Prioritized factors of decision making of medical equipment analyzer purchasing by using fuzzy analytic hierarchy process: a case study of Health Service Support department

Wittita Pannao* Sani Boonyagul Anantasak Wongkamhang and Anuchit Nirapai

College of Biomedical Engineering, Rangsit University, Pathum Thani, Thailand
*Corresponding author, E-mail: wittita.p62@rsu.ac.th

Abstract

The objective of this research is to prioritize the criteria that impact the decision to acquire medical equipment analyzers. By using a fuzzy hierarchical analysis process to gather judgment from experts with accountabilities aligned with the organizational structure and more than two decades of experience in the Department of Health Service Support's medical device calibration mission. The study's findings indicate that the seven major criteria were weighted in descending order: (1) Diagnostic failures 24.34 percent, (2) Impact on tested services 21.69 percent, (3) Analyzer age 15.41 percent, (4) After-sales support 13.39 percent, (5) Analyzer-related costs 9.42 percent, (6) Preferences for staff 8.25 percent, and (7) Tested medical equipment 7.49 percent. The consistency ratio (C.R.) for the primary judgment criterion was 0.03, which is satisfactory. However, based on the net score weights of the 16 sub-criteria, it was determined that the backup equipment sub-criteria has the highest priority at 11.76 percent, while the type of tested medical equipment has the lowest value at 0.96 percent.

Keywords: *Factors of decision making, Fuzzy analytic hierarchy process, Medical equipment analyzer*

1. Introduction

At the end of 2019, the global population faced a pandemic of pneumonia caused by 2019-nCoV, or COVID-19. As a result, the number of cases surpassed the health system's capability, resulting in millions of fatalities worldwide. In this situation, all hospitals had a greater need for medical equipment to treat patients' symptoms. Medical staff must exercise extreme caution while using medical equipment due to a lack of medical equipment and the difficulty of obtaining it. As a result, maintenance and testing of medical equipment were crucial throughout this period. According to the business research firm, the global medical equipment market valued at around $456.8 billion in 2020 (The business research company, 2021). In 2021, the business research firm While Markets and Markets published an opinion piece, and the company believed that the global medical device maintenance services market would reach around $45.2 billion in 2020, accounting for 10% of the overall medical equipment sector. The market expects to double in size to $74.2 billion by 2026 nearly. Asia-Pacific countries will grow the fastest, with a compound annual growth rate of 10.4 percent (Markets and Markets, 2021).

The global medical device maintenance services market was in stark contrast to Thailand's Gross Domestic Product (GDP) decline of 6.1 percent to about 501.795 billion US dollars in 2021 (The world bank, 2020). Additionally, Thailand's government issued an Emergency Decree on Public Administration in Emergencies to enforce the law on March 26, 2020. Additionally, the Thai government has borrowed nearly 1 trillion baht, or $30.51 billion to acquire vaccinations, medications, and equipment to aid in medical care (Public Debt Management Office, 2021). Therefore, as a government agency, the Department of Health Service Support must maximize the effectiveness of the funding. Between 2013 and 2022, the agency spent over 198 million baht on electrical and radio equipment, including over 600 medical device analyzers for medical device servicing (Bureau of the Budget, 2022).

The Department of Health Service Support is responsible for inspecting, testing, and calibrating medical equipment. Its services are provided by the Medical Engineering Division and 12 Health Service Support Centers, which check over 100,000 medical equipment yearly from over 800 hospitals around Thailand. This activity has been continuing for more than a decade. As a result, the Department of Health Service Support must consider replacing the old technology or model. However, procuring a medical device analyzer for each item is a considerable investment; for example, replacing 26 vital signal simulators to meet the organization's requirements would require a budget of more than 10.4-15.6 million baht (approximately 4-6 hundred thousand baht per device). Prioritization and purchase choices are decided without a logical format or criterion, based only on the request for "replacement" or on the age of equipment.

