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Exploring the Hospital Performance during the Covid-19 Pandemic from the Perspective of Intellectual Capital: An Empirical Study of Taipei Hospital in Taiwan

Hsing-Hua Hsiung[1], Yu-Jie Lin[2]

Abstract

The COVID-19 pandemic, starting in 2019, posed unprecedented challenges to global healthcare systems, with Taiwan's rapid response gaining notable attention (Cheng, Li, & Yang, 2020). This paper examines how non-profit hospitals can improve crisis management capabilities, using Taipei Hospital as an empirical study. It proposes a framework for constructing an intellectual capital report based on the ARC model, enhancing traditional financial statements with a comprehensive view of the hospital's intangible assets. Employing Data Envelopment Analysis (DEA) to evaluate Taipei Hospital's operational performance from 2013 to 2023, the study finds that the hospital's operational efficiency during the pandemic exceeded pre-pandemic levels, demonstrating its ability to leverage the crisis for improvement. This supports the assertion that intellectual capital is crucial for research and development organizations, validating the proposed reporting framework.

Keywords: *Intellectual Capital, Data Envelopment Analysis (DEA), Performance Evaluation, Intangible Assets, Covid 19 Pandemic, Strategic Management.*

Introduction

Motivation

From 2019 to 2023, the world faced an unprecedented pandemic. The outbreak of the novel coronavirus triggered a significant global public health crisis, deeply impacting various societal aspects and leading to novel transactional and healthcare models worldwide. Taiwan was particularly noted for its effective early response, which included measures such as surveillance, border controls, and expanded laboratory capacities, effectively curbing local transmission. These efforts were supported by proactive government actions (Cheng, Li, & Yang, 2020; Jian, Kao, Chang, Chen, & Liu, 2021). Researchers have highlighted the pivotal role of nurses in providing direct healthcare, conducting contact tracing, and offering community services, suggesting that future pandemic preparations should focus on ensuring adequate protective gear and safe staffing levels (Huang, Chen, Chen, & Wang, 2020; Liang, Wu & Wu, 2021). Furthermore, there are studies investigating the healthcare response protocols (Lee, Chu, Chou, Hu, Huang, & Yen, 2020). Yet, there is a relative scarcity of academic discussion on how individual hospitals managed to turn the crisis into an opportunity to transform and improve their operational efficiency.

Hospitals, as non-profit entities, inherently feature external economic traits. In Taiwan, healthcare facilities largely operate in conjunction with the national health insurance system. The evaluation of these institutions' effectiveness, particularly in selecting indicators and quantitative assessment models, remains a subject of significant debate (Bahadori, Izadi, Ghardashi, Ravangard & Hosseini, 2016; Liao, Mi, Yu, & Luo, 2019). Unlike profit-driven enterprises that measure R&D success through revenue and profit from new products, non-profit research outcomes are demonstrated through the enhancement of human capital, knowledge diffusion, and efficiency improvements in processes. These intangible outcomes, difficult to quantify, underscore the limitations of traditional financial reporting tools (Chu et al., 2005). Therefore,

[1] Department of Accounting, Chaoyang University of Technology. 168, Jifeng E. Rd., Wufeng District, Taichung, 41330 Taiwan, Email: sandyhsi@cyut.edu.tw, (Corresponding Author)

[2] Department of Accounting, Chaoyang University of Technology.168, Jifeng E. Rd., Wufeng District, Taichung, 41330 Taiwan.

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effectively disclosing and evaluating the value and impact of intangible assets in hospital performance assessments is a critical research area.

Roos & Jacobsen (1998) highlighted that the concept of intellectual capital is not only about understanding, measuring, or graphically representing a company's hidden value, but also about transforming the results of such evaluations into new value. This approach aims to present the organization's comprehensive dimensions with a clearer logical structure. As providers of medical services, hospitals' primary goals include delivering high-quality medical care, promoting disease prevention, conducting medical research, and training healthcare professionals. The mission of hospitals extends beyond curing diseases to enhancing quality of life and advancing medical technology. Hospitals operate with unique and complex characteristics that demonstrate the diversity and depth of their services. Edvinsson & Sullivan (1996) noted that an organization's value comprises not only tangible assets but also intangible assets, which traditional financial statements cannot adequately measure. Given the intangible nature of hospital management and services, traditional financial reports fall short in fully representing their operational performance and value. Employing an intellectual capital framework to explore hospital performance is thus an apt approach.

In December 2019, the global outbreak of COVID-19 prompted extreme measures such as travel restrictions and border closures, causing widespread public panic. Faced with the daunting pandemic, Taipei Hospital implemented a series of strategic responses. Despite numerous challenges, the hospital successfully transformed this crisis into an opportunity. Through innovative management strategies and rapid responses, it significantly enhanced its operational performance. By 2023, the hospital's domestic and foreign income reached a new high for the decade, reflecting its competitive edge. The pandemic became a crucial catalyst for change at Taipei Hospital. This adaptability not only showcased the hospital's excellent performance during emergencies but also highlighted its leadership's ability to make swift decisions in dynamic conditions. Consequently, this study examines Taipei Hospital's use of intellectual capital—human, structural, and relational—to effectively manage the challenges of time, manpower, and facilities during the COVID-19 crisis, ultimately turning a potential setback into a strategic advantage.

Research Purpose

This study aims to compile an intellectual capital report for Taipei Hospital using the concept of intellectual capital. It will describe the hospital's input, processes, and outcomes of intellectual capital across three dimensions: human capital, structural capital, and relational capital. In recent years, the concept of sustainability has gained emphasis. To lead in industry competition, innovation is essential; without it, organizations cannot sustain themselves long-term. Innovation requires robust intellectual capital, which is critical for developing new methods, improving efficiency, and maintaining competitive advantage in the healthcare industry. (Santos-Rodrigues et al., 2003).

