	0.0000	0.0000		
		0.7500	0.4000	0.6000	0.5646		
	L	0.6355	0.0000	0.4252	0.7520	0.2322	0.0194
		0.0000	0.0000	0.0000	0.0000		
		0.2000	0.2000	0.3500	0.2410		
	K	0.2601	0.0000	0.4252	0.7520		
		0.0000	0.0000	0.0000	0.0000		
C7		0.6000	0.6000	0.7500	0.6605		
	M	0.6215	0.7695	0.8517	0.5916		
		0.0000	0.0000	0.0000	0.0000		
		0.6000	0.6000	0.4000	0.5241		
	L	0.4252	0.3385	0.2601	0.6383	0.3870	0.0323
		0.0000	0.0000	0.0000	0.0000		
		0.3500	0.3500	0.2000	0.2904		
	K	0.4252	0.3385	0.2601	0.6383		
		0.0000	0.0000	0.0000	0.0000		
C8		0.6000	0.6000	0.7500	0.6605		
	M	0.6215	0.7695	0.8517	0.5916	0.3870	0.0323
		0.0000	0.0000	0.0000	0.0000		

		0.6000	0.6000	0.4000	0.5241		
	L	0.4252	0.3385	0.2601	0.6383		
		0.0000	0.0000	0.0000	0.0000		
		0.3500	0.3500	0.2000	0.2904		
	K	0.4252	0.3385	0.2601	0.6383		
		0.0000	0.0000	0.0000	0.0000		
C9		0.7500	0.9000	0.9000	0.8655		
	M	0.8517	0.0000	1.0000	1.0000		
		0.0000	0.0000	0.0000	0.0000		
		0.4000	0.2500	0.2500	0.2924		
	L	0.2601	0.0000	0.0000	0.0000	1.1646	0.0972
		0.0000	0.0000	0.0000	0.0000		
		0.2000	0.0500	0.0500	0.0794		
	K	0.2601	0.0000	0.0000	0.0000		
		0.0000	0.0000	0.0000	0.0000		
C10		0.7500	0.7500	0.9000	0.8177		
	M	0.8517	1.0000	1.0000	1.0000		
		0.0000	0.0000	0.0000	0.0000		
		0.4000	0.4000	0.2500	0.3420		
	L	0.2601	0.0000	0.0000	0.0000	1.1166	0.0932
		0.0000	0.0000	0.0000	0.0000		
		0.2000	0.2000	0.0500	0.1260		
	K	0.2601	0.0000	0.0000	0.0000		
		0.0000	0.0000	0.0000	0.0000		
C11		0.4000	0.6000	0.7500	0.6187		
	M	0.4267	0.7695	0.8517	0.5916		
		0.0000	0.0000	0.0000	0.0000		
		0.7500	0.6000	0.4000	0.5646		
	L	0.6355	0.3385	0.2601	0.6383	0.3760	0.0314
		0.0000	0.0000	0.0000	0.0000		
		0.2000	0.3500	0.2000	0.2410		
	K	0.2601	0.3385	0.2601	0.6383		
		0.0000	0.0000	0.0000	0.0000		
C12		0.4000	0.4000	0.9000	0.6987		
	M	0.4267	0.5470	1.0000	1.0000		
		0.0000	0.0000	0.0000	0.0000		
		0.7500	0.7500	0.2500	0.5200		
	L	0.6355	0.5879	0.0000	0.0000	1.0176	0.0849
		0.0000	0.0000	0.0000	0.0000		
		0.2000	0.2000	0.0500	0.1260		
	K	0.2601	0.0000	0.0000	0.0000		
		0.0000	0.0000	0.0000	0.0000		
C13		0.4000	0.6000	0.6000	0.5471		
	M	0.4267	0.7695	0.6215	0.3876	0.1646	0.0137
		0.0000	0.0000	0.0000	0.0000		

		0.7500	0.6000	0.6000	0.6463		
	L	0.6355	0.3385	0.4252	0.7520		
		0.0000	0.0000	0.0000	0.0000		
		0.2000	0.3500	0.3500	0.2904		
	K	0.2601	0.3385	0.4252	0.7520		
		0.0000	0.0000	0.0000	0.0000		
C14		0.4000	0.6000	0.9000	0.7298		
	M	0.4267	0.7695	1.0000	1.0000		
		0.0000	0.0000	0.0000	0.0000		
		0.7500	0.6000	0.2500	0.4827		
	L	0.6355	0.3385	0.0000	0.0000	1.0317	0.0861
		0.0000	0.0000	0.0000	0.0000		
		0.2000	0.3500	0.0500	0.1518		
	K	0.2601	0.3385	0.0000	0.0000		
		0.0000	0.0000	0.0000	0.0000		
C15		0.9000	0.7500	0.9000	0.8655		
	M	1.0000	1.0000	1.0000	1.0000		
		0.0000	0.0000	0.0000	0.0000		
		0.2500	0.4000	0.2500	0.2924		
	L	0.0000	0.0000	0.0000	0.0000	1.1646	0.0972
		0.0000	0.0000	0.0000	0.0000		
		0.0500	0.2000	0.0500	0.0794		
	K	0.0000	0.0000	0.0000	0.0000		
		0.0000	0.0000	0.0000	0.0000		

Table A. 4 Samples of 16 patients' cases of the augmented dataset (hospitals 2 and 3)

	Hospital 2														
Criteria Patients	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
P472	1	No	No	No	No	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	2
P3592	1	No	Yes	Yes	Yes	No	No	No	No	No	No	Yes	Yes	Yes	1
P7270	1	Yes	Yes	Yes	No	No	No	Yes	Yes	No	No	Yes	No	Yes	1
P16057	2	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	No	No	No	2
P16227	2	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	No	No	Yes	No	1
P16540	3	No	No	No	No	No	Yes	No	No	Yes	Yes	No	Yes	Yes	1
P20515	3	Yes	No	No	No	No	No	No	Yes	No	No	No	Yes	No	2
P22375	3	Yes	No	Yes	Yes	Yes	No	Yes	Yes	No	No	Yes	Yes	No	1
P23742	3	Yes	Yes	Yes	No	No	Yes	No	Yes	Yes	Yes	Yes	No	Yes	2
P13079	2	Yes	No	No	Yes	Yes	No	No	No	Yes	No	Yes	Yes	No	2
P4549	1	Yes	No	No	No	Yes	Yes	Yes	No	No	No	Yes	No	No	1
P4776	1	Yes	No	No	Yes	No	Yes	No	Yes	No	No	Yes	Yes	Yes	1
P14734	2	Yes	Yes	No	No	Yes	Yes	No	No	No	Yes	Yes	No	Yes	2

