Annals of Operations Research (2023) 328:1151–1179
https://doi.org/10.1007/s10479-022-05016-4

ORIGINAL RESEARCH

National IoMT platform strategy portfolio decision model under the COVID-19 environment: based on the financial and non-financial value view

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Accepted: 29 September 2022 / Published online: 15 October 2022

Abstract
The Internet of Medical Things (IoMT) is an emerging technology in the healthcare revolution which provides real-time healthcare information communication and reasonable medical resource allocation. The COVID-19 pandemic has had a significant effect on people's lives and has affected healthcare capacities. It is important for integrated IoMT platform development to overcome the global pandemic challenges. This study proposed the national IoMT platform strategy portfolio decision-making model from the non-financial (technology, organization, environment) and financial perspectives. As a solution to the decision problem, initially, the decision-making trial and evaluation laboratory (DEMATEL) technology were employed to capture the cause-effect relationship based on the perspectives and criteria obtained from the insight of an expert team. The analytic network process (ANP) and pairwise comparisons were then used to determine the weights for the strategy. Simultaneously, this study incorporated IoMT platform resource limitations into the zero–one goal programming (ZOGP) method to obtain an optimal portfolio selection for IoMT platform strategy planning. The results showed that the integrated MCDM method produced reasonable results for selecting the most appropriate IoMT platform strategy portfolio when considering resource constraints such as system installation costs, consultant fees, infrastructure costs, reduction of medical staff demand, and improvement rates for diagnosis efficiency. The decision-making model of the IoMT platform in this study was conclusive and significantly compelling to aid government decision makers in concentrating their efforts on planning IoMT strategies in response to various pandemic and medical resource allocations.

Keywords National IoMT platform strategy · COVID-19 · Resource planning in pandemics · Multiple criteria decision making (MCDM) · Zero–one goal programming (ZOGP)

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1 Introduction

At the end of 2019, an unexplained type of pneumonia, the symptoms of which were fever and respiratory illness, appeared in Wuhan of China, but there was no evidence of transmission from person to person (Chakraborty & Maity, 2020; Sohrabi et al., 2020). In January 2020, the first confirmed case of 2019-novel coronavirus (2019-nCoV) appeared outside of China, and the World Health Organization (WHO) confirmed that the virus could transmit from person to person through droplets and contact (McFee, 2020). In February 2020, the epidemic was officially named Coronavirus Disease 2019 (COVID-19), and the WHO announced that COVID-19 was a pandemic (WHO, 2021).

Taiwan faced the Severe Acute Respiratory Syndrome (SARS) epidemic in 2003. With the lessons learned from SARS, the Taiwan Centers for Disease Control (Taiwan CDC) implemented border control measures with various countries and required entrants to fill in COVID-19 health declaration cards in the airports (Nakamura & Managi, 2020). However, at the beginning, most countries and the WHO ignored the threat of COVID-19, and this resulted in a large number of patients swarming into hospitals and causing medical staff, intensive care units, negative pressure isolation wards and various medical resources to be insufficient, and medical staff became infected (Dey et al., 2020). With the pandemic continuing to worsen, the prices for important medical supplies went up and medical systems became stressed, causing patients to be unable to get proper care and creating panic.

Taiwan has advantages over other countries in the development of the semiconductor industry and the 5th generation (5G) wireless system industry. The rapid development of the Internet of Things (IoT) and the combination of the semiconductor industry with the medical industry have led to the development of many connected medical equipment and devices. Jin et al. (2019) pointed out that the real-time acquisition of data by technology based on the Internet of Medical Things (IoMT) is helpful for the analysis and prediction of medical data. Greco et al. (2020) suggested that the growth of connected devices will greatly change the way global healthcare is performed. Singh et al. (2020a, 2020b) pointed out that IoMT has advantages in data sharing, report monitoring, patient tracking, information collection and analysis, and health care. During the COVID-19 pandemic, the Taiwan government used advanced medical technology to effectively control the situation.

Although the COVID-19 pandemic seemed to be controlled in Taiwan during 2020, it was actually still unstable. COVID-19 could not be controlled and solved in any country, and a number of variants emerged. In December 2020, a variant of the coronavirus was found in the United Kingdom, and this variant spread to the entire world. At the end of April 2021, a variant of the coronavirus was found in India. This variant spread faster than before, causing India to have the second highest number of confirmed cases in the world.

From May 2021, Taiwan also suffered from the second wave of COVID-19. Community transmission broke out and many hospitals developed cluster infections, which caused the need for negative pressure isolation wards to increase and put additional pressure on the medical staff. The pandemic was so serious that the Taiwan CDC was unable to finish conducting investigations immediately. Therefore, the Taiwan government launched the Taiwan Social Distancing app and promoted a contact tracing policy to record and integrate people's interactions to send automated warnings about suspicious cases. People who received a warning could then report their status to the Taiwan CDC, which sped up the investigation of the epidemic and the screening and isolation of suspicious cases.

During the COVID-19 period, to avoid contact with others, people mostly stayed at home and reduced their work and various activities, which reduced industrial exhaust emissions and made the earth as seen from outer space look particularly clean and beautiful (Chakraborty & Maity, 2020; Saxena & Raj, 2021). However, global warming continues to endanger species and even wake up dormant bacteria and viruses in icebergs and deep seabeds. In the future, people may face more severe public health challenges than COVID-19 (Hiscott et al., 2020; Manzanedo & Manning, 2020; Naderipour et al., 2020). In addition to facing sudden public health problems, most developed countries have aging societies with declining birthrates, putting increased pressure on medical systems and the economy (Algarni, 2019). Long-term care and healthy cities are becoming more important (Niu et al., 2020).

The popularity of emerging digital technologies has provided solutions in the fight against the unprecedented COVID-19 pandemic and contributed to increasing the efficiency of humanitarian supply chain operation processes (Bhusiri et al., 2021; Marić et al., 2021; Queiroz & Wamba, 2021). The Taiwan government used numerous information systems at the beginning of COVID-19 to control the pandemic, used these information systems to maintain medical resources in 2020, and used them again to fight the second wave of the COVID-19 pandemic. However, the systems developed in response to COVID-19 were scattered. As people may face similar public health problems again in the future, this study aimed to explore the integration and connection of these dispersed systems and find out the priority of which alternatives, under the technology, organization, environment, and financial perspectives, affect the construction of the IoMT platform. IoMT platform evaluation is a complex problem that needs to utilize a suitable methodology to select the best solutions. Multi-criteria decision making (MCDM) is a decision-making method that assists decision-makers in assessing the optimal solutions from multiple dimensions and alternatives. Under the COVID-19 pandemic environment, it is important to develop a hybrid academic and practice decision model that employs operations research (OR) to respond to COVID-19 challenges (Choi, 2021).

The technology-organization-environment theory proposed by Tornatzky, Fleischer, and Chakrabarti in 1990 is often used to study the influencing factors of new information systems. Al-Turjman et al. (2020) pointed out that the development of the medical industry in the twenty-first century needs to rely on medical technology. The main challenge of medical technology is increasing costs; therefore, reducing medical costs while improving medical quality, efficiency, and effectiveness is important. This study explored the key factors of establishing a national IoMT platform strategy based on technology, organization, environment, and financial aspects. COVID-19 is a sudden public health problem. Asadzadeh et al. (2020) indicated that IoMT is key to the success of controlling COVID-19, and the government plays an important role in building IoMT systems and supporting them with financial resources. The government should try to establish a complete national IoMT platform. However, resources are limited, and decision makers cannot establish all information strategies at once. Besides, the information systems and evaluation criteria related to COVID-19 are new and complex. Therefore, this study established a national IoMT platform strategy decision model based on the financial and non-financial (technology, organization, environment)value views employed by the integrated multi-criteria decision-making (MCDM) method, including the decision-making trial and evaluation laboratory (DEMATEL), analytic network process (ANP), and zero–one goal programming (ZOGP).