Santos-Rodrigues et al. (2013) have identified a direct link between human capital and innovativeness, particularly in relation to the generation of new ideas. Structural capital is somewhat related to the adoption of innovations, while relational capital uniquely influences both the creation and adoption of innovations, underscoring the deep interconnections between intellectual capital, innovation, and organizational growth. In the highly competitive and challenging healthcare sector of Taiwan, which is rife with opportunities, Bontis (1998) asserted a significant and substantial causal relationship between intellectual capital and organizational performance. To more thoroughly explore the impact of intellectual capital on the performance of non-profit hospital organizations, this study establishes the following objectives:

- Using Taipei Hospital as a case study, propose the content and recommended steps for compiling a report on the hospital's intellectual capital.

- Differentiate the dimensions of intellectual capital and performance indicators into input and output metrics, and employ the Data Envelopment Analysis (DEA) research method to empirically analyze the operational efficiency of Taipei Hospital from 2013 to 2023, before and after the COVID-19 pandemic.

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Literature Review

Hospitals and Intellectual Capital

As information technology advances, the healthcare environment evolves, and management theories develop, the significance of intellectual capital in the healthcare sector is increasingly recognized (Taie, 2014; Durrah, Allil, & Alkhalaf, 2018; Santos-Rodrigues, Faria, Morais, & Cranfield, 2013). Research on intellectual capital within hospitals can be divided into three main themes: first, the measurement of intellectual capital indicators within hospital organizations (Santos-Rodrigues et al., 2013); second, the examination of the relationship and importance between intellectual capital and hospital performance (Taie, 2014; Durrah, Allil, & Alkhalaf, 2018); third, broadening the scope of intellectual capital applications to include management accounting, strategic management processes, and communications with stakeholders (Vagnoni & Oppi, 2015).

Intellectual capital is essential for measuring and displaying an organization's intangible assets, which include human capital, structural capital, and relational capital. Roos, Bainbridge & Jacobsen （2001）notes that intellectual capital provides significant advantages, particularly in the effective implementation and assessment of strategic performance. Hospitals, as highly specialized service institutions, depend greatly on knowledge, skills, customer relationships, and internal processes for their operational success and performance. The use of intellectual capital in hospitals therefore goes beyond assessing financial outcomes to also encompass the valuation and potential of non-financial assets. Consequently, some researchers focus on developing intellectual capital reporting and metrics for hospitals. For example, Hermansson, Holberg & Ringquist (2003) introduced a prototype framework for intellectual capital reporting in healthcare centers, which aids hospitals in identifying and bolstering their core strengths while improving areas of weakness to enhance overall performance and competitiveness. Furthermore, a study by Santos-Rodrigues et al., (2013) created an instrument to measure intellectual capital within hospital nursing organizations, verifying its validity and reliability in pinpointing key components such as human capital, structural capital, and customer capital.

Although scholars have varying perspectives on the nature and composition of intellectual capital within hospitals, synthesizing the research and definitions from Hermansson et al. (2003), Santos-Rodrigues et al., (2013) provides a clear framework in the healthcare sector. Human capital is defined as encompassing the knowledge, skills, and innovation of employees, evaluated through indicators such as the leadership index and training duration, which measure staff engagement and skill enhancement. Structural capital is comprised of critical systems and intellectual properties, quantified by metrics like IT expenditure ratios and patent values, which support the organization's functions. Relational capital is characterized by the value derived from stakeholder relationships, with metrics including marketing expenses per customer and investments in customer education to gauge the strength of these ties. These facets of intellectual capital are essential for grasping an organization's intangible assets and their impact on competitive advantage.

Intellectual capital, comprising human, structural, and relational capitals, is instrumental in enhancing the quality and efficiency of medical services, thereby impacting hospital performance indicators. Indeed, numerous studies have demonstrated a significant positive correlation between a hospital's intellectual capital and its operational performance (Taie, 2014; Durrah, Allil, & Alkhalaf, 2018). Taie (2014) conducted an empirical study using Egyptian Hospitals as samples and found a strong and significant correlation between human capital, structural capital, and relational capital, each respectively associated with competitive advantage. Additionally, Durrah et al., (2018) explored the combined effect of these dimensions of intellectual capital—human capital (HC), structural capital (SC), and relational capital (RC)—on enhancing the learning organization capability, particularly within the healthcare sector.

Research into the value of intellectual capital (IC) extends beyond mere performance assessment. Vagnoni & Oppi (2015) explored the organizational processes of university hospitals using an intellectual capital framework, demonstrating that IC is crucial for strategic management, management accounting, and organizational planning within such settings. This framework enhances strategic decision-making by

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increasing the visibility of strategic elements and aligning resources with long-term objectives. In the realm of management accounting, IC improves the control and reporting of intangible assets, which are essential for a thorough performance evaluation. Regarding organizational planning, IC aids in the optimal use and leveraging of human, structural, and relational capitals. This enhances innovation and operational efficiency in healthcare services, thereby highlighting the critical role of intangible assets in securing a competitive advantage and achieving success.

The Impact of The Covid-19 Pandemic on Hospitals

Beginning in late 2019, the COVID-19 outbreak emerged in China and swiftly spread across the globe. Traditionally, the healthcare industry was seen as resilient to economic fluctuations, with the need for medical services remaining constant regardless of economic conditions, since people require healthcare in both prosperous and challenging times. Yet, the COVID-19 pandemic has profoundly impacted the global healthcare system, introducing significant challenges and transformations to frontline medical institutions.

Taking the United States as an example, the pandemic caused the most severe impact on hospitals and clinics since the great depression, particularly affecting those that were already financially fragile, such as rural and poverty-focused medical facilities （Barnett, Mehrotra, & Landon, 2020）. The direct cause of this unprecedented crisis in healthcare operations was a drastic and unexpected shift in medical service demand. On one hand, this emerging infectious disease increased the need for specialized acute care, overwhelming some hospitals; on the other hand, the demand for routine medical services plummeted, significantly reducing revenue for healthcare institutions.