P22377	3	Yes	No	Yes	Yes	Yes	No	Yes	Yes	No	Yes	No	No	No	2
P4615	1	Yes	No	No	Yes	No	No	No	No	No	No	Yes	Yes	No	1
P20719	3	Yes	No	No	No	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	2
Hospital 3															
Criteria Patients	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
P570	1	No	No	No	Yes	No	No	No	Yes	Yes	Yes	No	No	Yes	1
P4695	1	Yes	No	No	Yes	No	No	Yes	No	Yes	No	Yes	Yes	No	2
P7073	1	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No	No	No	No	No	2
P11545	2	No	Yes	Yes	No	Yes	No	No	No	Yes	Yes	No	No	No	1
P14874	2	Yes	Yes	No	Yes	No	No	No	No	Yes	Yes	No	No	Yes	2
P16185	2	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	No	No	No	2
P19522	3	No	Yes	Yes	No	No	No	Yes	No	No	No	No	No	Yes	1
P23867	3	Yes	Yes	Yes	No	Yes	No	No	Yes	Yes	Yes	No	Yes	No	1
P23926	3	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	No	Yes	No	Yes	2
P9600	2	No	No	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	1
P6737	1	Yes	Yes	No	Yes	No	No	Yes	No	Yes	No	No	No	No	1
P5052	1	Yes	No	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Yes	2
P11234	2	No	Yes	No	Yes	Yes	Yes	Yes	Yes	No	No	No	No	Yes	1
P19195	3	No	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	No	Yes	No	2
P19257	3	No	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	No	No	No	1
P4518	1	Yes	No	No	No	Yes	Yes	No	Yes	No	No	Yes	No	Yes	2

Table A. 5 The results of the normalized metrices of the three hospitals

Hospital 1															
Patients	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
H1_P1	0.8	0.8	0.8	0.8	0.8	0.8	1.0	0.8	0.8	0.8	1.0	0.8	0.8	1.0	1.0
H1_P2	0.8	1.0	0.8	0.8	0.8	0.8	1.0	0.8	1.0	1.0	1.0	1.0	0.8	1.0	1.0
H1_P3	0.8	1.0	1.0	0.8	1.0	0.8	1.0	0.8	0.8	0.8	1.0	1.0	1.0	1.0	1.0
H1_P4	0.8	1.0	1.0	0.8	1.0	1.0	0.8	1.0	0.8	0.8	1.0	0.8	1.0	0.8	0.8
H1_P5	1.0	0.8	0.8	0.8	1.0	0.8	0.8	1.0	1.0	0.8	1.0	0.8	1.0	1.0	0.8
H1_P6	1.0	0.8	0.8	0.8	1.0	1.0	0.8	0.8	1.0	0.8	0.8	1.0	1.0	1.0	1.0
H1_P7	1.0	1.0	1.0	0.8	0.8	0.8	0.8	0.8	0.8	1.0	0.8	1.0	1.0	1.0	0.8
H1_P8	0.8	1.0	1.0	0.8	1.0	1.0	1.0	1.0	0.8	0.8	0.8	1.0	1.0	1.0	0.8
H1_P9	1.0	1.0	0.8	0.8	0.8	0.8	1.0	0.8	1.0	0.8	1.0	0.8	0.8	0.8	1.0
H1_P10	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.8	1.0	1.0	0.8	1.0	0.8	0.8
H1_P11	0.9	0.8	1.0	0.8	1.0	1.0	0.8	1.0	1.0	0.8	0.8	1.0	0.8	0.8	0.8
H1_P12	0.9	1.0	0.8	1.0	1.0	1.0	0.8	0.8	0.8	1.0	1.0	0.8	0.8	1.0	1.0
H1_P13	0.9	1.0	1.0	0.8	0.8	0.8	0.8	0.8	1.0	0.8	0.8	0.8	1.0	1.0	0.8
H1_P14	0.9	1.0	1.0	1.0	1.0	0.8	1.0	1.0	0.8	0.8	0.8	0.8	0.8	1.0	1.0
H1_P15	1.0	0.8	1.0	1.0	0.8	0.8	1.0	0.8	1.0	1.0	0.8	1.0	1.0	0.8	0.8
H1_P16	1.0	0.8	1.0	1.0	0.8	1.0	0.8	0.8	1.0	1.0	0.8	0.8	0.8	0.8	0.8

Hospital 2															
Patients	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
H2_P1	0.8	0.8	0.8	0.8	0.8	1.0	1.0	1.0	0.8	1.0	0.8	1.0	1.0	1.0	1.0
H2_P2	0.8	0.8	1.0	1.0	1.0	0.8	0.8	0.8	0.8	0.8	0.8	1.0	1.0	1.0	0.8
H2_P3	0.8	1.0	1.0	1.0	0.8	0.8	0.8	1.0	1.0	0.8	0.8	1.0	0.8	1.0	0.8
H2_P4	0.9	1.0	1.0	1.0	1.0	0.8	1.0	0.8	1.0	1.0	1.0	0.8	0.8	0.8	1.0
H2_P5	0.9	1.0	1.0	1.0	1.0	1.0	0.8	1.0	1.0	0.8	0.8	0.8	1.0	0.8	0.8
H2_P6	1.0	0.8	0.8	0.8	0.8	0.8	1.0	0.8	0.8	1.0	1.0	0.8	1.0	1.0	0.8
H2_P7	1.0	1.0	0.8	0.8	0.8	0.8	0.8	0.8	1.0	0.8	0.8	0.8	1.0	0.8	1.0
H2_P8	1.0	1.0	0.8	1.0	1.0	1.0	0.8	1.0	1.0	0.8	0.8	1.0	1.0	0.8	0.8
H2_P9	1.0	1.0	1.0	1.0	0.8	0.8	1.0	0.8	1.0	1.0	1.0	1.0	0.8	1.0	1.0
H2_P10	0.9	1.0	0.8	0.8	1.0	1.0	0.8	0.8	0.8	1.0	0.8	1.0	1.0	0.8	1.0
H2_P11	0.8	1.0	0.8	0.8	0.8	1.0	1.0	1.0	0.8	0.8	0.8	1.0	0.8	0.8	0.8
H2_P12	0.8	1.0	0.8	0.8	1.0	0.8	1.0	0.8	1.0	0.8	0.8	1.0	1.0	1.0	0.8
H2_P13	0.9	1.0	1.0	0.8	0.8	1.0	1.0	0.8	0.8	0.8	1.0	1.0	0.8	1.0	1.0
H2_P14	1.0	1.0	0.8	1.0	1.0	1.0	0.8	1.0	1.0	0.8	1.0	0.8	0.8	0.8	1.0
H2_P15	0.8	1.0	0.8	0.8	1.0	0.8	0.8	0.8	0.8	0.8	0.8	1.0	1.0	0.8	0.8
H2_P16	1.0	1.0	0.8	0.8	0.8	0.8	1.0	1.0	1.0	0.8	1.0	1.0	1.0	0.8	1.0
Hospital 3															
Patients	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
H3_P1	0.8	0.8	0.8	0.8	1.0	0.8	0.8	0.8	1.0	1.0	1.0	0.8	0.8	1.0	0.8
H3_P2	0.8	1.0	0.8	0.8	1.0	0.8	0.8	1.0	0.8	1.0	0.8	1.0	1.0	0.8	1.0
H3_P3	0.8	1.0	1.0	0.8	1.0	1.0	1.0	0.8	1.0	0.8	0.8	0.8	0.8	0.8	1.0
H3_P4	0.9	0.8	1.0	1.0	0.8	1.0	0.8	0.8	0.8	1.0	1.0	0.8	0.8	0.8	0.8
H3_P5	0.9	1.0	1.0	0.8	1.0	0.8	0.8	0.8	0.8	1.0	1.0	0.8	0.8	1.0	1.0
H3_P6	0.9	1.0	1.0	1.0	1.0	1.0	0.8	0.8	1.0	1.0	1.0	0.8	0.8	0.8	1.0
H3_P7	1.0	0.8	1.0	1.0	0.8	0.8	0.8	1.0	0.8	0.8	0.8	0.8	0.8	1.0	0.8
H3_P8	1.0	1.0	1.0	1.0	0.8	1.0	0.8	0.8	1.0	1.0	1.0	0.8	1.0	0.8	0.8
H3_P9	1.0	1.0	1.0	1.0	0.8	1.0	0.8	1.0	1.0	1.0	0.8	1.0	0.8	1.0	1.0
H3_P10	0.9	0.8	0.8	1.0	0.8	1.0	0.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.8
H3_P11	0.8	1.0	1.0	0.8	1.0	0.8	0.8	1.0	0.8	1.0	0.8	0.8	0.8	0.8	0.8
H3_P12	0.8	1.0	0.8	0.8	1.0	1.0	1.0	0.8	1.0	1.0	1.0	0.8	1.0	1.0	1.0
H3_P13	0.9	0.8	1.0	0.8	1.0	1.0	1.0	1.0	1.0	0.8	0.8	0.8	0.8	1.0	0.8
H3_P14	1.0	0.8	1.0	0.8	1.0	0.8	1.0	1.0	1.0	1.0	1.0	0.8	1.0	0.8	1.0
H3_P15	1.0	0.8	1.0	0.8	1.0	1.0	0.8	0.8	1.0	1.0	1.0	0.8	0.8	0.8	0.8
H3_P16	0.8	1.0	0.8	0.8	0.8	1.0	1.0	0.8	1.0	0.8	0.8	1.0	0.8	1.0	1.0