Modern decision-makers use mathematical programming methods when solving strategically significant and innovative issues, such as the formulation of the sustainable periodic capacitated arc routing problem (PCARP) for MSW management by the mixed-integer linear programming (MILP) model (Tirkolaee et al., 2022), and developed Grey Wolf Optimization (GWO) and Particle Swarm Optimization (PSO) algorithms to solve a novel two-echelon multi-product Location-Allocation-Routing problem (LARP) in a Supply Chain Network

(Tirkolaee et al., 2021). Many studies have applied mathematical programming model to healthcare issues, such as optimization computation for the organ transplants supply chain under shipment time uncertainty (Goli et al., 2022), developed a state-variable model to solve the two-stage stochastic weekly operating room planning problem with an exponential number of scenarios (Hashemi Doulabi & Khalilpourazari, 2022), and focus on the COVID-19 pandemic trend prediction (Khalilpourazari & Hashemi Doulabi, 2021; Khalilpourazari et al, 2021). Therefore, to optimize the limited resource of IoMT platform, it is essential to establish the decision model to control the COVID-19 pandemic risk effectively.

Incorporating resource constraints planning into matrix computations and mathematical programming can satisfy the need for rigorous decision model effectiveness while simultaneously identifying cause-effect associations and the optimal IoMT platform strategy portfolios. Compared to the analytic hierarchy process (AHP), which focused on the independence to multiple evaluate components regarding the decision goal with multiple separate matrices. Clearly, DEMATL and ANP integrated provide several directional associations and cause-effect implications. DEMATEL and ANP have the advantage of collecting expert opinions, accompanied by agile and flexible characteristics for identifying the interdependence between decision components. Simultaneously, resource planning for IoMT platforms is important. ZOGP has the primary advantages of identifying the resource requirements of the platform strategy, and considering the obtained weights of the ANP method as well as multiple resource goals. Finally, the hybrid MCDM methodology can provide the optimal strategy portfolios as well as reasonable resource input and allocation suggestions.

The findings of this study contributed to the academia, industry, and official policy makers by providing an optimal decision model for IoMT platform strategy portfolios.

- For the academic field, this study contributed to the innovation operation research (OR) literature on IoMT platform strategy planning. In addition, it demonstrated the interrelationships among financial and non-financial criteria and the influence of evaluation criteria on each other, and it provided more precise and optimal strategy portfolios using goal programming methodology.
- For the industrial field, this study contributed to a better understanding of how IoMT platform system suppliers can improve resource allocation. The integrated model of this study considers financial and non-financial criteria, system construction costs, consultant fees, and IoMT infrastructure costs, in addition to incorporating the reduction of the medical staff demand and improvement rate for diagnosis efficiency into the model to promote the decision quality.
- For the policy field, this study provided innovative ideas and directions for developing the integrated IoMT platform strategy portfolio decision model, which may help governments and policymakers make efficient and effective policy formulations to face the challenges of medical resource allocations under the effects of the COVID-19 pandemic.

The content of this article is as follows. Chapter 2 provides a comprehensive literature review of the Internet of Medical Things, using the technology, organization, environment, and financial perspectives to establish evaluation criteria that are applicable to the decision-making of national IoMT platform strategies under the impact of the pandemic. Chapter 3 describes the research methods used in this study. Chapter 4 briefly introduces case studies and provides the results. Chapter 5 introduces the discussion and compare prior study results. Chapter 6 provides a conclusion and management implication for the hybrid decision model.

2 Literature review

This section mainly discusses the Internet of Medical Things (IoMT) and various medical information strategies under the COVID-19 environment by a review of the relevant literature and then proposes a decision model with key evaluation perspectives and criteria.

2.1 Internet of medical things (IoMT)

In the era of Industry 4.0, cyber-physical systems (CPS) and the Internet of Things (IoT) are being used as innovative technological based, and Innovation 2.0 is being used to develop smart cities that include smart healthcare. Based on sensors, integrated circuits, and wireless communication, the Internet of Things (IoT) is being applied in many fields. With the rapid development of medical technology, there has been a massive increase in connected medical devices that can send health records to cloud platforms through fast network transmissions and save information in large databases under a safe network environment (Javaid et al., 2020). The increasing number of connected medical devices has caused the Internet of Medical Things (IoMT) to boom. People use the IoMT to generate, collect, analyze, and transmit data, which reduces the workload of medical staff, decreases the cost of medical, and enhances treatment efficiency (El-shafeiy et al., 2021; Singh et al., 2020a, 2020b).

In the COVID-19 environment, IoMT can help patients infected with COVID-19 to identify symptoms quickly and help medical staff get real-time patient data, make accurate medical plans, monitor patients from a distance, reduce direct contact with patients, and soothe their workload, as well as help governments track and monitor the infected and those at risk of infection (Singh et al., 2020a, 2020b; Swayamsiddha & Mohanty, 2020). The number of confirmed worldwide COVID-19 cases continues to increase, therefore an IoMT platform should be established to handle a large number of interconnected devices and systems, strengthen the public health system, and create an intelligent network to end the spread of COVID-19 as soon as possible (Singh et al., 2020a, 2020b; Swayamsiddha & Mohanty, 2020).

Asadzadeh et al. (2020) indicated that the IoMT is the key to controlling COVID-19, and the government plays an important role in building IoMT systems and providing financial resource support. With the number of confirmed worldwide cases increasing continuously, building a sound network environment and analyzing its cost and benefit is necessary for organizations to use IoMT technology to control COVID-19 (Singh et al., 2020a, 2020b; Swayamsiddha & Mohanty, 2020). During the COVID-19 pandemic, the Taiwan government integrated industry and academia to use the benefits of the IoMT for public health problems and to support the development of a smart medical ecosystem. However, the medical information system of Taiwan has not been fully integrated, the cloud database has not been built completely, and the system cannot completely resist hackers at present. In the future, the government must work to solve these problems and continue to strengthen the training of digital talents, revise digital laws and regulations, create a comprehensive national IoMT platform, improve the quality of value-based care, and reduce the cost of national medical care.

2.2 National IoMT platform strategy (NIoMTPS) in the COVID-19 environment

Haughey et al. (2018) pointed out that people, data, processes, and key technology are integrated into the IoMT. “People” refers to patients and medical care clinicians, “data” refers to patient data or treatment result data, “processes” refers to medical services and patient support services, and “key technology” refers to connected medical equipment and mobile applications. Asadzadeh et al. (2020) indicated that it is important for governments to establish an IoMT platform. Therefore, under the continuing COVID-19 pandemic, this study discussed national IoMT platform strategies based on a literature discussion and then established the analytic framework. The information strategy is described in Table 1.

2.3 Evaluation perspectives and criteria of the national IoMT platform strategy

The aims of this study were to find the selection of national IoMT platform strategies in a COVID-19 environment and to take the technology-organization-environment theory (Tornatzky et al., 1990) as the evaluation perspective to discuss the important factors encountered in all processes of introducing new technologies and information systems into an organization. Zhang et al. (2020) stated the Technology, Organization, Environment (TOE) theory is useful for identifying necessary factors. Al-Turjman et al. (2020) pointed out that the development of the medical industry in the twenty-first century needs to rely on medical technology, and that the main challenge of medical technology is increasing costs. In addition, Asadzadeh et al. (2020) indicated that the IoMT is useful for controlling COVID-19, and it needs the financial resource support of the government. Therefore, this study also used financial perspectives to evaluate and establish a national IoMT platform strategy. This study reviewed the historical literature, found the corresponding criteria of the overall evaluation, and built a decision model for a national IoMT platform.

2.3.1 Technology perspective

The governments of all countries have been committed to finding a solution to the COVID-19 pandemic. Regarding the technology perspective, the medical industry is using numerous connected medical devices to gather and monitor patient data (Tian et al., 2019). However, data formats are not unified, and the right to the free use of data is limited to the systems developed by each company, therefore data cannot be widely used. Governments must try their best to cooperate with the industry to obtain the right to use data and integrate data. Connected medical devices can be used to develop a pandemic prevention technology platform and precision medicine technology to fight the COVID-19 pandemic (Yadav et al., 2021; Yang et al., 2020).

Alam and Rahmani (2020) mentioned that the current IoMT data formats are inconsistent and distributed on devices with different access rights, presenting numerous challenges for effectively using healthcare data. IoMT information strategies enable the increased development speed of pandemic prevention technology platforms. François et al. (2021) established an emergency additive manufacturing platform and used 3D printed medical technology to manufacture personal protective equipment and medical equipment and to ease equipment shortages. IoMT information strategies can promote the development of precision medical technology. Carney (2014) pointed out that as the knowledge of genomics increases, the application of precision medicine will expand to the entire field of cancer treatment. Precision medicine defined as collecting clinical care information and processing complex genomic information to treat various diseases. However, the recent definition of precision medicine is broader. Denicolai and Previtali (2020) indicated that precision medicine is part of a medical revolution in which treatment transitions to prevention. Therefore, governments of various countries should build IoMT platforms to generate data, develop pandemic prevention technology platforms, and promote the development of precision medical technology to control COVID-19.