Ghazanchaei, Varahram, Roozbahani, & Dizaji (2024) conducted a systematic study exploring the challenges faced by hospital management during the COVID-19 crisis. By meticulously reviewing 32 related literature pieces, the study identified five main challenges in hospital management during the pandemic: psychological distress among medical staff, lack of facilities and equipment, financial constraints, insufficient emergency management leadership, and weak resilience of the health system. In contrast, Taiwan's government demonstrated highly effective and decisive pandemic response capabilities, earning international acclaim. Compared to other countries, Taiwan maintained a controlled situation until a surge in May 2021, when, within just three months, the death toll exceeded 800 and confirmed cases rose from over a thousand to 15,000. Most scholars believe Taiwan's success in containing this disaster was due not only to the experience gained from previous major infectious disease outbreaks but also to well-implemented preventive measures and proactive government strategies(Cheng, Li, & Yang, 2020;Jian, Kao, Chang, Chen, & Liu, 2021).

Additionally, due to the pandemic, patients have become accustomed to remote and virtual healthcare, which has accelerated the digital transformation of the medical industry post-COVID-19. The focus is not only on epidemic prevention and disaster reduction but also on how digital strategies can add value to medical services and provide integrated, seamless care that combines physical and virtual elements—potentially shaping the future of healthcare services. Babamahmoodi et al. (2022) examines the unique challenges and strategies associated with telehealth in the post-COVID-19 era, highlighting how developments like the internet, social media, and remote health technologies distinguish this period from previous pandemics. The study criticizes the focus on building telehealth infrastructure at the cost of strategic planning and adaptation to the evolving health market. Meanwhile, Vargas, Gomes, Fernandes, Vallejos & Carvalho (2023) emphasizes the need to enhance future models with technology and patient safety to strengthen the resilience of health systems.

The subject of this study, Taipei Hospital, is a public hospital in Taiwan under the jurisdiction of the Ministry of Health and Welfare. Consequently, when faced with the sudden outbreak, the hospital not only had to manage the surge in demand for government-funded and self-paid COVID-19 testing through the Taiwan Centers for Disease Control (CDC) but also had to fulfill its social responsibilities for medical protection. The pandemic-induced shortages in human resources, medical equipment, and space posed significant challenges to the hospital's emergency management capabilities and resource allocation efficiency.

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However, Taipei Hospital not only successfully addressed the issues of pressure and resource shortages but also turned the crisis into an opportunity through a series of measures, thereby significantly enhancing its management performance and outperforming its competitors. These measures included altering the specimen reception method to meet the challenges of high-volume testing demands; adding instrumentation to increase testing efficiency; automating the production process of self-paid reports to reduce human error and increase report processing speed; implementing an automated system for uploading test reports to ensure faster and more reliable data transmission; and fostering inter-departmental collaboration to enhance information and resource sharing among different departments, thus significantly improving Taipei Hospital's operational effectiveness during the pandemic.

Methodology

Framework For Compiling the Intellectual Capital Report of Taipei Hospital

The fundamental goal of an intellectual capital report is to clarify and make measurable the intangible assets within an organization. This report is part of the integration of knowledge management within the organization, demonstrating the processes and outputs of acquiring, developing, and sharing knowledge resources. Mouritsen, Larsen, Bukh & Johansen （2001） introduces a new model that links intellectual capital indicators to the company's knowledge strategy. This intellectual capital accounting system details the transactions involved in implementing knowledge strategies and plans a monitoring agenda for the effectiveness of intellectual resources. This enables the evaluation and enhancement of these resources and the examination of the composition of intellectual assets.

In addition to referencing the intellectual capital report framework by Austrian Research Centers （ARC）, this study also draws on the ARC model from the research by Chu et al. (2005）and Lin (2024) to develop a framework for the non-profit R&D institution Industrial Technology Research Institute in Taiwan. The study aims to present a clear and systematic framework for the hospital's intellectual capital process. This framework provides an action, response, and consequence process model to better understand the operational process of the hospital's intellectual capital, as illustrated in Figure 1.

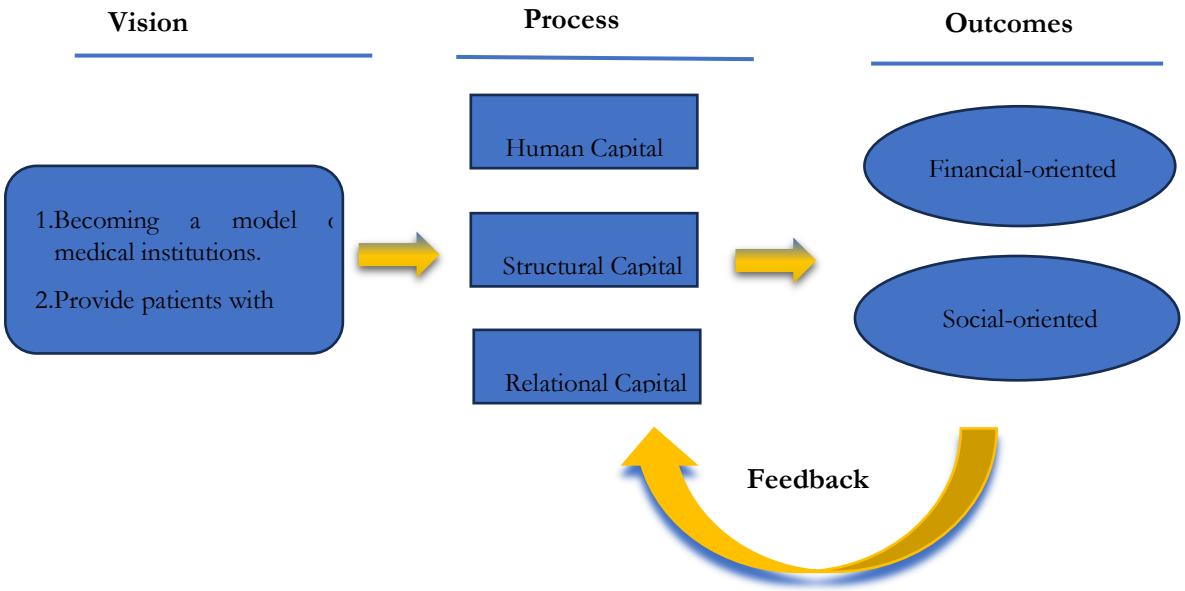

Figure 1 Framework of Intellectual Capital Report of Taipei Hospital

The steps for compiling the intellectual capital report for Taipei Hospital are as follows:

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Step I：Setting goals, vision, and values for a hospital. Taipei Hospital has consistently embraced the vision of "protecting public health and becoming a model public hospital." It is committed to introducing new ideas, technologies, methods, and recruiting outstanding doctors to continually improve the quality of medical services. The hospital strives to provide superior and patient-centric medical value and seeks innovative solutions. Therefore, this paper succinctly defines its mission as _becoming a model medical institution and providing patients with high-quality medical care.