Table A. 6 The results of the weighted metrices of the three hospitals

Hospital 1															
Patients	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15

H1_	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P1	801	295	722	722	760	155	323	258	777	745	314	679	110	861	972
H1_	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P2	801	369	722	722	760	155	323	258	972	932	314	849	110	861	972
H1_	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P3	801	369	903	722	950	155	323	258	777	745	314	849	137	861	972
H1_	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P4	801	369	903	722	950	194	258	323	777	745	314	679	137	689	777
H1_	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P5	001	295	722	722	950	155	258	323	972	745	314	679	137	861	777
H1_	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P6	001	295	722	722	950	194	258	258	972	745	251	849	137	861	972
H1_	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P7	001	369	903	722	760	155	258	258	777	932	251	849	137	861	777
H1_	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P8	801	369	903	722	950	194	323	323	777	745	251	849	137	861	777
H1_	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P9	001	369	722	722	760	155	323	258	972	745	314	679	110	689	972
H1_	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P10	001	369	903	903	950	194	323	323	777	932	314	679	137	689	777
H1_	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P11	901	295	903	722	950	194	258	323	972	745	251	849	110	689	777
H1_	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P12	901	369	722	903	950	194	258	258	777	932	314	679	110	861	972
H1_	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P13	901	369	903	722	760	155	258	258	972	745	251	679	137	861	777
H1_	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P14	901	369	903	903	950	155	323	323	777	745	251	679	110	861	972
H1_	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P15	001	295	903	903	760	155	323	258	972	932	251	849	137	689	777
H1_	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P16	001	295	903	903	760	194	258	258	972	932	251	679	110	689	777

Hospital 2

Patients	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
H2_	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P1	801	295	722	722	760	194	323	323	777	932	251	849	137	861	972
H2_	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P2	801	295	903	903	950	155	258	258	777	745	251	849	137	861	777
H2_	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P3	801	369	903	903	760	155	258	323	972	745	251	849	110	861	777
H2_	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P4	901	369	903	903	950	155	323	258	972	932	314	679	110	689	972

H2_	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P5	901	369	903	903	950	194	258	323	972	745	251	679	137	689	777
H2_	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P6	001	295	722	722	760	155	323	258	777	932	314	679	137	861	777
H2_	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P7	001	369	722	722	760	155	258	258	972	745	251	679	137	689	972
H2_	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P8	001	369	722	903	950	194	258	323	972	745	251	849	137	689	777
H2_	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P9	001	369	903	903	760	155	323	258	972	932	314	849	110	861	972
H2_	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P10	901	369	722	722	950	194	258	258	777	932	251	849	137	689	972
H2_	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P11	801	369	722	722	760	194	323	323	777	745	251	849	110	689	777
H2_	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P12	801	369	722	722	950	155	323	258	972	745	251	849	137	861	777
H2_	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P13	901	369	903	722	760	194	323	258	777	745	314	849	110	861	972
H2_	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P14	001	369	722	903	950	194	258	323	972	745	314	679	110	689	972
H2_	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P15	801	369	722	722	950	155	258	258	777	745	251	849	137	689	777
H2_	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P16	001	369	722	722	760	155	323	323	972	745	314	849	137	689	972

Hospital 3

Patients	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
H3_	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P1	801	295	722	722	950	155	258	258	972	932	314	679	110	861	777
H3_	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P2	801	369	722	722	950	155	258	323	777	932	251	849	137	689	972
H3_	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P3	801	369	903	722	950	194	323	258	972	745	251	679	110	689	972
H3_	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P4	901	295	903	903	760	194	258	258	777	932	314	679	110	689	777
H3_	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P5	901	369	903	722	950	155	258	258	777	932	314	679	110	861	972
H3_	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P6	901	369	903	903	950	194	258	258	972	932	314	679	110	689	972
H3_	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P7	001	295	903	903	760	155	258	323	777	745	251	679	110	861	777
H3_	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P8	001	369	903	903	760	194	258	258	972	932	314	679	137	689	777

H3_	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P9	001	369	903	903	760	194	258	323	972	932	251	849	110	861	972
H3_	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P10	901	295	722	903	760	194	258	323	972	932	314	849	137	861	777
H3_	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P11	801	369	903	722	950	155	258	323	777	932	251	679	110	689	777
H3_	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P12	801	369	722	722	950	194	323	258	972	932	314	679	137	861	972
H3_	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P13	901	295	903	722	950	194	323	323	972	745	251	679	110	861	777
H3_	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P14	001	295	903	722	950	155	323	323	972	932	314	679	137	689	972
H3_	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P15	001	295	903	722	950	194	258	258	972	932	314	679	110	689	777
H3_	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P16	801	369	722	722	760	194	323	258	972	745	251	849	110	861	972