Table 1 Information strategies of the national IoMT platform

Function	Information strategy	Information strategy requirement definition	References
People	Virtual care robots	Virtual care robots are a combination of databases and robots that can replace simple medical labor and reduce the work pressure of medical staff	Dey et al. (2020) Kuziemski & Misuraca (2020)
	Human resources for health	Human resources for health represent the improvement of health care quality. Through the system of human resources to provide stable human resource allocation information	Kroezen et al. (2018) Saw et al. (2019)
Data	Inventory management systems	The domestic emergency supply lines are necessary to adjust and build a complete medical material inventory management system to cope with unknown public health incidents	Tempe et al. (2020) Chigurupati et al. (2020)
	Electronic health records	Electronic health records can ensure data confidentiality, integrity, and availability during the COVID-19 pandemic, and can promote medical monitoring and personalized medical services	Sharma & Balamurugan (2020) Shi et al. (2020)
Processes	Emergency medical services	Emergency medical services that provide rapid assessment, timely provision of appropriate interventions, and prompt transportation to the nearest appropriate health facility	Delaney et al. (2022) Dumka & Sah (2020)
	Remote robotic surgery	Remote robotic surgery allows patients to be in a safe space and allows doctors to perform operations from a distance, which can cut down the risk of infection between medical staff and patients	Alip et al. (2022) Hung et al.(2018)
Key technology	Remote health monitoring systems	Remote health monitoring systems use safe and mature telemedicine facilities to assist medical consultations, and can be used to collect, transmit, store, and analyze patient data	Javaid et al. (2020) Swayamsiddha & Mohanty (2020)

Table 1 (continued)

Function	Information strategy	Information strategy requirement definition	References
	Geographic information systems	Geographic information systems can locate infected persons and their contacts, monitor individuals under home quarantine, and perform a complete investigation of an epidemic	Saeed et al. (2021) Milenkovic et al. (2020)

2.3.2 Organization perspective

Regarding the organization orientation, when governments face a shortage of medical staff, they will use medical technology to fill the gap. With the development of medical technology, many regulations on medical equipment, medical behavior, and medical ethics must be revised so as to standardize the development of emerging technologies (Jan et al.,2021). At the same time, the training of digital technology R&D talents and smart medical related talents should be strengthened to cope with the rapid development of medical technology (Minissian et al., 2020).

IoMT information strategies promote the government's modification of digital healthcare-related laws and regulations to facilitate the development of the IoMT. Shenkoya (2020) mentioned that Europe and the United States are actively revising digital medical regulations to regulate the privacy of medical information and the network security issues arising from the use of connected medical devices. Regulation reform is an important success factor in the development of connected medical devices and the IoMT. Minissian et al. (2020) and Adesoye et al. (2020) pointed out that COVID-19 has changed how medical staff takes care of patients as well as the education and training methods of medical staff. COVID-19 is a fast-developing situation, and it is important to actively train digital talent to develop advanced medical technology and train medical staff to use innovative medical technology to achieve the goal of effective pandemic control. IoMT information strategies can alleviate the shortage of medical staff and reduce the chance of human error. Dey et al. (2020) found that most countries are facing the challenge of medical staff shortages under the COVID-19 situation. Elbay et al. (2020) and Lefèvre et al. (2020) pointed out that the workload of medical staff in the fight against COVID-19 has increased dramatically, and this has also increased the mental stress and psychological problems of medical staff. Swayamsiddha and Mohanty (2020) pointed out that the IoMT can track, screen, and monitor patients, reduce the workload of the medical industry, and relieve medical stress.

2.3.3 Environment perspective

In terms of the environment, the government is supporting the medical industry chain and promoting the development of the medical ecosystem so that more emerging medical technologies can be created to solve the COVID-19 problem. At the same time, it is strengthening the privacy and security of patient information and allowing emerging connected medical technologies to effectively and safely control the pandemic (Farouk et al., 2020).

Samuel et al. (2020) found that remote healthcare systems, including IoMT systems, could achieve effective medical risk monitoring of heart disease. The IoMT can improve the speed and accuracy of diagnosis and treatment and provide real-time risk monitoring of the health status of patients. Ray et al. (2020) and Konwar and Borse (2020) indicated that the IoMT promotes the cooperation and development of the medical ecosystem, including medical practitioners, caregivers, hospitals, and clinics. In order to control COVID-19, the medical industry is using a large number of connected facilities, which prompts medical material manufacturers to continue developing medical technology, changes the way medical staff take care of patients, lets patients receive better care and promotes the development of the medical ecosystem. IoMT information strategies can promote the government to establish a safer network environment and protect the privacy of patients. Farouk et al. (2020) pointed out that the IoMT environment needs to ensure privacy and security to improve the diagnostic accuracy of shared electronic health records. Yaacoub et al. (2020) emphasized that information security and privacy are important for enhancing the immunity of the IoMT to cyber-attacks. Singh et al., (2020a, 2020b) mentioned the importance of the security and privacy of received data when using the IoMT in the age of COVID-19.

2.3.4 Financial perspective

In terms of the financial perspective, because resources are limited and the COVID-19 pandemic must be resolved immediately, the government has committed to establishing an IoMT platform to reduce redundant investments and resource waste in the medical system. Establishing an IoMT platform can enable medical staff to work efficiently and effectively, enable patients to obtain value-based care (Demiris et al., 2020), and enable the medical industry to obtain shared data resources to create more medical technologies. Such actions could reduce costs for the medical industry, improve the value of medical care, and control the COVID-19 pandemic (Manjunathan et al., 2020).

Pereno and Eriksson (2020) pointed out that innovative technology is essential to promote fundamental sustainable innovation in the medical industry. Under COVID-19, innovative IoMT information strategies have changed the way medical staff care for patients to provide specialized care for each patient. In addition to treating existing diseases, these strategies also provide value-based care for future healthy lives. Newell (2020) mentioned that COVID-19 has changed the way of medical care to improve work processes and reduce costs. During the period of COVID-19, the medical industry has increasingly used IoMT equipment to supervise patient conditions through remote monitoring, thereby reducing the transportation cost of going to the hospital. These systems also protect patients from emergency situations through real-time monitoring, and they can reduce the amount of additional medical expenses. Chen et al. (2020) believed that to solve the COVID-19 problem, it is necessary to strengthen cooperation and resource sharing between various departments. Galvin et al. (2020) mentioned that resource and data sharing can enable the medical industry to develop better medical care to fight COVID-19.

3 Research methodology

This study combined multiple methods into the multiple-criteria decision-making (MCDM) method, including the decision-making trial and evaluation laboratory (DEMATEL), analytic network process (ANP), and zero–one goal programming (ZOGP), to establish the national

IoMT platform framework and obtain optimal portfolios under resource limitations. The detailed study methodologies are shown in the following sections.

3.1 Decision making trial and evaluation laboratory (DEMATEL)

The decision making trial and evaluation laboratory (DEMATEL) is a structural modeling tool used to address complex problems with interacting factors. It can be used to find cause-effect influencing relationships between factors, including the intensities and directions, and can visualize the impact-relation map. DEMATEL was developed by Gabus and Fontela, who worked on the Science and Human Affairs Program of the Battelle Memorial Institute in Geneva from 1972 to 1976. DEMATEL is usually combined with expert surveys to get the advice of professionals. The questionnaire implemented by this study used a five-level assessment scale to measure the perspectives and criteria of the NIoMTPS.

In this study, the IoMT platform strategy evaluation factors extracted from the literature on the technology, organization, environment, and financial dimensions were used to construct a structured set of questions to identify the evaluation criteria that may influence the selection of IoMT platform strategies (the function of people, data, process, and key technology). These criteria are outlined in Table 2.

This study asked the experts to provide their professional advice on the effect of each factor i on each factor j. a_{ij} denotes the average influence degree of the experts' advice. $B = \{B_1, B_2, \cdots, B_n\}$ is a set of nodes, available perspectives, and criteria, for which particular pair-wise relations can be determined.