Thus, this study used the Fuzzy Analytic Hierarchy Process to prioritize decision-making criteria for purchasing a medical equipment analyzer based on expert opinion during the organizing process. Therefore, this research will assist the Department of Health Service Support to make investment strategies and budget usage transparent, reliable, and based on academic content that will assist the company and hospital managers in selecting a viable alternative.

2. Objectives

To study the priority of the criteria used in the decision to purchase a medical equipment analyzer for inspection, testing, and calibrating medical equipment of the Department of Health Service Support by using the Fuzzy Analytic Hierarchy Process

3. Materials and Methods

3.1 Study and gather relevant information

Conduct a study of relevant theories, concepts, and research about the procurement process and the fuzzy hierarchical analysis process to establish a framework for knowledge in prioritizing purchasing decision criteria.

3.2 Determine the main criteria and sub-criteria of the decision-making process.

Domnguez and Carnero (2020) conducted the critical reference study using a fuzzy hierarchical analytic technique to prioritize hospital medical equipment replacements, including seven significant criteria, sixteen sub-criteria, and four alternative options. The researchers analyzed relevant literature to find characteristics influencing purchasing decisions. Consequently, the researcher presented factors to experts at the organization. They reviewed and adjusted the criteria in the context of the organization's situation to incorporate them into the decision to purchase medical equipment analyzers, as seen in Figure 1 (Domínguez, & Carnero, 2020).

3.3 Create a questionnaire for data collection.

Using questionnaires as a study method, the researcher adopted the Fuzzy Analytic Hierarchy Process to prioritize the purchase decision criteria for medical equipment analyzers. To include the viewpoints of four experts, the experts rated each criterion on a scale of 1 to 9 using comparative technical—the scores based on a fuzzy hierarchical analytic method shown in Table 1 in a triangle membership function.

An illustration of scoring, If the expert judges that both criteria for comparison are equally essential, they give a grade of one. Alternatively, if the first criterion (on the left) is more important than the second criterion (on the right), the left scores 9. By contrast, the second criterion is more important than the first, getting a score of six on the right, as in Table 2.

Table 1 Questionnaire ratings using triangle membership functions (Kabir, & Hasin, 2011)

Questionnaire ratings	Triangular fuzzy scale (l, m, u)	Verbal scale
1	(1,1,3)	Equally preferable
2	(1,2,4)	Between equally and moderately preferable
3	(1,3,5)	Moderately preferable
4	(2,4,6)	Between moderately and strongly preferable
5	(3,5,7)	Strongly preferable
6	(4,6,8)	Between strongly and very strongly preferable
7	(5,7,9)	Very strongly preferable
8	(6,8,9)	Between very strongly and extremely preferable
9	(7,9,9)	Extremely preferable

3.4 Collecting data and interviewing experts

Although the Department of Health Service Support employs more than 1,000 people, the population of specialists involved in the purchase of a medical device analyzer is equal to four, which is a group of people at the head of section and sub-section levels in the Division of Medical Engineering's biomedical engineering standards group. So, this study used judgment sampling to sample a population. The informants are four professionals with more than two decades of operational experience who wield authority inside the medical equipment analyzer procurement procedure's organizational structure, as shown in Table 3.