Table A. 7 The score and ranking results of the eligible treatment patient at the LM (β = 0.4, 0.6, and 0.8)

hospital 1								
β =0.4			β = 0.6			β =0.8		
Patient	score	rank	Patient	score	rank	Patient	score	rank
H1_P6	0.246293	1	H1_P6	0.225818	1	H1_P6	0.205342	1
H1_P15	0.245984	2	H1_P15	0.225354	2	H1_P15	0.204723	2
H1_P14	0.242845	3	H1_P14	0.220646	3	H1_P14	0.198447	3
H1_P12	0.242569	4	H1_P12	0.220231	4	H1_P12	0.197893	4
H1_P10	0.240601	5	H1_P10	0.21728	5	H1_P10	0.193958	5
H1_P2	0.235787	6	H1_P2	0.210059	6	H1_P2	0.18433	6
H1_P16	0.234757	7	H1_P16	0.208513	7	H1_P16	0.182269	7
H1_P3	0.234733	8	H1_P3	0.208478	8	H1_P3	0.182223	8
H1_P7	0.232246	9	H1_P7	0.204747	9	H1_P7	0.177248	9
H1_P11	0.228392	10	H1_P11	0.198966	10	H1_P11	0.16954	10
H1_P5	0.225411	11	H1_P5	0.194495	11	H1_P5	0.163579	11
H1_P8	0.222192	12	H1_P8	0.189666	12	H1_P8	0.15714	12
H1_P9	0.217308	13	H1_P9	0.182339	13	H1_P9	0.147371	13
H1_P13	0.216293	14	H1_P13	0.180817	14	H1_P13	0.145342	14
H1_P4	0.201758	15	H1_P4	0.159015	15	H1_P4	0.116272	15
H1_P1	0.19863	16	H1_P1	0.154323	16	H1_P1	0.110016	16
hospital 2								
β =0.4			β = 0.6			β =0.8		
Patient	score	rank	Patient	score	rank	Patient	score	rank
H2_P9	0.272446	1	H2_P9	0.265047	1	H2_P9	0.257648	1
H2_P4	0.257676	2	H2_P4	0.242892	2	H2_P4	0.228108	2
H2_P14	0.241743	3	H2_P14	0.218992	3	H2_P14	0.196241	3

H2_P8	0.237526	4	H2_P8	0.212666	4	H2_P8	0.187807	4
H2_P3	0.23189	5	H2_P3	0.204213	5	H2_P3	0.176535	5
H2_P5	0.231862	6	H2_P5	0.204171	6	H2_P5	0.17648	6
H2_P10	0.229829	7	H2_P10	0.201121	7	H2_P10	0.172414	7
H2_P13	0.22941	8	H2_P13	0.200493	8	H2_P13	0.171576	8
H2_P16	0.229057	9	H2_P16	0.199964	9	H2_P16	0.17087	9
H2_P2	0.228225	10	H2_P2	0.198716	10	H2_P2	0.169206	10
H2_P12	0.222012	11	H2_P12	0.189396	11	H2_P12	0.156781	11
H2_P1	0.221616	12	H2_P1	0.188802	12	H2_P1	0.155988	12
H2_P7	0.214749	13	H2_P7	0.178501	13	H2_P7	0.142253	13
H2_P6	0.211789	14	H2_P6	0.174061	14	H2_P6	0.136333	14
H2_P15	0.197099	15	H2_P15	0.152026	15	H2_P15	0.106954	15
H2_P11	0.1877	16	H2_P11	0.137928	16	H2_P11	0.088156	16
				hospital 3				
	β =0.4			β = 0.6			β =0.8	
Patient	score	rank	Patient	score	rank	Patient	score	rank
H3_P9	0.271598	1	H3_P9	0.263775	1	H3_P9	0.255952	1
H3_P6	0.256748	2	H3_P6	0.241499	2	H3_P6	0.226251	2
H3_P14	0.253126	3	H3_P14	0.236066	3	H3_P14	0.219007	3
H3_P5	0.242046	4	H3_P5	0.219447	4	H3_P5	0.196848	4
H3_P10	0.239864	5	H3_P10	0.216175	5	H3_P10	0.192485	5
H3_P12	0.239098	6	H3_P12	0.215026	6	H3_P12	0.190953	6
H3_P8	0.238282	7	H3_P8	0.213801	7	H3_P8	0.18932	7
H3_P15	0.237338	8	H3_P15	0.212384	8	H3_P15	0.187431	8
H3_P13	0.230125	9	H3_P13	0.201565	9	H3_P13	0.173005	9
H3_P3	0.226415	10	H3_P3	0.196001	10	H3_P3	0.165587	10
H3_P2	0.223779	11	H3_P2	0.192047	11	H3_P2	0.160314	11
H3_P16	0.222856	12	H3_P16	0.190661	12	H3_P16	0.158467	12
H3_P1	0.221824	13	H3_P1	0.189115	13	H3_P1	0.156405	13
H3_P7	0.220773	14	H3_P7	0.187538	14	H3_P7	0.154303	14
H3_P4	0.216003	15	H3_P4	0.180383	15	H3_P4	0.144763	15
H3_P11	0.211687	16	H3_P11	0.173908	16	H3_P11	0.136129	16

Table A. 8 The results of the prioritized patients at the CFS (β =0.4, 0.6, and 0.8)

	β =0.4			β = 0.6			β =0.8	
Patient	score	rank	Patient	score	rank	Patient	score	rank
H2_P9	0.272446	1	H2_P9	0.265047	1	H2_P9	0.257648	1
H3_P9	0.271598	2	H3_P9	0.263775	2	H3_P9	0.255952	2
H2_P4	0.257676	3	H2_P4	0.242892	3	H2_P4	0.228108	3
H3_P6	0.256748	4	H3_P6	0.241499	4	H3_P6	0.226251	4
H3_P14	0.253126	5	H3_P14	0.236066	5	H3_P14	0.219007	5
H1_P6	0.246293	6	H1_P6	0.225818	6	H1_P6	0.205342	6
H1_P15	0.245984	7	H1_P15	0.225354	7	H1_P15	0.204723	7
H1_P14	0.242845	8	H1_P14	0.220646	8	H1_P14	0.198447	8