The matrix Q is the initial average matrix. When i is equal to j, a_{ij} is equal to zero. The initial average matrix Q is shown in Eq. (1). Through k, the initial average matrix Q is normalized into the normalized direct influence matrix W, as shown in Eqs. (2) and (3). The total relation matrix S is derived through Eq. (4). The total relation matrix S is the sum of the direct and indirect influence between factors.

Table 2 National IoMT platform strategy perspective and criteria

Perspective	Criteria
Technology	Effective data integration (EDI)
	Epidemic prevention technology platform development (EPTPD)
	Precision medicine development (PMD)
Organization	Modification of digital medical regulations (MDMR)
	Digital talent training (DTT)
	Medical stress release (MSR)
Environment	Medical risk monitoring (MRM)
	Medical ecosystem development (MED)
	Network information security enhancement (NISE)
Financial	Value-based care (VC)
	Healthcare cost reduction (HCR)
	Resource sharing benefits (RSB)

$$Q = \begin{array}{c} \\ B_1 \\ B_2 \\ \vdots \\ B_n \end{array} \begin{array}{c} \begin{array}{cccc} B_1 & B_2 & \cdots & B_n \end{array} \\ \begin{bmatrix} 0 & a_{12} & \cdots & a_{1n} \\ a_{21} & 0 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & 0 \end{bmatrix} \end{array} \tag{1}$$

$$W = k \cdot Qk > 0 \tag{2}$$

$$k = Min\left(\frac{1}{\underset{1\le i\le n}{max} \sum_{j=1}^{n} a_{ij}}, \frac{1}{\underset{1\le j\le n}{max} \sum_{i=1}^{n} a_{ij}}\right), i, j \in \{1, 2, 3, \ldots, n\} \tag{3}$$

$$S = W + W^2 + W^3 + \cdots + W^m = W(I - W)^{-1}, when W^m = [0]_{n\times n} \tag{4}$$

$$S = W + W^2 + W^3 + \cdots + W^m$$

$$= W\left(I + W + W^2 + W^3 + \cdots + W^{m-1}\right)(I - W)(I - W)^{-1}$$

$$= W\left(I - W^m\right)(I - W)^{-1}$$

I denotes an n $\times$ n identity matrix, then

$$S = W(I - W)^{-1}, when m \to \infty$$

The total relation matrix S is composed by S_{ij}, which refers to the direct or indirect relation of each factor i on each factor j, and $i, j = 1, 2, \ldots.., n$. D is the sums of the rows in the total relation matrix S, and R is the sums of the columns in the total relation matrix S. Vectors D and R can be calculated as shown in Eqs. (5) to (7). The value of $D + R$ indicates the influencing intensity, which is the sum of the delivered and received relation between each criterion. The value of $D - R$ indicates the net influences of criterion i on other factors. If the value of $D - R$ is greater than zero, the criterion i will be classified in the cause group; conversely, if the value of $D - R$ is less than zero, the criterion i will be classified in the effect group. The threshold value p, the average of S_{ij}, indicates the main cause-effect relation. If the value of S_{ij} is greater than the threshold value p, it means the influencing direction of criterion i to criterion j. In addition, this study visualized the complex interrelationship into the impact-relation map (IRM), constructed by the values of $(D + R,\ D - R)$, where the horizontal axis is $D + R$ and the vertical axis is $D - R$. Finally, this study got the most important influencing criteria and the influencing relations among the criteria.

$$S = \left[S_{ij}\right]_{n\times n}, i, j \in \{1, 2, 3, \ldots, n\} \tag{5}$$

$$D = \left[\sum_{j=1}^{n} S_{ij}\right]_{n\times 1} = [S_i]_{n\times 1} \tag{6}$$

$$R = \left[\sum_{i=1}^{n} S_{ij}\right]_{1\times n} = \left[S_j\right]_{1\times n} \tag{7}$$

3.2 Analytic network process (ANP)

Saaty developed the analytic hierarchy process (AHP) in 1977 to address complex problems with numerous evaluation criteria, such as political candidacy selection. AHP systematizes complex problems into hierarchies, classifies the evaluation criteria to different hierarchies, and evaluates the interrelation of criteria from top to bottom. Realistic problems are always complex, and the interrelation of criteria is dependent, which is against the important assumption of the AHP that the interrelation of criteria is independent. To solve this problem, in 1996, Saaty developed the analytic network process (ANP), which can consider the dependent interrelations of criteria.

First, the decision goal must be clearly defined, and all interrelationships among the criteria should be considered. Decision-makers use their professional opinions at this time to form the network structure through interviews and brainstorming. Second, pairwise comparisons of the criteria are analyzed to create a priority weight matrix, and consistency testing is conducted. The interrelationships are measured using pairwise comparisons. The level of importance can be decided by using a scale from 1 to 9 to represent a range from "equal importance" to "extreme importance", respectively. The general form of matrix K is as follows:

$$K = \begin{matrix} B_1 \\ B_2 \\ \vdots \\ B_N \end{matrix} \begin{bmatrix} B_1 B_2 & \cdots & B_N \\ 1 m_{12} & \cdots & m_{1n} \\ 1/m_{12} 1 & \cdots & m_{2n} \\ \vdots\vdots & \ddots & \vdots \\ 1/m_{1n} 1/m_{2n} & \cdots & 1 \end{bmatrix} \tag{8}$$

In matrix *K,* the problem becomes one of assigning B_1, $B_2 \ldots$, B_n to N criteria. Set B_1 of numerical weights m_{1n}, $m_{2n} \ldots$, m_n represents the expert judgments. The largest eigenvalue can be seen in Eq. (9):

$$\lambda_{max} = \sum_{j=1}^{n} m_{ij} w_j / w_i \tag{9}$$

Saaty (2001) proposed certifying the consistency of the judgments using the decision-makers' CI and CR through the value of a consistency index, as shown in Eqs. (10) and (11):

$$CI = (\lambda_{max} - n)/(n - 1) \tag{10}$$

$$CR = CI/RI \tag{11}$$

The random index (RI) indicates the average consistency index of numerous random entries in the reciprocal matrices. If the CR is less than 0.1, the outcome of the pairwise comparison is acceptable; if the CR is greater than 0.1, the result presents the pairwise criteria for comparison again. Finally, the results of the comparisons are used to generate a supermatrix. According to their relationships with the supermatrix, it is possible to derive the inter-dependence of each evaluation criterion and the weighting priorities of the projects. The results of higher priority weighting projects indicate that the projects with the greatest priority will be selected.

3.3 Zero–one goal programming (ZOGP)

The goal programming (GP) method was first implemented by Charnes, Cooper, and Ferguson in 1955. GP can address problems with many goals, limitations, and factors, incorporating non-linear problems into linear mathematical programming and find the optimal solution under the limitations. However, GP is not exactly the same as linear mathematical programming, the goal of which is to get the best answer (such as the maximum and minimum). The goal of GP is to get the minimum deviation result after considering all goals and limitations. Zero–one goal programming (ZOGP) is an extended application of GP, and the main feature of ZOGP is that optional factors are binary parameters. The ZOGP model is illustrated as follows (Lee & Kim, 2000):

$$MinimizeG = P_k\left(w_j d_i^+, w_j d_i^-\right)$$

Subject to:

$$\sum_{j=1}^{n} f_{ij}x_j + d_i^- - d_i^+ = B_i for i = 1, 2, \cdots, m, j = 1, 2, \cdots, n$$

$$x_j + d_i^- = 1 for i = m+1, m+2, \cdots, m+n, j = 1, 2, \cdots, n$$

$$d_i^+ \geq 0, d_i^- \geq 0 for \forall_i$$

$$x_j = 0 \text{ or } 1 \text{ for } \forall_j$$

Deviational variables can be positive or negative. A positive deviation variable $\left(d_i^+\right)$ represents the over-achievement of the goal, while a negative deviation variable $\left(d_i^-\right)$ represents the under-achievement of the goal. G denotes the sum of the derivation variables from the m goals considered; i denotes m restricted resources; j denotes n selected platform strategy portfolios; P_k is the preemptive priority ($P_1 > P_2 > P_3 >> > P_k$) for goal G; x_j is the