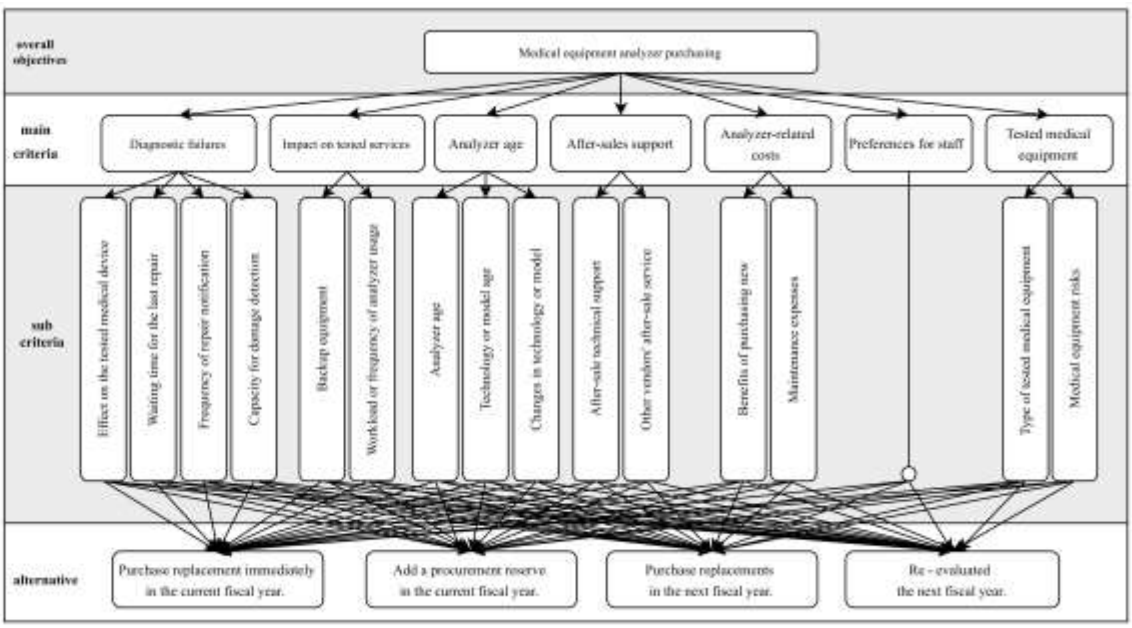

Figure 1 The hierarchical structure of a medical device analyzer's purchasing decision-making process.

Table 2 Sample scoring in the questionnaire

No.	First criterion	The first criterion is more important than the second.								Equally	The first criterion is more important than the second.								Second criterion
1	Diagnostic failures	9	8	7	6	5	4	3	2	①	2	3	4	5	6	7	8	9	Impact on tested services
2	Diagnostic failures	⑨	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Analyzer age
3	Diagnostic failures	9	8	7	6	5	4	3	2	1	2	3	4	5	⑥	7	8	9	After-sales support

Table 3 Job Title and work experiences of experts

Number	Job Title	Work Experience
1	Head of Biomedical Engineering Standards section	24
2	Head of Laboratory sub-section	38
3	Head of Safety and Environmental Engineering Standards sub-section	38
4	Head of the Promotion of Biomedical Engineering Standards sub-section	37

3.2.5 Analyze the data using fuzzy hierarchical analysis.

3.2.5.1 Create fuzzy pairwise matrices using fuzzy judgments from experts by comparing criteria on the fuzzy numerical scale in table2. All diagnostic matrices for experts can be constructed in the following N x N matrix, $\tilde{r}_{ij} = (r_{ijl}, r_{ijm}, r_{iju})$: (Teeranupattana, Kitisrivorapoj, & Boonchom, 2012).

$$\tilde{R} = \begin{vmatrix} \tilde{r}_{11} & \tilde{r}_{12} & \cdots & \tilde{r}_{1N} \\ \tilde{r}_{21} & \tilde{r}_{22} & \cdots & \tilde{r}_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{r}_{N1} & \tilde{r}_{N1} & \cdots & \tilde{r}_{NN} \end{vmatrix} \quad (1)$$

when $\tilde{r}_{ii} = (1,1,1)$ and $\tilde{r}_{ij} = 1/\tilde{r}_{ij}$, i,j = 1,2, … , N

N is the number of members in each vertical row of the matrix.