H1_P12	0.242569	9	H1_P12	0.220231	9	H1_P12	0.197893	9
H3_P5	0.242046	10	H3_P5	0.219447	10	H3_P5	0.196848	10
H2_P14	0.241743	11	H2_P14	0.218992	11	H2_P14	0.196241	11
H1_P10	0.240601	12	H1_P10	0.21728	12	H1_P10	0.193958	12
H3_P10	0.239864	13	H3_P10	0.216175	13	H3_P10	0.192485	13
H3_P12	0.239098	14	H3_P12	0.215026	14	H3_P12	0.190953	14
H3_P8	0.238282	15	H3_P8	0.213801	15	H3_P8	0.18932	15
H2_P8	0.237526	16	H2_P8	0.212666	16	H2_P8	0.187807	16
H3_P15	0.237338	17	H3_P15	0.212384	17	H3_P15	0.187431	17
H1_P2	0.235787	18	H1_P2	0.210059	18	H1_P2	0.18433	18
H1_P16	0.234757	19	H1_P16	0.208513	19	H1_P16	0.182269	19
H1_P3	0.234733	20	H1_P3	0.208478	20	H1_P3	0.182223	20
H1_P7	0.232246	21	H1_P7	0.204747	21	H1_P7	0.177248	21
H2_P3	0.23189	22	H2_P3	0.204213	22	H2_P3	0.176535	22
H2_P5	0.231862	23	H2_P5	0.204171	23	H2_P5	0.17648	23
H3_P13	0.230125	24	H3_P13	0.201565	24	H3_P13	0.173005	24
H2_P10	0.229829	25	H2_P10	0.201121	25	H2_P10	0.172414	25
H2_P13	0.22941	26	H2_P13	0.200493	26	H2_P13	0.171576	26
H2_P16	0.229057	27	H2_P16	0.199964	27	H2_P16	0.17087	27
H1_P11	0.228392	28	H1_P11	0.198966	28	H1_P11	0.16954	28
H2_P2	0.228225	29	H2_P2	0.198716	29	H2_P2	0.169206	29
H3_P3	0.226415	30	H3_P3	0.196001	30	H3_P3	0.165587	30
H1_P5	0.225411	31	H1_P5	0.194495	31	H1_P5	0.163579	31
H3_P2	0.223779	32	H3_P2	0.192047	32	H3_P2	0.160314	32
H3_P16	0.222856	33	H3_P16	0.190661	33	H3_P16	0.158467	33
H1_P8	0.222192	34	H1_P8	0.189666	34	H1_P8	0.15714	34
H2_P12	0.222012	35	H2_P12	0.189396	35	H2_P12	0.156781	35
H3_P1	0.221824	36	H3_P1	0.189115	36	H3_P1	0.156405	36
H2_P1	0.221616	37	H2_P1	0.188802	37	H2_P1	0.155988	37
H3_P7	0.220773	38	H3_P7	0.187538	38	H3_P7	0.154303	38
H1_P9	0.217308	39	H1_P9	0.182339	39	H1_P9	0.147371	39
H1_P13	0.216293	40	H1_P13	0.180817	40	H1_P13	0.145342	40
H3_P4	0.216003	41	H3_P4	0.180383	41	H3_P4	0.144763	41
H2_P7	0.214749	42	H2_P7	0.178501	42	H2_P7	0.142253	42
H2_P6	0.211789	43	H2_P6	0.174061	43	H2_P6	0.136333	43
H3_P11	0.211687	44	H3_P11	0.173908	44	H3_P11	0.136129	44
H1_P4	0.201758	45	H1_P4	0.159015	45	H1_P4	0.116272	45
H1_P1	0.19863	46	H1_P1	0.154323	46	H1_P1	0.110016	46
H2_P15	0.197099	47	H2_P15	0.152026	47	H2_P15	0.106954	47
H2_P11	0.1877	48	H2_P11	0.137928	48	H2_P11	0.088156	48

Table A.9: The evaluation results of the eligible treatment patients DDM Hospital 2

Patients	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
H2_P1	1	0	0	0	0	1	1	1	0	1	0	1	1	1	2
H2_P2	1	0	1	1	1	0	0	0	0	0	0	1	1	1	1
H2_P3	1	1	1	1	0	0	0	1	1	0	0	1	0	1	1
H2_P4	2	1	1	1	1	0	1	0	1	1	1	0	0	0	2
H2_P5	2	1	1	1	1	1	0	1	1	0	0	0	1	0	1
H2_P6	3	0	0	0	0	0	1	0	0	1	1	0	1	1	1
H2_P7	3	1	0	0	0	0	0	0	1	0	0	0	1	0	2
H2_P8	3	1	0	1	1	1	0	1	1	0	0	1	1	0	1
H2_P9	3	1	1	1	0	0	1	0	1	1	1	1	0	1	2
H2_P10	2	1	0	0	1	1	0	0	0	1	0	1	1	0	2
H2_P11	1	1	0	0	0	1	1	1	0	0	0	1	0	0	1
H2_P12	1	1	0	0	1	0	1	0	1	0	0	1	1	1	1
H2_P13	2	1	1	0	0	1	1	0	0	0	1	1	0	1	2
H2_P14	3	1	0	1	1	1	0	1	1	0	1	0	0	0	2
H2_P15	1	1	0	0	1	0	0	0	0	0	0	1	1	0	1
H2_P16	3	1	0	0	0	0	1	1	1	0	1	1	1	0	2

Hospital 3

Patients	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
H3_P1	1	0	0	0	1	0	0	0	1	1	1	0	0	1	1
H3_P2	1	1	0	0	1	0	0	1	0	1	0	1	1	0	2
H3_P3	1	1	1	0	1	1	1	0	1	0	0	0	0	0	2
H3_P4	2	0	1	1	0	1	0	0	0	1	1	0	0	0	1
H3_P5	2	1	1	0	1	0	0	0	0	1	1	0	0	1	2
H3_P6	2	1	1	1	1	1	0	0	1	1	1	0	0	0	2
H3_P7	3	0	1	1	0	0	0	1	0	0	0	0	0	1	1
H3_P8	3	1	1	1	0	1	0	0	1	1	1	0	1	0	1
H3_P9	3	1	1	1	0	1	0	1	1	1	0	1	0	1	2
H3_P10	2	0	0	1	0	1	0	1	1	1	1	1	1	1	1
H3_P11	1	1	1	0	1	0	0	1	0	1	0	0	0	0	1
H3_P12	1	1	0	0	1	1	1	0	1	1	1	0	1	1	2
H3_P13	2	0	1	0	1	1	1	1	1	0	0	0	0	1	1
H3_P14	3	0	1	0	1	0	1	1	1	1	1	0	1	0	2
H3_P15	3	0	1	0	1	1	0	0	1	1	1	0	0	0	1
H3_P16	1	1	0	0	0	1	1	0	1	0	0	1	0	1	2

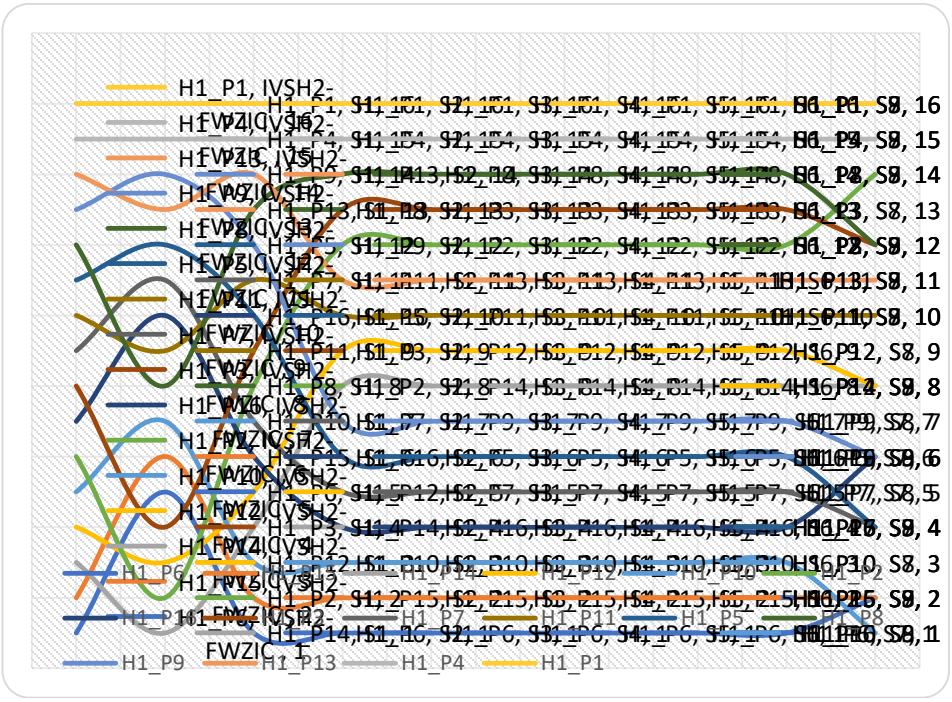

Figure A. 1 Sensitivity analysis of SARS-CoV-2 patients' ranking in the nine scenarios (hospital 1)