Step II：To delineate the structure of intellectual capital in a hospital setting, we draw from the three core components: human capital, structural capital, and relational capital. The selection of indicators for this study is guided by Koch (2003)'s ARC intellectual capital framework, the insights from Vagnoni & Oppi (2015), and the specific characteristics of Taipei Hospital.

Human Capital：Human capital broadly refers to the knowledge, tenure, turnover rates, skills, and experiences of all employees and managers in a company. The human capital indicators for Taipei Hospital include the number of employees, employee working hours, payroll expenses, and employee satisfaction. These indicators help evaluate the scale of human resources through the number of hospital staff (including outpatient, inpatient, management, and research personnel); understand the efficiency of human resources through the number of hours worked by hospital staff; estimate staff stability through employee satisfaction surveys, with satisfied employees more likely to provide efficient and high-quality care; and assess the hospital's operational efficiency through total payroll expenses as a comprehensive indicator of human resource investment. From Table 1, it is observed that the total number of employees and working hours at Taipei Hospital from 2021 to 2023 consistently exceeded the average, indicating that the medical staff were able to withstand high pressures and maintain normal hospital operations during the pandemic, demonstrating strong human capital capabilities at the hospital.

Structural Capital：Structural capital refers to the systems and processes that organizations utilize to solve problems and generate value. At Taipei Hospital, this includes investments in research and development (R&D), training expenses, machinery and equipment acquisitions, real estate purchases, net interest income, and the proportion of government subsidies to total revenue. Investments in R&D and training are crucial for enhancing the hospital's capabilities in professional knowledge and skills. Machinery and equipment purchases improve the medical technology standards of the hospital, while investments in real estate are essential for the hospital's expansion and maintaining its competitiveness. According to Table 1, during the pandemic, Taipei Hospital's equipment investments in 2021, 2022, and 2023 surpassed averages of previous years. This highlights the hospital's agile response to equipment procurement, its ability to make precise judgments about the pandemic, and its flexible purchasing strategies, enabling it to acquire suitable equipment to add value to the hospital.

Net interest income, derived from total interest earned minus interest expenses, indicates the hospital's effectiveness in utilizing funds for financial activities. The ratio of government subsidies to total revenue illustrates the extent of financial support the public hospital receives from the government.

Relational Capital：Relational capital broadly refers to the establishment, maintenance, and development of external relationships by an organization, including the satisfaction of customers, suppliers, and strategic partners. The indicators of relational capital for Taipei Hospital include aspects from customers, the government, and upstream vendors. From Table 2, it can be observed that during the pandemic, there were no significant changes in the relational capital with the government and upstream vendors. However, following the outbreak in 2022 and 2023, the number of outpatient visits increased significantly, exceeding the historical average by 17% to 24%. Customer capital is directly related to the hospital's revenue; more patients can bring more income to the hospital, but this also necessitates an increase in corresponding costs.

The satisfaction levels of outpatients, emergency patients, and inpatients, as well as the customer complaint

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rates, are determined by surveys conducted annually through external agencies by Taipei Hospital. In the report on intellectual capital, the satisfaction scores for the outpatient, emergency, and inpatient departments are summed and averaged to determine overall patient satisfaction. High levels of customer satisfaction are crucial for enhancing patients' loyalty and affiliation with the hospital, thereby cultivating a base of loyal supporters.

Step III：To measure the performance of Taipei Hospital, the outcomes are categorized into two dimensions: financial oriented results and socially oriented results. The financial dimension is divided into three categories: operating income, non-operating income, and net surplus. Operating income consists of medical revenue and other business income. Non-operating income includes interest income, rental income, fines, and miscellaneous income. The net surplus is calculated by subtracting costs and expenses from the total of operating and non-operating incomes, adjusted for special reserves.Socially oriented results include donated income, subsidies for disadvantaged patients, the number of journal publications, awards, and external evaluations and certifications. These indicators reflect Taipei Hospital's commitment to medical policy and care for vulnerable groups. The number of publications in national and international journals indirectly indicates the level of research activity and the hospital's research capabilities. Awards and external certifications enhance Taipei Hospital's reputation and establish its standing in the field.

Step IV：This study integrates the framework of intellectual capital with a dynamic perspective. We have defined a structural model for Taipei Hospital, encompassing its vision, processes, and outputs. Portions of the results are transformed into the stock of intellectual capital, which continuously provides feedback to the organization, thereby facilitating the creation of performance. This approach not only maps out how Taipei Hospital utilizes its resources but also demonstrates the cyclical nature of value creation through intellectual capital, ensuring sustained improvement and adaptation in its operations and strategic initiatives.

Intellectual Capital Indicators for Taipei Hospital

Table 1 delineates the Intellectual capital indicators for Taipei Hospital for the period 2020 to 2023, as formulated based on the steps of intellectual capital measurement. This table was constructed using data extracted from the final account statements available on the official Taipei Hospital website(https://www.tph.mohw.gov.tw/?aid=533). It offers a comprehensive view of the changes and outcomes associated with intellectual capital over the four years following the onset of the pandemic. Furthermore, the table includes comparative average data spanning from 2013 to 2023, allowing for a detailed longitudinal analysis that elucidates the evolution of Taipei Hospital's intellectual capital in the post-pandemic era.