3.2.5.2 Calculate the judgments made by a group of decision-makers by calculating the geometric mean or the mean value of the data produced by the root K in equation 2.

$$l_{ij} = \left(\prod_{k=1}^{K} l_{ijk}\right)^{1/K}, \quad m_{ij} = \left(\prod_{k=1}^{K} m_{ijk}\right)^{1/K}, \quad u_{ij} = \left(\prod_{k=1}^{K} u_{ijk}\right)^{1/K} \quad (2)$$

when l_{ij}, m_{ij}, u_{ij} is the geometric mean fuzzy number based on the expert group decision.

$l_{ijk}, m_{ijk}, u_{ijk}$ is a fuzzy number for each expert’s judgments.

K is the number of experts or decision-makers.

3.2.5.3 Calculating weights using Eigenvectors or computing the normalized matrix in each row using Buckley’s (1985) approach as follows:

$$\tilde{r}_i = (\tilde{r}_{i1} \cdot \tilde{r}_{i2} \cdot \cdot \tilde{r}_{iN})^{1/N} = \left(\left(\prod_{j=1}^{N} r_{ijl}\right)^{1/N}, \left(\prod_{j=1}^{N} r_{ijm}\right)^{1/N}, \left(\prod_{j=1}^{N} r_{iju}\right)^{1/N} \right) \quad (3)$$

when $\tilde{r}_i$ is the geometric mean in each vertical row of the matrix.
$\tilde{r}_{ij}$ is a fuzzy number of a group of experts' judgments.
N is the number of members in each vertical row of the matrix.

Calculate the Geometric Mean for each vertical row of the matrix and divide by the geometric means for all vertical rows of all matrices. Equation 4 may be used to get the weighted values for each criterion.

$$\tilde{w}_i = \tilde{r}_i \cdot (\tilde{r}_1 + \tilde{r}_2 + + \tilde{r}_n)^{-1} = \left(\frac{\prod_{j=1}^{N} (r_{ijl})^{1/N}}{\sum_{i=1}^{N} \prod_{j=1}^{N} (r_{iju})^{1/N}}, \frac{\prod_{j=1}^{N} (r_{ijm})^{1/N}}{\sum_{i=1}^{N} \prod_{j=1}^{N} (r_{ijm})^{1/N}}, \frac{\prod_{j=1}^{N} (r_{iju})^{1/N}}{\sum_{i=1}^{N} \prod_{j=1}^{N} (r_{ijl})^{1/N}} \right) \quad (4)$$

when $\tilde{w}_i$ is the weight of each criterion.

Reduce the defuzzified value of the fuzzy vector is obtained by transforming it to a Crisp Numeric Value using the following equation:

$$w_i = (l_i + m_i + u_i) / 3 \quad \text{when i = 1,2,…,N} \quad (5)$$

After that, the weight has been normalized according to Equation 6.

$$z_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \quad \text{when i = 1,2,…,N} \quad (6)$$

3.2.6 Calculate the Consistency Ratio: C.R.

It is calculated by multiplying the sum of each vertical value by the sum of the horizontal mean. Then all products are multiplied, called the Largest Eigenvector or as shown in Equation 7 (Sanguanrat, 2014).

$$\lambda_{max} = \sum_{i=1}^{n} \left[\sum_{j=1}^{n} a_{ij} w_j \right] \quad (7)$$

The consistency ratio (C.R.) was obtained by dividing the Consistency Index (C.I.) by the Random Consistency index: R.I., as shown in Equations 8 and 9, respectively.

$$\text{C.I.} = \frac{\lambda_{max} - n}{n - 1} \quad (8)$$

$$\text{C.R.} = \frac{\text{C.I.}}{\text{R.I.}} \quad (9)$$

Table 4 Random consistency index (RCI)

N	3	4	5	6	7	8	9	10	11	12	13	14	15
R.I.	0.58	0.90	1.12	1.24	1.32	1.40	1.45	1.49	1.51	1.54	1.56	1.57	1.58

Source: Golden and Wang cited in (Rungjaeng, & Yumwilai, 2020)

If the expert's Consistency Ratio (C.R.) equals zero, the expert's judgment is consistent. However, if the value surpasses the critical threshold, it should be evaluated or re-diagnosed. In general, critical levels for C.R. values vary depending on the number of criteria evaluated. On the other hand, a high value suggests a level of discretionary inconsistency. To be considered acceptable in this study, the C.R. value must be less than or equal to 0.10 or 10% (Teeranupattana, & Thiesiriphet, 2011).