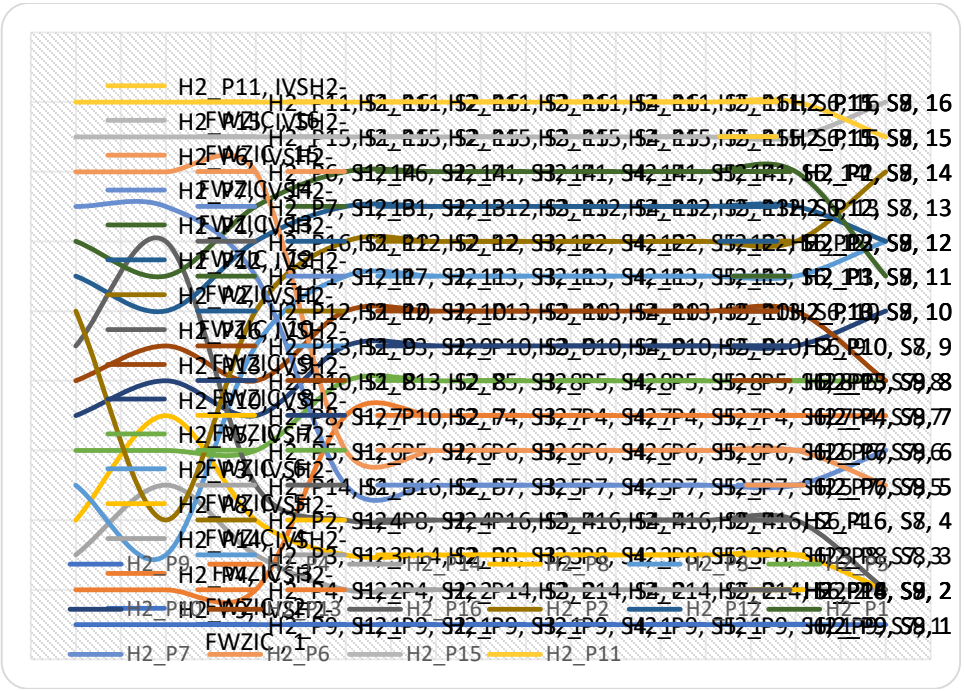

Figure A. 2 Sensitivity analysis of SARS-CoV-2 patients' ranking in the nine scenarios (hospital 2)

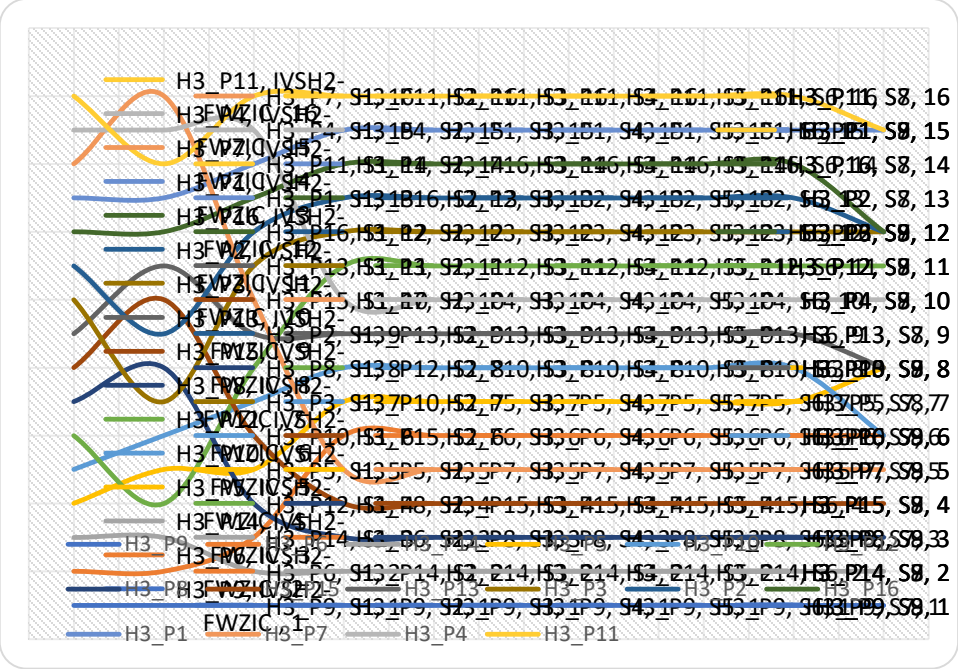

Figure A. 3 Sensitivity analysis of SARS-CoV-2 patients' ranking in the nine scenarios (hospital 3)

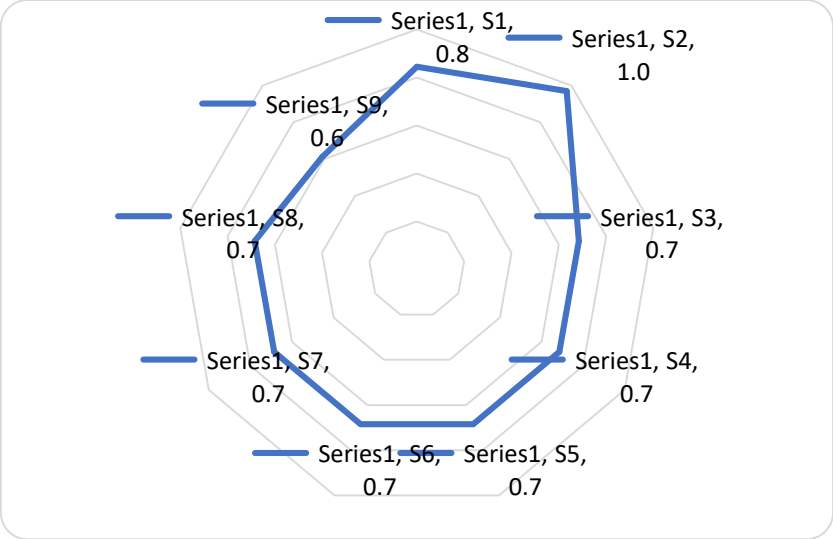

Figure A. 4 Correlation of ranks of the nine scenarios for 16 SARS-CoV-2 patients' (hospital 1)

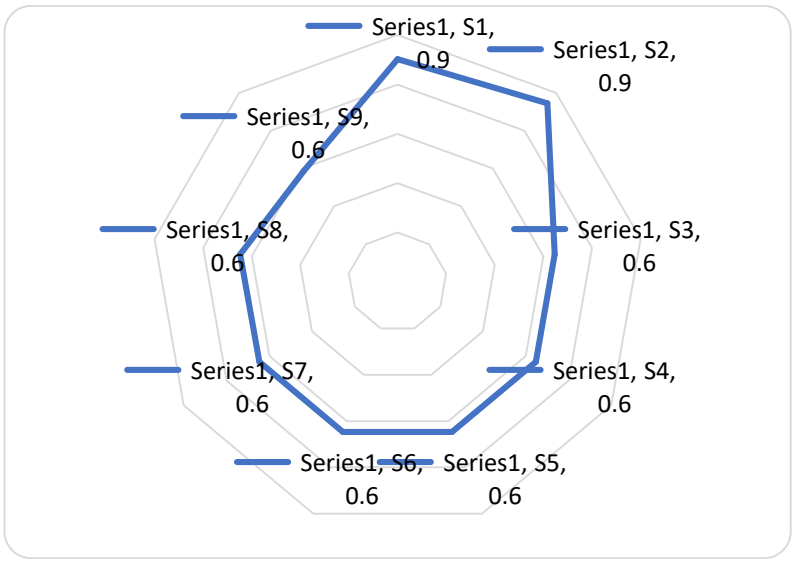

Figure A. 5 Correlation of ranks of the nine scenarios for 16 SARS-CoV-2 patients' (hospital 2)