The analysis of Table 1 reveals significant trends in the human capital of Taipei Hospital following the pandemic. Both the total number of employees and overall employment costs have consistently exceeded historical averages, reflecting a steady annual increase in staffing. Remarkably, employee satisfaction has also shown a continuous upward trajectory, culminating in a high of 71.15% in 2022. This upward trend suggests that the hospital's strategic efforts in enhancing human capital—through improved working conditions, additional welfare measures, and refined management practices—have effectively elevated employee satisfaction. Consequently, Taipei Hospital has not only minimized employee turnover but also attracted a greater number of professionals to its workforce.

Observing the structural capital, it is evident that both research and training expenditures, as well as equipment expenses, have consistently exceeded historical averages post-pandemic. Structural capital, defined as the hospital's investment in infrastructure to enhance performance, signifies the systems and know-how processes through which Taipei Hospital creates value. Despite the challenges posed by the pandemic, Taipei Hospital did not cease investing in structural capital. On the contrary, in 2022, the hospital

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fully implemented a comprehensive medical information system, integrating various smart medical devices and upgrading a total of 133 system modules. This strategic investment has significantly bolstered the hospital's development capacity.

Observing the customer capital reveals that while the total number of patient visits initially fell below historical averages at the beginning of the pandemic, both patient visits and inpatient admissions reached record highs by 2023. This trend reflects the hospital's successful enhancement of service and medical care quality, earning patient trust and recognition. The continuous rise in customer satisfaction demonstrates the hospital's ability to improve care and treatment, fostering patient loyalty and attracting new patients through positive word-of-mouth. This positive feedback loop is crucial for the hospital's long-term development, enabling it to expand its service scope and market influence. Additionally, Taipei Hospital's commitment to social responsibility—providing care and medical subsidies to disadvantaged groups, homeless individuals, and victims of domestic violence and sexual assault—has further enhanced its public image.

The analysis of outcome benefits can be categorized into financial-oriented and social-oriented outcomes. Remarkably, internal revenue has shown a continuous and significant upward trend since the onset of the pandemic in 2020, reaching an all-time high in 2023. This increase in internal revenue indicates the hospital's outstanding performance in its core medical services. Additionally, external revenue also achieved a historic high in 2023, signifying the hospital's success in providing value-added services and other business activities. The primary sources of external revenue include health check-ups, rehabilitation services, and education and training programs.

Analyzing the overall performance of Taipei Hospital through the four dimensions of human capital, structural capital, relational capital, and outcome-oriented benefits provides a clearer perspective on the hospital's added value and achievements. This approach particularly addresses the limitations of traditional financial statements, which often classify human capital expenditures, such as salaries, and structural capital investments as costs without considering their deferred benefits to the organization. Furthermore, the social-oriented benefits within the outcome-oriented dimension, due to their significant externalities, can elucidate the unique value of the hospital when appropriately disclosed

Table 1 The Indicators of Intellectual Capital Report of Taipei Hospital Amount Unit: Usd

Category	Indicators	Year 2020	Year 2021	Year 2022	Year 2023	Year 2013-2023
Human capital						
	Total Number of Employees (persons)	815	897	975	1040	814
	Total Number of Outpatient Staff (persons)	350	398	441	483	349
	Total Number of Inpatient Staff (persons)	293	324	314	332	285
	R&D Personnel (persons)	8	4	5	5	6.5
	Total Employee Work Hours (hours)	2,187,496	2,220,82	2,424,808	-	-
	Employee Satisfaction Rate (%)	68.33	6	71.15	-	-
	Total Employment Costs (USD)	27,343,81	70.51	35,843,16	36,647,1	28,229,8
		5	32,301,7	9	39	76
			85			
Strucural capital						
	R&D Expenses (USD)	1,051,724	981,604	1,091,995	1,079,63	1,045,56
	Training Expenses (USD)	344,781	268,976	287,329	1	9
	Machinery and Equipment Purchases (USD)	2,544,522	4,476,88	3,309,762	348,954	383,969
	Building and Construction Purchases (USD)	1,936,221	5	148,506	4,164,47	2,948,00
	Net Interest Income (USD)	157,073	711,594	242,555	7	0
	Government Subsidies as a Percentage of Revenue (%)	-	125,191	22.8	0	353,908
			-		401,908	176,554

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Relational capital					
Customer resources	498,781	517,154	685,377	721,282	582,000
Total Outpatient Visits (persons)	127,185	132,813	146,580	154,740	130,000
Total Inpatient Admissions (persons)	84.34	86.87	86.51	-	-
Outpatient, Emergency, and Inpatient Patient Satisfaction (%)	16.55	15.55	12.19	-	-
Customer Non-Complaint Rate (%)					
Government reourcess	2,214	2,949	2,853	-	-
Total Number of Emergency Medical Services Provided to Police, Firefighters, Coast Guard, Air Service, and Military Personnel (persons)					
Upstream resources	31.9	32.4	33.8	33.0	29.4%
Procurement Cost Rate (%)					
Financial oriented	78,764,589	93,616,722	113,859,440	117,112,615	79,640,000
Internal Revenue (USD)	1,022,044	1,529,835	3,119,174	3,798,800	2,455,231
External Revenue (USD)	2,435,158		5,236,523		
Current Period Surplus (USD)		3,884,025		5,582,984	3,371,908
Social oriented	166,678	563,822	300,886	339,446	247046
Donated Income (USD)	104	125	150	-	-
Average Subsidy Amount for Economically Disadvantaged Patients (USD)	15	21	23	-	-
Average Subsidy Amount for Homeless Individuals (USD)	27	32	36	-	-
Average Subsidy Amount for Domestic Violence and Sexual Assault Cases (USD)	121	51	136	-	-
Number of Publications in Domestic and International Journals (articles)	13	7	15	17	21.6
Number of Awards and External Evaluations/Certifications (items)					

Source: Taipei Hospital annual reports; Compiled by this study.