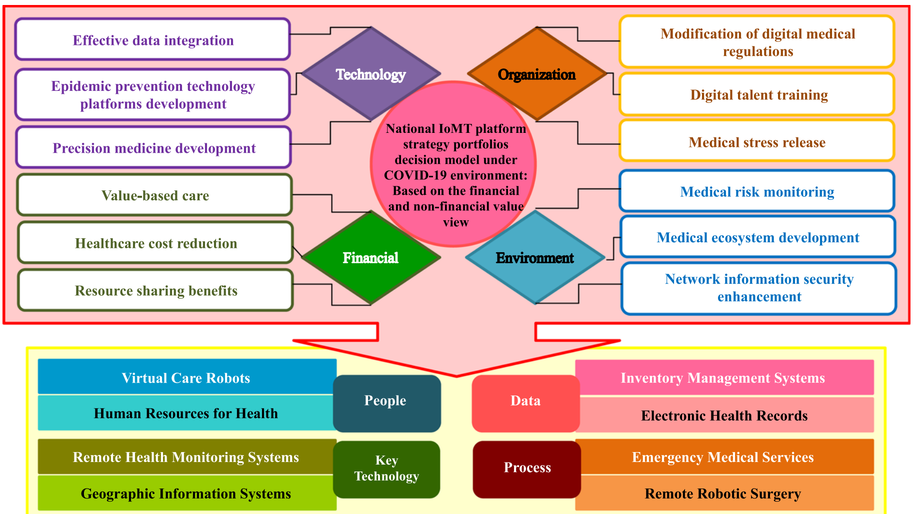

Fig. 1 National IoMT platform strategy portfolio decision model framework

binary variable of the j_{th} project;x_i is the weight value of the ANP results for the i_{th} strategy; f_{ij} is platform parameter j of selection resource i; and B_i is the available resources or limiting factors that must be considered in the process of decision-making and evaluation. The resource requirements considered include the system construction cost, consultant fees, total cost of the IoMT infrastructure, reduction of medical staff demand, and the diagnosis efficiency improvement rate. This study used LINGO 13.0 software to calculate the final optimal portfolio for the national IoMT platform strategy under resource limitations. The National IoMT platform strategy portfolio decision model, as shown in Fig. 1:

4 Empirical example

According to the defined evaluation perspective and criteria introduced in this study, it was important to demonstrate the feasibility of the hybrid MCDM methodology. This study aimed to establish the national IoMT platform strategy decision model under the COVID-19 environment to obtain the optimal IoMT platform strategy portfolios that could effectively satisfy multiple resource constraints. The research flow is shown in Fig. 2.

4.1 Empirical example assumption

COVID-19 appeared without warning at the end of 2019, and a large number of patients poured into hospitals in a short period of time, resulting in insufficient medical staff, medical equipment, and supplies. This study supposed that, at the beginning of the pandemic, the Taiwan government grasped the dynamics of confirmed persons to avoid the expansion of infection and planned to introduce an IoMT platform that could be used to deploy medical staff and equipment resources. In addition, the Taiwan government expected to use the IoMT platform continuously to enhance the quality of the medical industry during the pandemic and in the future. Based on the financial and non-financial views, the Taiwan government looked forward to gaining the optimal national IoMT platform under resource limitations.

4.2 Proposed methodology

This study constructed the evaluation criteria and alternatives of the IoMT platform based on the literature and invited ten experts, including medical institution supervisors, doctors, respiratory therapists, care attendants, and assistant professors, to fill out the questionnaires; however, there was one invalid questionnaire. The experts were engaged in related work such as making diagnoses, taking care of patients, and teaching medical students. The average seniority of the nine experts was 12.9 years. This study designed a DEMTAL questionnaire and an ANP questionnaire, which were both pre-tested by the research team. After revising, this study delivered the DEMATEL questionnaire to the experts in August 2020 and delivered the ANP questionnaire in October 2020. This study let the experts fill in the questionnaires to get their expert professional judgment. This study was separated into three phases to obtain the results. The first phase consisted of using the DEMATEL questionnaire to learn the cause-and-effect relationships among the perspectives and criteria. According to the DEMATEL result into the second phase, the ANP questionnaire, to obtain the expert professional result, which is the weight and priority among criteria and alternatives. The third phase consisted of combining the weights from the ANP and resource limitations into the mathematical programming model of ZOGP to get the optimal NIoMT platform portfolio.

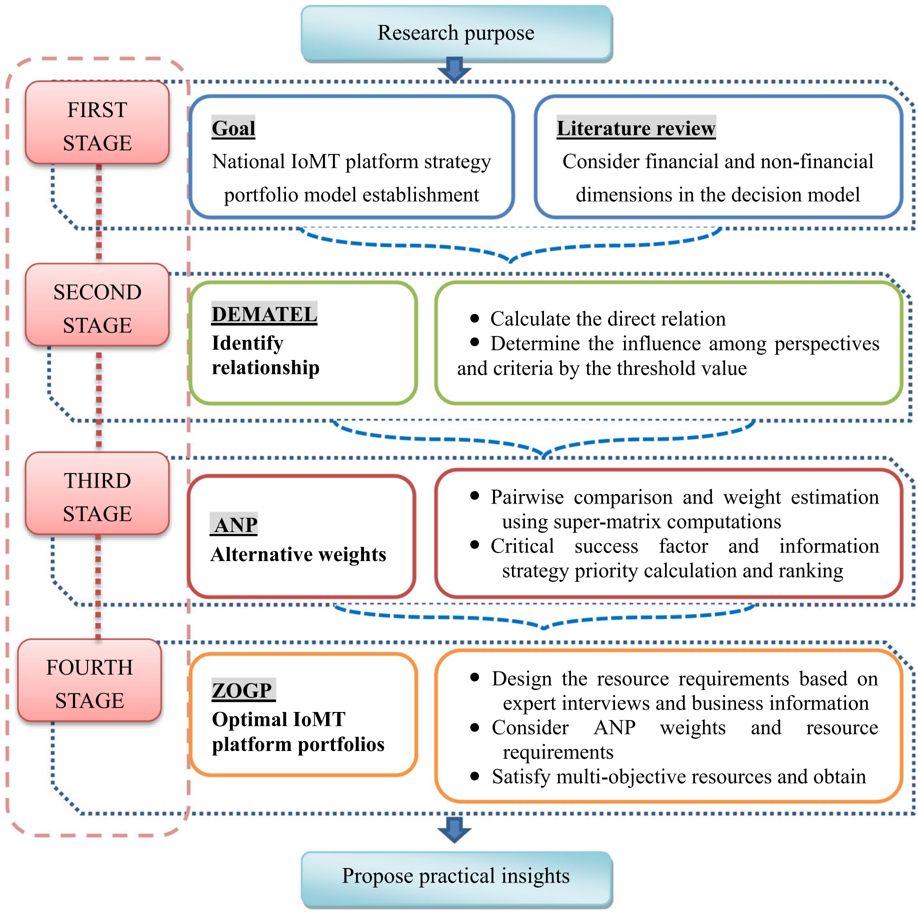

Fig. 2 Proposed hybrid MCDM methodology flowchart

4.3 Application of the research methodology

4.3.1 Evaluate the relationships among perspectives and criteria using DEMATEL

This study implemented DEMATEL to explore the interrelation of each perspective and criterion and then utilized expert feedback to determine the influence directions. If the value was higher than the threshold value of 0.946 for the perspectives and 0.453 for the criteria, the column criteria would affect the row criteria. As shown in Table 3 and Fig. 3, D + R is the horizontal axis and D-R is the vertical axis. The result of D + R indicates the importance value, and the value of D-R is used to separate the result into the cause group and the effect group. The results indicated that the financial perspective (F), with a D + R score of 7.931, had the highest degree of importance. In addition, according to the D-R score, organization (O), with a score of 0.015, and the financial perspective (F), with a score of 1.163, were above the horizontal axis and could be categorized as cause group factors, while technology

Table 3 Total relation matrix of the perspectives for NIoMT platform selection ($p \geq 0.946$)

	Technology	Organization	Environment	Financial	D	D + R	D−R
Technology	0.786	0.921	***0.946***	0.854	3.507	7.572	− 0.558
Organization	***1.080***	0.811	***1.037***	0.917	3.845	7.675	0.015
Environment	0.904	0.882	0.689	0.763	3.238	7.096	− 0.620
Financial	***1.295***	***1.216***	***1.186***	0.850	4.547	7.931	1.163
R	4.065	3.830	3.858	3.384			

The bold values are over the threshold value

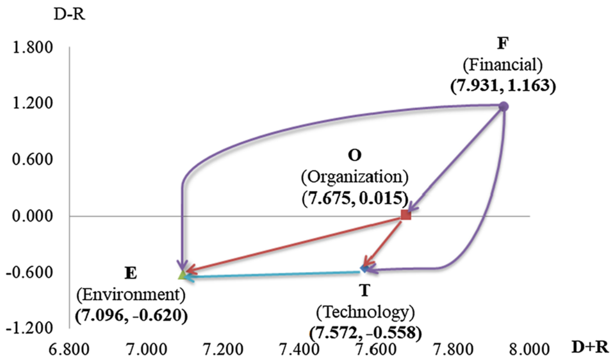

Fig. 3 The impact relation map of perspectives for NIoMT platform (p 0.946)

(T), with a score of − 0.558, and environment (E), with a score of − 0.620, were below the horizontal axis and could be categorized as effect group factors.