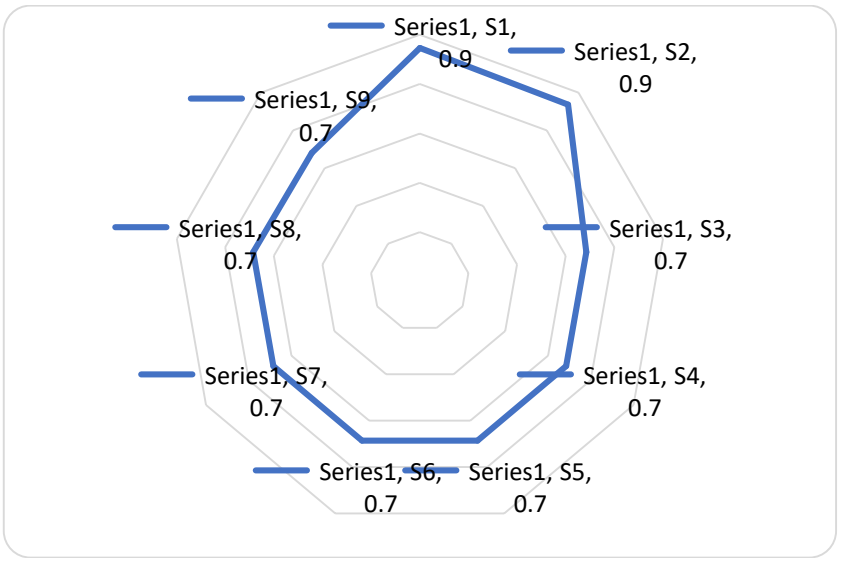

Figure A. 6 Correlation of ranks of the nine scenarios for 16 SARS-CoV-2 patients' (hospital 3)

A.7: MATLAB code for generating augmented dataset

```
clc;
clear;
E=[0 1];
S=[];
for i1=1:3
for i2=1:2
for i3=1:2
```

```
for i4=1:2
for i5=1:2
for i6=1:2
for i7=1:2
for i8=1:2
for i9=1:2
for i10=1:2
for i11=1:2
for i12=1:2
for i13=1:2
for i14=1:2
for i15=1:2
S=[S;[i1 E(i2) E(i3) E(i4) E(i5) E(i6) E(i7) E(i8) E(i9) E(i10) E(i11) E(i12) E(i13)
E(i14) i15]];
 end
end
end
end
end
end
end
end
end
end
end
end
end
end
end
```

A.8: Experts contact details

Expert name	Academic's Institution	Email address
Prof. Dr. Nazia Binti Abdul Majid	Institute of Biological Sciences Faculty of Science, University of Malaya	nazia@um.edu.my
Dr. Jameel Rabee Jameel Al-Obbaid	Faculty if science and mathematics, University Pendidkan Sultan Idris	jameel@fsmt.upsi.edu.my
Dr . Leong Huey Yng	Faculty of Science, University of Malaya	leonghy@um.edu.my

A.9: COVID 19 Treatment Evaluation Survey

COVID 19 Treatment Evaluation based on 15 evaluation criteria

Dear Professors/ Doctors,
This survey intends to analyze 14 criteria in order to identify the most serious cases that should be prioritized for COVID 19 treatment and specify the importance of each criterion against the others in order to assist us in selecting which patient should be treated first.
We would like to mention that this survey is a part of the collecting data for the Phd study.

Participant Background

Please Provide the Following Information;
Name *
Your answer
University *
Your answer
How long have you been working in this field? *
Your answer
E-mail *
Your answer

A Brief Overview of Selected Criteria

Based on the literature, we have chosen 14 criteria to select the most critical cases that should be prioritized in taking the treatment for COVID 19, which are

1) Age
2) Hypertension
3) Cardiovascular disease
4) Heart diseases
5) Chronic respiratory disease

6) Chronic Kidney disease
7) Diabetes
8) Immunosuppressive disease
9) Receiving immunosuppressive treatment
10) Pregnant
11) Sickle cell disease
12) Neurodevelopmental disorder
13) Medical-related technological dependence
14) Covid-19 disease severity

Each one of these criteria is detailed with a brief explanation in the following sections.

Age

The risk increases for people in their 50s and increases in 60s, 70s, and 80s. People 85 and older are the most likely to get very sick. Other factors can also make you more likely to get severely ill with COVID-19, such as having certain underlying medical conditions in older citizens.

What does the "Age" criteria's importance level mean to you if it is used to evaluate the most critical cases that should be prioritized in taking the treatment?*

Very low importance
Low important
Medium importance
Important
Very important

Hypertension

COVID-19 around the world shows a higher risk of COVID-19 infections and medical complications in people with high blood pressure. The data from both China and the U.S. also shows that high blood pressure is the most commonly shared pre-existing condition among those hospitalized due to COVID-19 infections.

What does the "Hypertension" criteria's importance level mean to you if it is used to evaluate the most critical cases that should be prioritized in taking the treatment? *

Very low importance
Low important
Medium importance
Important
Very important

Cardiovascular disease

COVID-19 interacts with the cardiovascular system on multiple levels, increasing morbidity in patients with underlying cardiovascular conditions and provoking myocardial injury and dysfunction.

What does the "Cardiovascular disease" criteria's importance level mean to you if it is used to evaluate the most critical cases that should be prioritized in taking the treatment?*

Very low importance
Low important

Medium importance
Important
Very important

Heart diseases

Having heart conditions such as heart failure, coronary artery disease, cardiomyopathies, and possibly high blood pressure (hypertension) can make you more likely to get severely ill from COVID-19. Having heart conditions such as heart failure, coronary artery disease, cardiomyopathies, and possibly high blood pressure (hypertension) can make you more likely to get severely ill from COVID-19.

What does the "Heart diseases" criteria's importance level mean to you if it is used to evaluate the most critical cases that should be prioritized in taking the treatment?*

Very low importance
Low important
Medium importance
Important
Very important

Chronic respiratory disease

Patients with chronic respiratory diseases, particularly chronic obstructive pulmonary disease, have a high risk for COVID-19 infection due to their poor underlying lung reserve and increased expression of angiotensin-converting enzyme 2 (ACE-2) receptor in the small airways.

Obesity Body Mass Index: Obesity is a common, serious, and costly chronic disease. Having obesity puts people at risk for many other serious chronic diseases and increases the risk of severe illness from COVID-19. Obesity is linked to impaired immune function and decreased lung capacity and reserve and can make ventilation more difficult.