To facilitate computations, the researcher created a computer program using Microsoft Excel Spreadsheet version Microsoft 365 and evaluated the results against the Fuzzy AHP package application (Caha, 2017).

3.2.7 Summary of research results

Summary of the results of the primary and sub-criterion in the decision to purchase equipment of the Department of Health Service Support and research recommendations for further use in other types.

4. Results and Discussion

The researcher synthesized questionnaire data and used a fuzzy hierarchical analytic approach to prioritize decision-making criteria for medical device analyzers. According to the judgments of the four experts have the authority to consider the requests for the medical device analyzer purchase budget; they have over two decades of expertise working with the Department of Health Service Support in the field of medical equipment inspection, testing, calibration, and maintenance in government hospitals.

The most critical factor, according to experts, is the diagnostic failures criteria (24.34 percent), followed by criteria of the impact on the testing service (21.69 percent) and the Analyzer age (15.41 percent).

While the criteria for the tested medical equipment were the least important (7.49 percent), followed by user satisfaction (8.25 percent), the cost of the analyzer (9.42), and After-sales support (13.39 percent), respectively, in expert judgments, a C.R. value of 0.03 for a 7x7 matrix is acceptable.

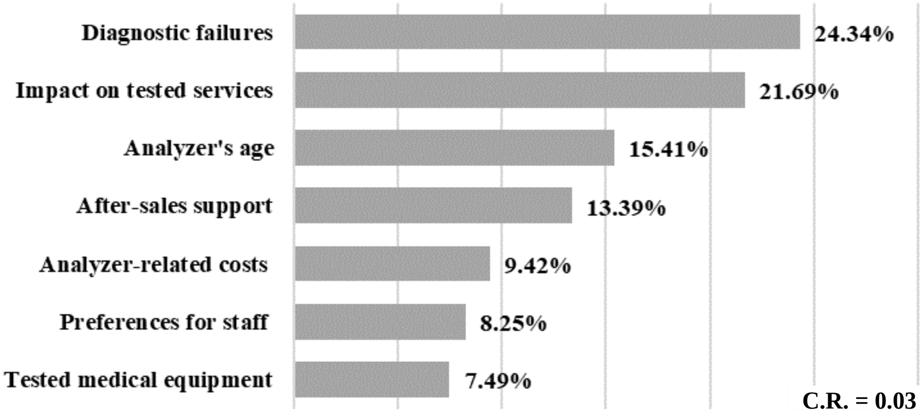

Figure 3 The priority of the main criteria

Table 5 The priority of sub-criteria

Main criteria	Sub-criteria	Sub-criteria score	Net Score Weight
Diagnostic failures (C.R. = 0.07)	Effect on the tested medical device	40.44%	9.84%
	Waiting time for the last repair	30.09%	7.33%
	Frequency of repair notification	21.28%	5.18%
	Capacity for damage detection	8.19%	1.99%
Impact on testing services (C.R. = 0)	Backup equipment in use	54.21%	11.76%
	Workload or frequency of analyzer usage	45.79%	9.93%
Age of the analyzer (C.R. = 0)	Analyzer age	53.64%	8.27%
	Technology or model age	26.11%	4.02%
	Changes in technology or model	20.25%	3.12%
After-sales support (C.R. = 0)	After-sale technical support	87.22%	11.68%
	Other vendors' after-sale service	12.78%	1.71%
Analyzer-related costs (C.R. = 0)	Benefits of purchasing new	86.93%	8.19%
	Maintenance expenses	13.07%	1.23%
Preferences for staff (C.R. = 0)	-	-	8.25%
Tested medical equipment (C.R. = 0)	Type of tested medical equipment	87.22%	6.53%
	Medical equipment risks	12.78%	0.96%