Based on Table 4 and Fig. 4, the evaluation criteria could also be classified in the cause-and-effect group.

4.3.2 Determine the priority weights of the criteria and alternatives using ANP

The outcome of DEMATEL was put into the ANP questionnaire. The experts gave their professional advice through pairwise comparisons based on Saaty's nine-point scale, so as to determine the relative values and indicate the levels of influence between each criterion and alternative. The whole computing process was performed using Super Decision software and the consistency test was based on a consistency ratio (CR) less than 0.1. Therefore, this study determined the non-financial critical success factors (CSF) and the priority weights of the national IoMT platform strategies.

The results shown in Table 5 indicate that, regarding the critical success factors of the national IoMT platform strategy, the experts gave high priority to pandemic prevention technology platform development (EPTPD), with a weight of 0.1672.

The results shown in Table 6 indicate that, regarding the national IoMT platform strategies, the experts gave high priority to inventory management systems (IMS), followed by emergency medical services (EMS), remote health monitoring systems (RHMS), electronic

Table 4 Total relation matrix of the criteria for NIoMT platform selection (p ≥ 0.453)

	EDI	EPTPD	PMD	MDMR	DT	MSR	MRM	MED	NISE	VC	HCR	RSB	D	D + R	D− R
EDI	***0.492***	***0.608***	***0.602***	0.449	0.446	0.448	***0.542***	***0.507***	0.430	***0.577***	***0.488***	***0.549***	6.138	12.221	0.055
EPTPD	***0.561***	***0.490***	***0.576***	***0.456***	0.416	0.448	***0.525***	***0.484***	0.393	***0.558***	***0.458***	***0.531***	5.896	12.226	−0.434
PMD	***0.548***	***0.566***	***0.473***	0.429	0.413	0.430	***0.520***	***0.488***	0.368	***0.546***	0.447	***0.504***	5.732	11.999	−0.535
MDMR	0.447	***0.485***	***0.489***	0.313	0.366	0.356	0.407	0.427	0.334	0.434	0.362	0.427	4.847	9.772	−0.078
DTT	***0.461***	***0.491***	***0.471***	0.363	0.298	0.347	0.405	0.401	0.357	0.432	0.361	0.433	4.820	9.530	0.110
MSR	***0.475***	***0.500***	***0.511***	0.402	0.387	0.336	***0.466***	0.426	0.343	***0.519***	0.442	***0.494***	5.301	10.110	0.492
MRM	***0.544***	***0.548***	***0.560***	0.435	0.404	0.451	0.422	0.447	0.374	***0.551***	***0.454***	***0.509***	5.699	11.290	0.108
MED	***0.466***	***0.466***	***0.463***	0.363	0.358	0.340	0.390	0.328	0.312	0.439	0.354	0.424	4.703	9.976	−0.570
NISE	0.442	***0.458***	0.431	0.374	0.330	0.344	0.368	0.349	0.258	0.400	0.349	0.410	4.513	8.838	0.188
VC	***0.550***	***0.583***	***0.587***	***0.459***	0.427	0.443	***0.528***	***0.495***	0.388	***0.472***	***0.468***	***0.542***	5.942	11.968	−0.084
HCR	***0.498***	***0.515***	***0.489***	0.388	0.381	0.389	***0.467***	0.405	0.331	***0.504***	0.346	***0.487***	5.200	10.232	0.168
RSB	***0.599***	***0.620***	***0.615***	***0.494***	***0.484***	***0.477***	***0.551***	***0.516***	0.437	***0.594***	***0.503***	***0.485***	6.375	12.170	0.580
R	6.083	6.330	6.267	4.925	4.710	4.809	5.591	5.273	4.325	6.026	5.032	5.795			

The bold values are over the threshold value

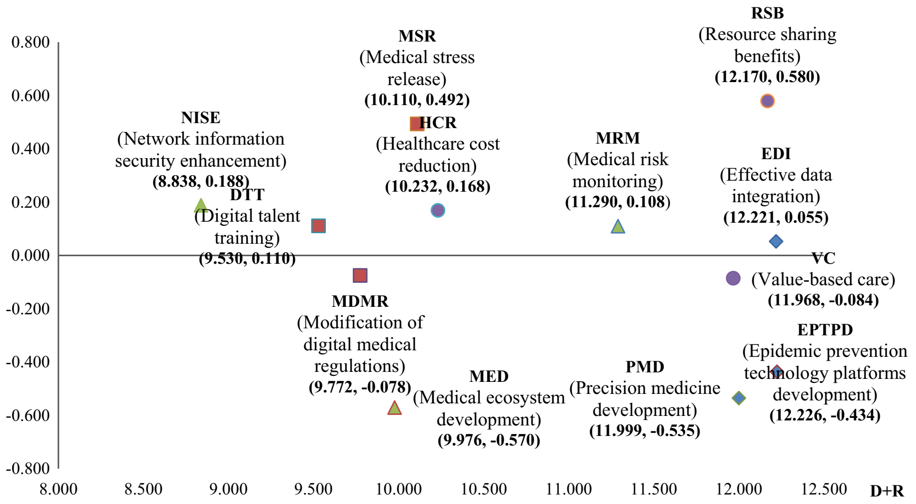

Fig. 4 The impact-relation map of the criteria for NIoMT platform ($p \geq 0.453$)

Table 5 Critical success factor weights for the NIoMT platform strategy evaluation

Critical success fators	Weights	Rank
Effective data integration (EDI)	0.1615	3
Epidemic prevention technology platforms development (EPTPD)	0.1672	1
Precision medicine development (PMD)	0.1562	4
Modification of digital medical regulations (MDMR)	0.0308	9
Digital talent training (DTT)	0.0052	11
Medical stress release (MSR)	0.0070	10
Medical risk monitoring (MRM)	0.1616	2
Medical ecosystem development (MED)	0.0857	6
Network information security enhancement (NISE)	0.0001	12
Value-based care (VC)	0.1073	5
Healthcare cost reduction (HCR)	0.0491	8
Resource sharing benefits (RSB)	0.0682	7

health records (EHR), human resources for health (HRH), remote robotic surgery (RRS), virtual care robots (VCR), and geographic information systems (GIS).

4.3.3 Find the optimal portfolio for NIoMT platform using the ZOGP model

This study applied the ZOGP model to solve the problems with multiple conflicting alternatives. Five resource limitations were used as necessary goals (as shown in Table 7): (1) an NT$75 million system construction cost; (2) an NT$20 million consultant fee; (3) an NT$48 million total IoMT infrastructure cost; (4) a 55% reduction in medical staff demand and (5) a 45% diagnostic efficiency improvement.

Table 6 Information strategy weights for the NIoMT platform strategy evaluation

Information strategy	Weights	Rank
Virtual care robots	0.0679	7
Human resources for health	0.1157	5
Inventory management systems	0.2098	1
Electronic health records	0.1489	4
Emergency medical services	0.1695	2
Remote robotic surgery	0.0680	6
Remote health monitoring systems	0.1610	3
Geographic information systems	0.0591	8

The mathematical optimization model in this study considered the limitations of the resources and used the weights obtained from the ANP results. The final ZOGP model formulation is shown in Table 8. It respectively presents the goals (P_i) to minimize G, five limitation-related formulations with the weight from ANP and x_j, d_i^+ and d_i^-. x_j is a binary variable and includes $x_1(VCR)$, $x_2(HRH)$, $x_3(IMS)$, $x_4(EHR)$, $x_5(EMS)$, $x_6(RRS)$, $x_7(RHMS)$, and $x_8(GIS)$. $x_j = 1$ shows that the $j\ th$ NIoMTPS is chosen, and $x_j = 0$ shows that the jth NIoMTPS is not chosen. Haughey et al. (2018) pointed out that the IoMT integrates people, data, processes, and key technology. This study aimed to build a national IoMT platform strategy portfolio decision model that included four alternatives and four functions. d_i^+ is a positive deviation variable indicating that the target is overfulfilled, while d_i^- is a negative deviation variable indicating that the target is not reached.