What does the "Chronic respiratory disease" criteria's importance level mean to you if it is used to evaluate the most critical cases that should be prioritized in taking the treatment?*

Very low importance
Low important
Medium importance
Important
Very important

Chronic Kidney disease

Many studies reported a higher risk of COVID-19 disease among patients on dialysis or with kidney transplantation, and the poor outcome of COVID-19 in these patients. The incidence of COVID-19 among Chronic Kidney disease patients was strongly related to the spread of the infection in the community, while its lethality is associated with the underlying kidney condition and comorbidities. COVID-19 related mortality was about ten times higher than that of Chronic Kidney disease patients without COVID.

What does the "Chronic Kidney disease" criteria's importance level mean to you if it is used to evaluate the most critical cases that should be prioritized in taking the treatment?*

Very low importance

Low important
Medium importance
Important
Very important

Diabetes

People with diabetes are more likely to have serious complications from COVID-19. In general, people with diabetes are more likely to have more severe symptoms and complications when infected with any virus. It's not that people with diabetes are more prone to COVID, but if they develop COVID, the disease is much more severe and seems to progress faster.

What does the "Diabetes" criteria's importance level mean to you if it is used to evaluate the most critical cases that should be prioritized in taking the treatment?*

Very low importance
Low important
Medium importance
Important
Very important

Immunosuppressive disease

Immunosuppression is associated with a more severe course of COVID-19 with a higher odds of in-hospital death, in-hospital death or ICU admission, and several in-hospital complications (bacterial pneumonia, ADRS, heart failure, myocarditis, thromboembolic disease, and multiorgan failure).

What does the "Immunosuppressive disease" criteria's importance level mean to you if it is used to evaluate the most critical cases that should be prioritized in taking the treatment?*

Very low importance
Low important
Medium importance
Important
Very Important

Receiving immunosuppressive treatment

Patients with immune suppression (such as those with cancer, transplant recipients, or receiving immunosuppressive drugs) could be presumed to have a worse prognosis of COVID-19. Immunosuppressed patients hospitalized with COVID-19 have a higher odds of in-hospital death and several in-hospital complications than non-immune suppression patients.

What does the "Receiving immunosuppressive treatment" criteria's importance level mean to you if it is used to evaluate the most critical cases that should be prioritized in taking the treatment?*

Very low importance
Low important
Medium importance
Important
Very Important

Pregnant

Pregnant and recently pregnant people are more likely to get severely ill from COVID-19 compared to non-pregnant people. Data revealed that Pregnant Women were Slower to Respond to COVID-19 Vaccine.

What does the "Pregnant" criteria's importance level mean to you if it is used to evaluate the most critical cases that should be prioritized in taking the treatment?*

Very low importance
Low important
Medium importance
Important
Very Important

Sickle cell disease

Patients with sickle cell disease are more likely to have a high prevalence of the various comorbidities that can put individuals at high risk [for] severe illness and death related to COVID-19.

What does the "Sickle cell disease" criteria's importance level mean to you if it is used to evaluate the most critical cases that should be prioritized in taking the treatment?*

Very low importance
Low important
Medium importance
Important
Very Important

Neurodevelopmental disorder

people with Neurodevelopmental disorder disabilities who have serious underlying medical conditions may be at risk of serious illness. Some people with Neurodevelopmental disorder may have difficulties accessing information, understanding or practising preventative measures, and communicating symptoms of illness.

What does the "Neurodevelopmental disorder" criteria's importance level mean to you if it is used to evaluate the most critical cases that should be prioritized in taking the treatment?*

Very low importance
Low important
Medium importance
Important
Very Important

Medical-related technological dependence

Patients with Medical-related technological dependence (not related to COVID-19) such as (tracheostomy, positive pressure ventilation) may develop severe covid 19 illness. Those cases are considered high-risk criteria conditions that are associated with severe COVID-19 in adolescents.

What does the "Medical-related technological dependence" criteria's importance level mean to you if it is used to evaluate the most critical cases that should be prioritized in taking the treatment?*

Very low importance
Low important
Medium importance
Important
Very Important

Covid-19 disease severity

What does the "Covid-19 disease severity" criteria's importance level mean to you if it is used to evaluate the most critical cases that should be prioritized in taking the treatment?*
Very low importance
Low important
Medium importance
Important
Very Important

Thank You For Your Participation

A 10. COVID 19 Treatment survey Responses

Timestamp	Name	University	How long have you been working in this field?	E-mail	What does the "Age" criteria's importance level mean to you if it is used to evaluate the most critical cases that should be prioritized in taking the treatment?	What does the "Hypertension" criteria's importance level mean to you if it is used to evaluate the most critical cases that should be prioritized in taking the treatment?	What does the "Cardiovascular disease" criteria's importance level mean to you if it is used to evaluate the most critical cases that should be prioritized in taking the treatment?	What does the "Heart diseases" criteria's importance level mean to you if it is used to evaluate the most critical cases that should be prioritized in taking the treatment?	What does the "Chronic respiratory disease" criteria's importance level mean to you if it is used to evaluate the most critical cases that should be prioritized in taking the treatment?	What does the "(Obesity Body Mass Index" criteria's importance level mean to you if it is used to evaluate the most critical cases that should be prioritized in taking the treatment?	What does the "Chronic Kidney disease" criteria's importance level mean to you if it is used to evaluate the most critical cases that should be prioritized in taking the treatment?	What does the "Diabetes" criteria's importance level mean to you if it is used to evaluate the most critical cases that should be prioritized in taking the treatment?	What does the "Immunosuppressive disease" criteria's importance level mean to you if it is used to evaluate the most critical cases that should be prioritized in taking the treatment?	What does the "Receiving immunosuppressive treatment" criteria's importance level mean to you if it is used to evaluate the most critical cases that should be prioritized in taking the treatment?	What does the "Pregnant" criteria's importance level mean to you if it is used to evaluate the most critical cases that should be prioritized in taking the treatment?	What does the "Sickle cell disease" criteria's importance level mean to you if it is used to evaluate the most critical cases that should be prioritized in taking the treatment?	What does the "Neurodevelopmental disorder" criteria's importance level mean to you if it is used to evaluate the most critical cases that should be prioritized in taking the treatment?	What does the "Medical-related technological dependence" criteria's importance level mean to you if it is used to evaluate the most critical cases that should be prioritized in taking the treatment?	What does the "Covid-19 disease severity" criteria's importance level mean to you if it is used to evaluate the most critical cases that should be prioritized in taking the treatment?
11/2/2021 7:55:32	Jameel Al-Obaidi	Universiti Pendidikan Sultan Idris	17	jameel@fmt.upsi.edu.my	Very important	Important	Important	Important	Very important	Low important	Medium importance	Medium importance	Important	Important	Low important	Low important	Low important	Low important	Very Important
11/2/2021 11:44:23	Nazia Abdul Majid	Universiti Malaya	12	nazia.abdulmajid@gmail.c	Very important	Medium importance	Medium importance	Medium importance	Medium importance	Important	Medium importance	Medium importance	Very Important	Important	Medium importance	Low important	Medium importance	Medium importance	Important
11/2/2021 12:03:58	Leong Huey Yng	Universiti Malaya	Not related	leonghy@um.edu.my	Very important	Important	Very important	Very important	Very important	Medium importance	Important	Important	Very Important	Very Important	Important	Very Important	Medium importance	Very Important	Very Important