Data Envelopment Analysis (DEA) Method

Upon the establishment of the intellectual capital reporting indicators, this study will employ Data Envelopment Analysis to assess the input-output performance of Taipei Hospital over a period of 11 years, from 2013 to 2023. Each year will be treated as a Decision Making Unit (DMU) to analyze the relative efficiency of Taipei Hospital before and after the pandemic.

Due to the hospital's operations involving various inputs and outputs, Data Envelopment Analysis can comprehensively evaluate the efficiency of these diverse factors simultaneously. By comparing operational efficiency across different years, DEA helps identify performance strengths and weaknesses. Unlike traditional efficiency assessment methods, DEA does not require the pre-specification of any production function form. This means that there is no need to assume a specific mathematical relationship between inputs and outputs, making the analysis more flexible and adaptable.

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Charnes, Cooper, and Rhodes (1978) introduced Data Envelopment Analysis method. Sueyoshi, Yuan, and Goto (2017) described DEA as a non-parametric linear programming technique that offers high computational solvability and the ability to simultaneously handle the efficiency evaluation of multiple inputs and outputs. Since 1999, the cumulative number of DEA application papers has caught up with purely methodological papers. Among various applications, Liu, Lu, Lu, and Lin (2013) identified the top five industries utilizing DEA: banking, healthcare, agriculture and farming, transportation, and education.

Data Envelopment Analysis is used to evaluate the efficiency of DMUs such as businesses, hospitals, or schools in using specific resources (inputs) to generate outcomes (outputs). Imagine a group of athletes, where each athlete (DMU) needs to consume a certain amount of energy (input) to complete a track (output). DEA can help us reveal which units have achieved optimal efficiency in resource utilization. The efficiency frontier provided by DEA serves as a benchmark, constructed by the most efficient units. Other evaluated units can view this efficiency frontier as a goal and strive to move towards it to improve their efficiency. Therefore, DEA not only provides a relative efficiency assessment for each unit but also offers a comparative function, helping these units understand their performance levels relative to each other.

This study employs DEA using the following Constant Returns to Scale (CRS) and Variable Returns to Scale (VRS) models to describe the relationship between input increase and output increase:

Constant Returns to Scale (CRS)

Constant Returns to Scale implies that for every unit of input, the output increases by a fixed proportion, and the scale of operations does not affect efficiency. This means that efficiency is measured by the same standard regardless of the size of the operation. Using the DEA method under CRS, the efficiency of each DMU in terms of inputs and outputs is compared, and relative efficiency values are calculated, ranging from 0 to 1. Input-oriented DEA focuses on assessing the efficiency of resource utilization by each unit at the same output level. The mathematical model for CRS was proposed by Charnes, Cooper, and Rhodes, and is thus also known as the CCR model, named after the initials of its creators.

The efficiency value is the result of maximizing the output-to-input ratio, where $Y_{rj}$and $X_{rj}$are summed after being multiplied by their corresponding weightsu_{rj} and V_{rj}. E_r^{CRS}reflects the relative efficiency of a DMU in terms of its input-output ratio, also known as the Overall Efficiency (OE). The constraint ensures that the efficiency value of each DMU does not exceed 1. For each DMU k, its output-to-input ratio is calculated and compared to 1. Additionally, it ensures that all weights u_{rj} and $V_{rj}$are greater than a very small positive number ε to prevent any weight from being zero. According to Wu (2018), the mathematical model for CRS is as follows:

$$\text{MAX } E_r^{CRS} = \frac{\sum_{j=1}^{J} u_{rj} Y_{rj}}{\sum_{i=1}^{I} v_{ri} X_{ri}} \qquad (1)$$

$$\text{s.t.} \frac{\sum_{j=1}^{J} u_{rj} Y_{kj}}{\sum_{i=1}^{I} v_{ri} X_{ki}} \leq 1, \quad k = 1, \ldots, K$$

$$u_{rj}, v_{ri} \geq \varepsilon > 0, \quad \text{j} = 1, \ldots, \text{J} \ \text{i} = 1, \ldots, \text{I}$$

E_r^{CRS}: The efficiency value of DMU, also known as the Overall Efficiency (OE).

K:Number of DMU , r, k∈K

I：Number of inputs, i∈I

J：Number of outputs, j∈J

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ε：A very small positive value is referred to as a non-Archimedean constant.

X_{ki}：Decision-making unit k (k=1,...,K) uses the i-th (i=1,...,I) input.

Y_{kj}：Decision-making unit k（ k=1,...,K ）uses the j-th (j=1,...,J ）output.

u_{rj}：The weight of the j-th output of decision-making unit r.

v_{ri}：The weight of the i-th input of decision-making unit r.

u_{0r}：Allowing the production function to not pass through the origin enables the determination of the type of returns to scale.

Variable Returns to Scale (VRS)

Variable Returns to Scale (VRS) was proposed by Banker, Charnes, and Cooper (1984), and is therefore also known as the BCC model. This model is a modification of the Constant Returns to Scale (CRS) model, allowing for a more comprehensive evaluation of the efficiency of decision-making units. The VRS model takes into account the different production scales in real-world production, making it more realistic compared to the CRS model. It not only measures technical efficiency but also assesses whether the optimal production scale has been achieved. Therefore, this study incorporates the VRS model into the DEA analysis to gain a more thorough understanding of each unit's efficiency performance and the adaptability of their production scales.