There are three goals with prioritis according to the national IoMT platform strategy portfolio decision involvd in this study. Table 9 show the optimal value for each goal conditions, and all of the goals have been fully satified. The value of $d_1^+ + d_2^+ + d_3^+ + d_4^+ + d_5^+ = 0$ for P_1 indicates that first priority goal has been satisfied. The object optimal value of 0.3439 for P_2 indicates that second priority goals programming result to select the highest weights for the national IoMT platform strategy from the ANP weights. Then, the value of $d_{14}^+ + d_{14}^- = 900$ for P_3 indicates that third priority goals has been satisfied, and there is a decrease in the IoMT infrastructure total costs to NT$ 36 million dollars under the optimal national IoMT platform strategy portfolio.

The results indicated that inventory management systems (IMS), emergency medical services (EMS), remote health monitoring systems (RHMS), and human resources for health (HRH) represented the optimal national IoMT platform strategy portfolio in the COVID-19 environment. Under the system construction limitation, $d_1^- = 3800$ indicated that the model could save NT$38 million dollars. Under the consultant fee limitation, $d_2^- = 500$ indicated that the model could save NT$ 5 million dollars. Under the total IoMT infrastructure cost limitation, $d_3^- = 1200$ indicated that the model could save NT$ 12 million dollars, and to achieve the optimal cost of NT$ 36 million. Under the medical staff demand limitation, $d_4^- = 20$ indicated that the model could reduce demand by at least 35%. Under diagnosis efficiency improvement limitation, $d_5^- = 12$ indicated that the model could improve efficiency by at least 33%.

Table 7 Resource limitations of the NioMT platform: example data

Resource limitation	People		Data		Process		Key Technology		Goal
	VCR	HRH	IMS	EHR	EMS	ERS	RHMS	GIS	
ANP Weights	0.0679	0.1157	0.2098	0.1489	0.1695	0.0680	0.1610	0.0591	
System construction cost (NT$)(× NT $10,000)	1500	900	1000	1000	800	2000	1000	700	7500
Consultant fee (NT$)(× NT $10,000)	500	300	300	400	400	600	500	400	2000
Total cost of IoMT infrastructure (NT$)(× NT $10,000)	1000	200	1100	1100	800	800	1500	600	4800
Reduction rate of medical staff demand (%)	25	5	5	10	10	7	15	6	55
Improvement rate of diagnosis efficiency (%)	15	3	3	25	3	4	24	5	

Table 8 ZOGP model formulation of the NIoMT platform

ZOGP model formulation	Goal
$Minimize\ G = P_1\left(d_1^+ + d_2^+ + d_3^+ + d_4^+ + d_5^+\right)$	P_1: Satisfy five mandated resource limitations for the national IoMT platform strategy
$P_2\left(0.0679d_6^- + 0.1157d_7^- + 0.2098d_8^- + 0.1489d_9^- + 0.1695d_{10}^- + 0.0680d_{11}^- + 0.1610d_{12}^- + 0.0591d_{13}^-\right)$	P_2: Select the highest weights for the national IoMT platform strategy from the ANP results
$P_3\left(d_{14}^+ + d_{14}^-\right)$	P_3: Use the targeted total cost of 45 million for the IoMT infrastructure in the national IoMT platform strategy selection
Subject to	
$1500x_1 + 900x_2 + 1000x_3 + 1000x_4 + 800x_5 + 2000x_6 + 1000x_7 + 700x_8 + d_1^- - d_1^+ = 7500$	Avoid over-utilizing the maximum system construction cost (NT$) (× NT$10,000)
$500x_1 + 300x_2 + 300x_3 + 400x_4 + 400x_5 + 600x_6 + 500x_7 + 400x_8 + d_2^- - d_2^+ = 2000$	Avoid over-utilizing the maximum consultant fee (NT $) (× NT $10,000)
$1000x_1 + 200x_2 + 1100x_3 + 1100x_4 + 800x_5 + 800x_6 1500x_7 + 600x_8 + +d_3^- - d_3^+ = 4800$	Avoid over-utilizing the maximum total cost of the IoMT infrastructure (NT $) (× NT $10,000)
$25x_1 + 5x_2 + 5x_3 + 10x_4 + 10x_5 + 7x_6 + 15x_7 + 6x_8 + d_4^- - d_4^+ = 55$	Avoid over-utilizing the maximum reduction rate of medical staff demand (%)
$15x_1 + 3x_2 + 3x_3 + 25x_4 + 3x_5 + 4x_6 + 24x_7 + 5x_8 + d_5^- - d_5^+ = 45$	Avoid over-utilizing the maximum improvement rate of the diagnosis efficiency (%)
$x_1 + d_6^- = 1, x_2 + d_7^- = 1, x_3 + d_8^- = 1, x_4 + d_9^- = 1, x_5 + d_{10}^- = 1, x_6 + d_{11}^- = 1, x_7 + d_{12}^- = 1$	
$, x_8 + d_{13}^- = 1, x_1 + x_2 = 1, x_3 + x_4 = 1, x_5 + x_6 = 1, x_7 + x_8 = 1$	Select four national IoMT platform strategies
$1000x_1 + 200x_2 + 1100x_3 + 1100x_4 + 800x_5 + 800x_6 + 1500x_7 + 600x_8 + d_{14}^- - d_{14}^+ = 4500$	
$x_j = 0 or 1 for j = 1, 2, 3, 4, 5, 6, 7, 8$	Avoid the over- or under-expected targeted total cost of the IoMT infrastructure

Table 9 The ZOGP model results for the NIoMT platform

Priority goal	Programming results	Achievement
P_1	$d_1^+ + d_2^+ + d_3^+ + d_4^+ + d_5^+ = 0$	Satisfied
P_2	$0.0679d_6^- + 0.1157d_7^- + 0.2098d_8^- + 0.1489d_9^- + 0.1695d_{10}^- + 0.0680d_{11}^- + 0.1610d_{12}^- + 0.0591d_{13}^- = 0.3439$	Satisfied
P_3	$d_{14}^+ + d_{14}^- = 900$	Satisfied
Formulation results		
$x_1(VCR) = 0, x_2(HRH) = 1, x_3(IMS) = 1, x_4(EHR) = 0, x_5(EMS) = 1, x_6(ERS) = 0, x_7(RHMS) = 1, x_8(GIS) = 0 d_1^- = 3800, d_1^+ = 0, d_2^- = 500, d_2^+ = 0, d_3^- = 1200, d_3^+ = 0, d_4^- = 20, d_4^+ = 0, d_5^- = 12, d_5^+ = 0, d_6^- = 1, d_7^- = 0, d_8^- = 0, d_9^- = 1, d_{10}^- = 0, d_{11}^- = 1, d_{12}^- = 0, d_{13}^- = 1 d_{14}^- = 900, d_{14}^+ = 0$		

5 Discussion

This study aimed to improve the decision quality regarding the national IoMT platform strategy portfolio planning process. The proposed decision model could help to identify the cause-effect influence criteria and optimal portfolios of the NIoMT platform from the financial and non-financial viewpoints. According to Queiroz and Wamba (2021), the integration of emerging technologies (artificial intelligence, big data, blockchain, IoT, robotics, simulation, etc.) for COVID-19 pandemic control should be noticed that is one of the potential contributions to academic and management implications.

In this study, by developing the hybrid decision framework and analyzing the MCDM model combining the goal programming and based on ten experts, some findings from previous IoMT research in identifying the critical success factors affecting the utilizing to IoMT strategy was confirmed. Firstly, according to results gained from DEMATEL, among the financial and non-financial dimensions, divided into the cause group (organization ($D - R = 0.015$) and financial ($D - R = 1.163$) and effect group (technology ($D - R = -0.558$) and environment ($D - R = -0.620$). Hence, the IoMT platform experts considered the organization and financial perspectives to be significant influence factors in the decision process. This finding revealed that proper policies and regulatory frameworks are significant factors needed for IoMT platform strategy development (Tarikere et al., 2021), as IoMT platforms can provide innovative services to release medical stress and reduce the medical cost burden of the COVID-19 pandemic.