The impact on the tested medical equipment (40.44 percent) was determined to be the most significant component of the diagnostic failures sub-criterion, followed by the time required to complete the previous repair (30.09 percent), the frequency of repair notification (21.28 percent), and the capability for damage detection (8.19 percent). To accomplish this, experts suggest that backup equipment's weighting (54.21 percent) should be somewhat more than the workload or frequency of analyzer operation (45.79 percent).

While the analytical instrument lifespan sub-criteria for the age of the standard instrument (53.64 percent) had a higher significance score, the age of the technology or model (26.11 percent) and frequency of changing the technology or model had lower significant scores (20.25 percent).

Along with the expenses associated with the analyzer, experts assessed the advantages of acquiring new (86.93 percent) in terms of assisting in the reduction of direct and indirect costs when purchasing replacements that exceed the percentage of the cost of maintenance during the analytical instrument's three-year life (13.07 percent). For the sub-criterion of after-sales support service, the after-sales technical service contract (87.22 percent) was much more essential than the other seller's after-sales service contract (12.78 percent). The risk associated with the medical device (87.22 percent) was scored more remarkable than the type of medical device (12.78 percent). All sub-criteria had a C.R. value less than 0.1, demonstrating that the expert's judgment was consistent.

However, when the net significance score of the sub-criterion is considered, the top five factors that influence the purchase choice of the Department of Health Service Support's medical equipment analyzer are as follows: backup equipment for use (11.76 percent), after-sales technical service contract (11.68 percent), workload or frequency of analyzer usage (9.93 percent), effect on the tested medical device (9.84 percent), and analyzer age (percent 8.27). While the type of medical equipment tested (0.96 percent), the cost of maintenance (1.23 percent), and the after-sales service provided by other suppliers (1.71 percent) were the three criteria with the lowest importance.

5. Conclusion

The purpose of this study was to determine the relative importance of the criteria used in the Department of Health Service Support's purchase decision for a medical device analyzer—an organization that offers inspection, testing, and calibration services to over 800 hospitals across Thailand—by using a fuzzy hierarchical analysis process to elicit viewpoints from four procurement review experts with over 20 years of experience, using seven primary criteria and sixteen sub-criteria.

Expert group decision-making using a pairwise benchmarking technique found that weight of 24.34 percent for diagnostic malfunction was an important criterion in the seven major criteria. In comparison, the minor critical requirement for the medical device tested was 7.49 percent. C.R. is 0.03, which is within acceptable limits. While the weights assigned to each of the sixteen sub-criteria varied, the most significant was the availability of backup devices in operation, at 11.76 percent, and the least significant was the type of medical equipment at 0.96 percent.

Additionally, the researchers discovered that group decision results of experts using geometric means are inconsistent with the discretion of individual experts, such as those in the academic or administrative fields, who will focus on the symptoms of equipment malfunction because they affect service quality and device damage. By contrast, operational specialists will concentrate on testing services since this directly impacts the quantity of work or success measured by key performance measures. Consequently, the decision criterion significance score strikes in this research as an appropriate compromise between operator and management viewpoints. In the future, agencies may utilize the decision-making model to expand it as a qualitative factor for pricing according to Section 65 of the Government Procurement and Supplies Management Act B.E. 2560, enabling government agencies to employ additional criteria in selecting merchant proposals that demonstrate the value of spending money on the country's budget (Royal Thai Government Gazette, 2017).