This objective function aims to maximize the efficiency value$E_r^{VRS}$of a specific decision-making unit r under the conditions of Variable Returns to Scale (VRS). Similar to the CCR model, this model calculates the weighted ratio of outputs to inputs, with the addition of a free variable $u_{0r}$to accommodate the VRS conditions. The constraints ensure that the efficiency value of each DMU does not exceed 1. The efficiency calculation for each DMU also includes the free variableu_{0r} Additionally, it ensures that all weights $u_{rj}\ and\ V_{rj}$ are greater than a very small positive number ε. to prevent any weight from being zero. According to Wu (2018), the mathematical model for Variable Returns to Scale is as follows:

$$\text{MAX}\ E_r^{VRS} = \frac{\sum_{j=1}^{J} u_{rj} Y_{rj-u_{0r}}}{\sum_{i=1}^{I} v_{ri} X_{ri}} \qquad (2)$$

$$\text{s.t.} \frac{\sum_{j=1}^{J} u_{rj} Y_{kj-u_{0r}}}{\sum_{i=1}^{I} v_{ri}\, X_{ki}} \leq 1, \quad k = 1, \ldots, K$$

E_r^{VRS}：The efficiency value of DMU, also known as the Technical Efficiency (TE).

$$u_{rj}, v_{ri} \geq \varepsilon > 0, \quad \text{j} = 1, \ldots, \text{J}\ \ \text{i} = 1, \ldots, \text{I}$$

u_{0r} is free variable

To facilitate solving, the aforementioned CRS and VRS models are converted from fractional programming forms to linear programming models, thereby avoiding multiple solutions. The transformed models are as follows:

For the CRS model:

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$$Max\ E_r^{CRS} = \sum_{j=1}^{J} u_{rj} Y_{rj} \quad (3)$$

$$\text{s.t.} \sum_{i=1}^{I} v_{ri}\, x_{ri=1}$$

$$\sum_{j=1}^{J} u_{rj} Y_{kj} - \sum_{i=1}^{I} v_{rj} X_{ki} \leq 0, \qquad k = 1, .., K$$

$$u_{rj}, v_{rj \geq \varepsilon > 0}, \quad j=1,...,J\ i=1,...,I$$

For the VRS model:

$$Max\ E_r^{VRS} = \sum_{j=1}^{J} u_{rj} Y_{rj} - u_{0r} \quad (4)$$

$$\text{s.t.} \sum_{i=1}^{I} v_{ri}\, x_{ri=1}$$

$$\sum_{j=1}^{J} u_{rj} Y_{kj} - \sum_{i=1}^{I} v_{rj} X_{ki} - u_{0r} \leq 0, \qquad k = 1, .., K$$

$$u_{rj}, v_{rj \geq \varepsilon > 0}, \quad j=1,...,J\ i=1,...,I$$

u_{0r} is free variable

By comparing the Overall Efficiency (OE) with Technical Efficiency (TE), the Scale Efficiency (SE) can be determined. The formula is as follows:

$$\text{SE} = \frac{E_r^{CRS}}{E_r^{VRS}}$$

Empirical study of DEA

Description of Dmus and Input-Output Indicators

In DEA analysis, DMUs must be comparable and possess three characteristics: 1) DMUs share the same goals and perform similar tasks; 2) DMUs operate under the same market conditions; 3) DMUs have the same input and output factors affecting their performance. To measure the operational efficiency of Taipei Hospital before and after the COVID-19 pandemic, this study uses annual data from 2013 to 2023, setting each year as a DMU in the DEA analysis to compare the relative efficiency of Taipei Hospital across different years.

Additionally, this study selects appropriate indicators from the intellectual capital report as input and output indicators. Due to missing data for some indicators during the study period, these were excluded from the final set of indicators. Ultimately, 18 indicators were selected, categorized into 10 input indicators (I_1 to I_10) and 8 output indicators (O_1 to O_8) based on their nature in the intellectual capital report. The sample indicators and descriptive statistics are presented in Table 2. The data sources are from the Taipei Hospital website, specifically compiled from the final accounts announcement reports from 2013 to 2023.

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The input indicators are as follows: Total Number of Employees (I_1), Number of Outpatient Staff (I_2), Number of Inpatient Staff (I_3), Number of R&D Personnel (I_4), Employment Costs (I_5), R&D Expenses (I_6), Training Expenses (I_7), Machinery and Equipment Purchase Costs (I_8), Building and Construction Costs (I_9), Procurement Cost Rate (I_10). The output indicators are: Net Interest Income (O_1), Total Number of Outpatient Visits (O_2), Total Number of Inpatient Admissions (O_3), Internal Revenue (O_4), External Revenue (O_5), Current Period Surplus (O_6), Donated Income (O_7), and Number of Awards and External Evaluations/Certifications (O_8).

Due to the need to avoid zero values in DEA input-output data, if a variable has a value of zero in any given year, all values of that variable across all years will be shifted upward by +1 to meet the requirements of the DEA model. Additionally, to minimize the impact of outliers and facilitate model analysis, the data used in the DEA analysis will undergo logarithmic transformation.

Table 2 Descriptive Statistics of The Variables Amount Unit: USD

	N	Average	Std.	Min.	Max.
I_1 Total Number of	11	814	122.719		1040
I_2 Number of	11	349	75.238	203	483
I_3 Number of Inpatient	11	285	39.81	213	332
I_4 Number of R&D	11	6.5	3.4	4	16
I_5 Employment Costs	11	28,229,877	4,561,292	22,905,385	36,647,138
I_6 Employment Costs	11	1,045,569	134,862	927,754	1,418,677
I_7 Training Expenses	11	383,969	67,200	268,985	487,846
I_8 Machinery and	11	2,948,000	1,091,169	1,496,738	4,476,892
I_9 Building and	11	353,908	576,000	0	1,936,215
I_10 Procurement Cost	11	29.4	3.3	24.7	33.8
O_1 Net Interest Income	11	176553.846	82246.15385	120061.5385	401907.6923
O_2 Total Number of	11	582,000	66,000	499,000	721,000
O_3 Total Number of	11	130,000	120,000	116,000	155,000
O_4 Internal Revenue	11	79,640,000	19,972,769	61,432,431	117,112,615
O_5 External Revenue	11	2,455,231	874,400	1,022,031	3,798,800
O_6 Current Period	11	3,371,908	1,164,554	1,743,846	5,582,985
O_7 Donated Income	11	247,046	186,308	83,446	596,092
O_8 Number of Awards	11	21.6	8.2	7	34

Research period: from 2013 to 2023, a total of 11 years.