Next, this study applied the ANP method to rank the critical success factors and information strategies. In view of the critical success factors, the results indicated that epidemic prevention technology platform development (EPTPD) was the most important criteria for planning NIoMT platforms during the decision-making process, with a weight of 0.1672. In addition, medical risk monitoring (MRM) was identified as the second-most important criteria, with a weight of 0.1616. Some results obtained in previous studies were also supported by the findings in the present study, such as the benefits of emerging technology platform development for epidemic prevention and risk monitoring (Mbunge et al., 2021; Ogundokun et al., 2022).

Despite the fact that the ranking priority methodologies are simply explained and effective in determining the best criteria and alternatives, these cannot ensure the planning resource feasibility and are unable to deal with optimal portfolios problem. With regard to the IoMT topic, prior studies mainly focused on ranking the significant weights of particular objects, such as security evaluations (Huang & Nazir, 2000) and end user requirements (Georgia et al., 2021). In order to solve real world situations, this study considered the resource requirements for IoMT platform establishment in the decision process, including the system construction cost, consultant fees, the total cost of the IoMT infrastructure, reduction of medical staff demand, and the improvement rate for diagnosis efficiency. The zero–one goal programming approach proposed in the present study is that the main results obtained optimal National IoMT platform strategy portfolios can be addressed in order to prove the resource requirement feasibility and reasonable. The hybrid MCDM model results indicated that inventory management systems (IMS), emergency medical services (EMS), remote health monitoring systems (RHMS), and human resources for health (HRH) represented the optimal national IoMT platform strategy portfolio in the COVID-19 environment. Medical inventory management and human resources were found to be significant information strategies for the deployment of IoMT in the planning decision process. Simultaneously, innovative technology (emergency and remote monitoring services) with high compatibility with the existing healthcare information environment would be effective to be utilized by medical decision-makers and staff and would enable the incorporation within IoMT platform services.

The study found that the Taiwan government aggressively deploys various IoMT information strategy in healthcare service areas to promote the quality of value-based care, which is a significant factor for accelerating medical industry innovation development. The most important contributions of the hybrid MCDM methodology proposed in this study is that the results obtained at the end of the decision analysis process can be examined through zero–one mathematical programming optimal portfolio evaluation. The decision problem of optimal national IoMT platform strategy portfolio was addressed in order to confirm the feasibility of advantages of decision making approach proposed in the study. Therefore, in light of the results, the resource of the proposed hybrid model presents to obtain not only the priority of the information strategy of IoMT platform based on the financial and nonfinancial interrelated evaluation criteria, according to DEMATEL and ANP methodologies, but also to consider the resource requirement constraints to structure zero–one goal programming model to which the optimal NIoMT platform strategy portfolios is confirmed. This is particularly true for medical decision-makers because IoMT platform resource planning requires more precise information for platform implementation and adoption. Nowadays, governments around the world aggressively develop advanced IoMT information strategies to reduce the COVID-19 pandemic risk. This study provides optimal IoMT platform portfolio by considering the feasible decision alternative and resource limitations (system construction cost, total IoMT infrastructure cost, consultant fee, reduction in medical staff demand and diagnostic efficiency improvement).

6 Conclusion and implications

Recently, the massive development of connected medical devices and equipment, coupled with the development of the 5G industry, has promoted the vigorous development of IoMT, which connects people, data, processes, and key technology. As COVID-19 rages and the number of confirmed cases continues to rise, the WHO and various countries are trying their best to find ways to control the pandemic. Governments of various countries are using connected medical equipment, innovative medical technologies, and information systems to control the pandemic. IoMT platforms can integrate decentralized information systems and technologies to greatly improve the effectiveness of pandemic prevention. This study established an IoMT platform structure through a literature review, adopted the DEMATEL and ANP methods to determine the CSF criteria and the priority weights of the alternatives, and used the ZOGP method under limited resources to obtain the best national IoMT platform strategy portfolio.

The results of this study showed that the perspectives in the cause group were organization (O) and the financial perspective (F), according to the D-R value from the DEMATEL method. The evaluation criteria were also classified into the cause group, and within these criteria, resource sharing benefits (RSB) was the priority (0.579). This result revealed that a national IoMT platform must integrate numerous information systems and technologies as well as collect a large amount of data; therefore, resource sharing are a key factor in any national IoMT platform. In addition, this study applied the relationship between the perspectives and criteria calculated by DEMATEL to the ANP method. The CSF criteria were pandemic prevention technology platform development (EPTPD), followed by medical risk monitoring (MRM), effective data integration (EDI), precision medicine development (PMD), value-based care (VC), medical ecosystem development (MED), and so on. The priority weights of the NIoMTPS were inventory management systems (IMS), followed by emergency medical services (EMS), remote health monitoring systems (RHMS), electronic health records (EHR), human resources for health (HRH), and so on. The results pointed out that the national IoMT platform could grasp emergency medical supplies, keep people from being infected, and control the pandemic.

Finally, in consideration of resource limitations, inventory management systems (IMS), emergency medical services (EMS), remote health monitoring systems (RHMS), and human resources for health (HRH) were the optimal national IoMT platform strategy portfolio. Through the inventory management system, governments can grasp emergency medical resource inventories and further issue alerts to develop production lines and increase the production of emergency supplies. This can ensure people have enough medical resources to keep them from being infected. Emergency medical services can be used to screen, divert, and isolate suspicious patients from the beginning of an outbreak, prevent infected patients from entering the community and causing domestic community transmission, and reduce the burden of pandemic investigations. Remote health monitoring systems can allow medical staff to remotely monitor the health of patients through connected medical equipment and prevent patient emergencies in advance. Remote health monitoring systems can also reduce the time, distance, and money barriers of patients who live in remote areas. In the COVID-19 environment, remote health monitoring can also reduce the contact between patients and medical staff in medical institutions and reduce the chance of mutual infection. At last, human resources for health can help the government determine medical staff requirements and distribute staff appropriately. This technology can reduce the work pressure of medical staff, improve patient value-based care, and prevent the medical system from collapsing.

The limits of the current model included the use of only four evaluation perspectives (the technology, organization, environment, and financial perspectives). Therefore, the precise definition of a panel of perspectives and corresponding criteria are needed to generalize the practical application of the decision model. Despite the fact that proper expert groups specialize in IoMT platforms selected in this study, the level of importance of the criteria could still vary in different situations, including the number of experts. This study mainly focused on the establishment of a national IoMT platform strategy portfolio decision model and provided an optimal operation research methodology to control the COVID-19 pandemic risks. Future line of research could build on this by establishing decision objective from a company view and obtain optimal innovation information strategy (e.g., smart technology, circular economy business model, and sustainable development issues,etc.) considering resource constraints by hybrid decision model, and predetermined various scenario can offer useful management implications.

In addition, the contributions of the present study were threefold:

(a) For the academic field, this study contributed to the innovation operation research (OR) literature on IoMT platform strategy planning by demonstrating the interrelationships among financial and non-financial criteria and the influence of their evaluation criteria on each other, as well as by providing more precise and optimal strategy portfolios using goal programming methodology.
(b) For the industrial field, this study could allow IoMT platform system suppliers to accurately understand how to allocate resources and improve inefficient resource allocation. The integrated model considers financial and non-financial criteria, system construction costs, consultant fees, and IoMT infrastructure costs, in addition to incorporating the reduction of the medical staff demand and the diagnosis efficiency improvement rate into the model to promote reasonable decision quality.
(c) For the managerial and policy field, this study provided innovative ideas and directions for developing the integrated IoMT platform strategy portfolio decision model, which could help governments and policymakers formulate efficient and effective policies to face the challenges of medical resource allocation under the effects of the COVID-19 pandemic. Furthermore, more incentive policies (such as financial subsidy, smart technology investment) to increase the willingness of cooperation for medical industry. The critical success factor of the NIoMT platform could be considered by IoMT industries when developing operation policy for the future implementation of IoMT service platform worldwide.

Acknowledgements The authors would like to thank the Ministry of Science and Technology of Taiwan for financially supporting this research under Grant MOST 108-2410-H-606-009-MY2.

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