This study has certain limitations. The rarity of experienced individuals in the medical device industry who understand the organization's context and restrictions as they exist might affect the group's expert decision-making. Additionally, professionals use a sense of experience and logic while doing pairwise comparisons. If the discretion score is not logical or reasonable, the Consistency Ratio (C.R.) number will be more than acceptable. The researcher suggests developing a software that can automatically compute C.R. and visualize the data in a spider web graph (Radar Chart) during the interview and data collection from experts. Additionally, if the number of main and minor criteria is excessive, it might add time, effort, and confusion to experts' responses to surveys. Moreover, experts advocate that the model include mission relevance criteria, indications, and methods. To enhance oversight of the organization's activity and to put it to practical use.

6. Acknowledgements

This research was completed as a result of the recommendations and suggestions of three advisors from Rangsit University's College of Biomedical Engineering, including Asst. Prof. Dr. Sani Bunyakul, Ajarn Anantasak Wongkhamhaeng, and Ajarn Anuchit Nirapai. Experts from the Medical Engineering Division Department of Health Service Support also contributed to this research. The researcher wishes to express his thankfulness for this opportunity.

7. References

Bureau of the Budget, (2022). *Budget Procedures Act*. Retrieved October 1, 2022, from https://www.bb.go.th/topic3.php?sort=1&gid=862&mid=545

Domínguez, S., & Carnero, M. C. (2020). Fuzzy Multicriteria Modelling of Decision Making in the Renewal of Healthcare Technologies. *Mathematics, 8*(6), 944. doi.org/10.3390/math8060944

Caha, J. (2017*). Examples of FuzzyAHP package application* (ver. 0.9.0). https://www.researchgate.net/publication/314263936_Examples_of_FuzzyAHP_package_application_ver_090

Kabir, G., & Hasin, A. (2011). Comparative analysis Of AHP and fuzzy AHP models for multicriteria inventory classification. *International Journal of Fuzzy Logic Systems*, *1*, 1–16.

Mardani, A., Hooker, R. E., Ozkul, S., Yifan, S., Nilashi, M., Sabzi, H. Z., & Fei, G. C. (2019). Application of decision making and fuzzy sets theory to evaluate the healthcare and medical problems: a review of three decades of research with recent developments. *Expert Systems with Applications, 137*, 202-231. doi.org/10.1016/j.eswa.2019.07.002

Markets and Markets. (2021). *Medical Equipment Maintenance Market Size, Share and Trends forecast to 2026 by Product, Service, End User | COVID-19 Impact Analysis | MarketsandMarkets™* https://www.marketsandmarkets.com/Market-Reports/medical-equipment-maintenance-market-69695102.html

Public Debt Management Office. (2021). *Public Debt Accrual Information*—Public Debt Management Office. https://www.pdmo.go.th/th/public-debt/debt-outstanding

Rungjaeng, K., & Yumwilai, K. (2020). *Sustainability Factor Analysis in Water Resource Infrastructure Development in Thailand Using AHP*. 208–227.

Royal Thai Government Gazette. (2017). *Regulations of the Ministry of Finance on Public Procurement and Supplies Management B.E. 2560* (2017).

The business research company. (2564). *Global Medical Devices Opportunities And Strategies Market Report*. https://www.thebusinessresearchcompany.com/report/medical-devices-market

The world bank. (2563). *GDP (current US$) | Data*. https://data.worldbank.org/indicator/NY.GDP.MKTP.CD

Teeranupattana, A., Kitisrivorapoj, B., & Boonchom W. (2012). Selection of Logistics Service Providers. using hierarchical decision-making processes and fuzzyset theory. *Journal of Business Administration*, 39(152), 1–29. doi.org/10.14456/jba.2016.16.

Teeranupattana, A,. & Thiesiriphet, C. (2011). Prioritization of key metrics and processes in the supply chain. By means of a hierarchical decision-making process model. *Chulalongkorn Business Review*, 33(127), 1–32.

Sanguanrat, S. (2014). Supplier grading by FAHP process for a case study of integrated circuit board (IC) factory [industrial engineering]. Thammasat University.