Data sources: Taipei Hospital annual reports; Taipei Hospital sustainability reports; compiled by this study.

Empirical Result

While DEA is adept at handling multiple inputs and outputs, it is not without limitations. Specifically, the number of decision-making units must be sufficiently large to maintain the model's discriminating power. Each additional input or output variable can diminish this discriminating capability. Empirical guidelines suggest that the number of DMUs should be at least twice the sum of the number of input and output variables. Consequently, this study has made adjustments to the selection of input and output indicators. For DEA performance evaluation of Taipei Hospital from 2013 to 2023, the input indicators have been refined to include only two metrics: total number of employees and total expenses, with total expenses comprising personnel, research and development, training costs, and machinery and building purchases. The output indicators have been consolidated into three metrics: total number of patients, total number of inpatients, and surplus for the period. The calculations for overall efficiency, technical efficiency, and scale efficiency were conducted using the Gurobi-Python software on the Wu(2018) platform.

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This study employs the CCR model to calculate the annual overall efficiency under the assumption of CRS. Following this, the BCC model is used to determine technical efficiency under VRS. The ratio of technical efficiency to overall efficiency yields scale efficiency, which provides insight into the scale of returns for each year. The results indicate that an overall efficiency score of 1 signifies that the unit operates at optimal efficiency. Technical efficiency measures the effectiveness of each DMU in utilizing input resources to achieve maximum output, with higher values denoting more effective resource utilization. Conversely, scale efficiency evaluates whether the input and output variables of the DMU are functioning at their optimal levels for the given year.

Table 3 2 Results of DEA Analysis

DMU	OE	Rank	TE	Rank	Scale Efficiency
2013	1	1	1	1	1
2014	1	1	1	1	1
2015	0.998	5	1	1	0.998
2016	0.994	8	0.997	8	0.997
2017	0.996	6	0.999	6	0.997
2018	0.995	7	0.999	7	0.996
2019	0.993	9	0.994	9	0.999
2020	0.983	11	0.992	10	0.991
2021	0.988	10	0.991	11	0.997
2022	1	1	1	1	1
2023	1	1	1	1	1
MEAN	0.995		0.997		0.998

Overall Efficiency Analysis

Table 2 reveals that Taipei Hospital exhibited an overall efficiency value of 1 in the years 2013, 2014, 2022, and 2023, indicating these were periods of optimal efficiency. In contrast, the efficiency values for other years were below 1, suggesting reduced efficiency. The overall efficiency was notably at its lowest during the early pandemic years of 2020 and 2021.

Technical Efficiency Analysis

According to Table 2, Taipei Hospital achieved a technical efficiency value of 1 in 2013, 2014, 2015, 2022, and 2023, reflecting efficient utilization of input factors during these years. In contrast, other years displayed technical efficiency values below 1, indicating less effective use of inputs. The technical efficiency was particularly poor during the onset of the pandemic in 2020 and 2021.

Scale Efficiency Analysis

Scale efficiency can be categorized based on the scale efficiency value (SE) into three types: increasing returns to scale, constant returns to scale, and decreasing returns to scale. As shown in Table 3, no years reported a scale efficiency value exceeding 1, which suggests that there were no instances of excessive scale requiring reduction. The years 2013, 2014, 2022, and 2023, which also achieved an overall efficiency value of 1, demonstrated optimal scale efficiency. Conversely, years with scale efficiency values below 1 were characterized by increasing returns to scale, with 2020 exhibiting the lowest scale efficiency value of 0.991. This indicates that there was a substantial need for scale expansion during this period.

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Conclusions

This study introduces a framework for intellectual capital reporting tailored for hospitals and employs DEA to evaluate the operational performance of Taipei Hospital from 2013 to 2023. The research findings suggest that due to the non-profit nature of hospitals, an intellectual capital framework serves as a valuable supplement to traditional financial statements, enabling a more comprehensive assessment of performance through human, structural, and relational capital dimensions. Additionally, the DEA results indicate that the global pandemic, which began in 2019, significantly impacted Taipei Hospital's operations. Nonetheless, during this critical period, Taipei Hospital undertook a series of reforms and policy initiatives, which contributed to its emergence as a benchmark for high-quality medical services.

In summary, the findings of this study indicate a gradual decline in both fixed and variable returns to scale efficiency values for Taipei Hospital starting from 2016. The global spread of the COVID-19 pandemic, which began in 2019, also impacted Taiwan's healthcare environment. During this critical period, Dr. Shun-Ping Cheng assumed the position of Director of Taipei Hospital in August 2020 and initiated a series of reforms and policy measures, positioning Taipei Hospital as a model for high-quality medical service.

Empirical results reveal that both the CRS and VRS efficiency values achieved 1 in 2022 and 2023, indicating peak efficiency during the post-pandemic years. These results suggest that Taipei Hospital successfully capitalized on the pandemic response opportunities, transforming challenges into improvements. Through continuous reforms and optimizations, the hospital effectively enhanced its performance.

Suggestion and Limitations

According to Golany and Roll (1989), when conducting DEA, the number of DMUs should be at least twice the total number of inputs and outputs to ensure statistical validity and reliability. Failure to meet this criterion may lead to biased results where the majority of units are evaluated as efficient. Given that this study covers a period of only 11 years and considers each year as a separate DMU, the number of inputs and outputs was simplified, and logarithmic transformations were applied to mitigate the impact of extreme values. This approach was adopted to ensure the credibility of the research findings. Future studies should consider increasing the number of DMUs and refining the model to enhance the robustness of the results.

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Contributors

All authors provided a substantial contribution to the design and interpretation of the protocol and guidance, as well as writing sections of drafts, revising based on comments received, and approving the final version.

Availability of Data and Material

Primary data are available in the published articles as cited. All other data are available on the Taipei Hospital website (https://www.tph.mohw.gov.tw/?aid=533).

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