# DEVELOPING AND TESTING ECONOMIC MODEL FOR PICTURE ARCHIVING AND COMMUNICATION SYSTEM IN THAILAND

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**ABSTRACT:** A hospital needs cost-benefit evidence to support decision making to invest in high cost Picture Archiving and Communication System (PACS). However, not many hospitals are capable of conducting an economic study. The objectives of the study were to develop economic model**s** that help support decision making whether a hospital should implement PACS, partial PACS, or remain with film-based system and to test the developed models using examples of small, medium, and large sized hospitals. The study applied cost-benefit analysis as a framework. The model used provider's perspective. Cost items and model assumptions came from work process study, literature review and key informants interview. To evaluate the developed models, quantitative utilization data were acquired from previous studies in Thailand. Cost data were obtained from various public hospitals and Ministry of Public Health sources. Net Present Value (NPV) was the main outcome. Among the 3 alternatives, the one which produced the smallest NPV was a system a hospital should implement. Cost saving and break-even point were calculated. The developed model composed of 11 direct cost items and 3 indirect cost items for PACS, and 14 direct cost items and 5 indirect cost items for film-based system. The study assumed 9 years PACS lifetime, 5 years replacement of PACS related hardware, and 10 years replacement of other PACS and film-based items, 3% discount rate, and 8% increase in growth rate of service utilization. Maintenance cost and software upgrade cost were bundled and charged at 8% of first time investment cost. Inflation rate was estimated at 2% and salary was increased at 5%. As the models were tested using data from 3 hospitals which could not be considered representative of each hospital size, this study suggested that partial PACS may not be recommended for all hospital sizes. PACS showed no payback in a small size hospital, but was worth investing for medium and large size hospitals when compared to film-based system. For these particular examples, implementing PACS would have saved 24.5 and 60.2 million baht for medium and large size hospitals, respectively. Payback was received in the 4$^{th}$ year for both medium and large size hospitals. Sensitivity analysis suggested that lowering first time investment cost in a small size hospital by 30% would make PACS worthy of investment. Moreover, if growth rate of service utilization remained unchanged, a medium size hospital should not invest in PACS as there was no gain on investment in a 10 year period. The result for various hospital sizes cannot be generalized. A hospital should use its own data to find out if PACS worth investing.

**Keywords:** Picture Archiving and Communication System, Health technology assessment, Economic Model, Differential cost analysis, Net Present Value

## INTRODUCTION

Medical images are important information which help physicians make accurate diagnoses. Previously, medical images were recorded on film. With progression of information technology, now it is digitized and recorded in IT storage devices. Unlike film-based counterparts, a Picture Archiving and Communication System (PACS) utilizes a lot less storage space. It frees staff in radiology

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department from retrieving and returning film from and to the film storage room.

PACS has been created to manage digital images. It has been widely implemented in many hospitals and healthcare institutes. PACS operates by acquiring medical images from various x-ray modalities, and storing them in storage devices. With PACS, digital images can be directly accessed by radiologists. Significant changes in work process have been made especially fora case that needs urgent interpretation. Radiologists can more quickly enter written interpretation into the system. PACS allows authorized staff to simultaneously retrieve medical images from multiple workstations. It enhances multidiscipline team discussion which results in more accurate and faster diagnosis. Not only PACS allows comparison of images overtime on the same screen, it also provides tools for image adjustment e.g. lightening or darkening of image. Once PACS is used, patients do not have to carry a heavy stack of films from place to place [1-11].

PACS has been implemented in Thailand for approximately 10 years, mostly in big private and government hospitals. At that time, PACS was not widely used due to its high cost. Recently, however, demand for PACS has increased not only among big sized hospitals, but also medium and small sized hospitals. Some examples of hospitals with less than 150 beds which procured PACS were Koh-ka hospital, Somdej-Prayuparach-Dechudom hospital, Nong-song-hong hospital, Si-chon hospital and six more hospitals [12-16]. To implement PACS, all hospitals must analyze and show that PACS is worth investing [10, 17-19].

Many studies were conducted to see if PACS gave a cost benefit. These studies were different in many aspects such as comparing models (PACS vs film, or partial PACS vs film), hospital size (small, medium or large), duration of study (1, 5, 7, 8, 9 or 10 years), incremental utilization rate (changed or unchanged)and time value for money adjustment (discount rate = 0, 3% or 4%). Fang et al., conducted a cost and cost saving analysis comparing full PACS implementation to an existing film-based system. The study was done in a 500-bed public hospital in Taiwan [2]. They found that investment could be returned in 4th year after a complete PACS installation. MacDonal et al, and Alanen et al., compared the cost of partial PACS[1] and existing film-based system in 186 and 500 bed-hospitals. Both studies found that partial PACS was not worth the investment [1, 8]. Maass et al., compared cost of PACS, partial PACS and film-based system in a 900 bed-hospital, using only one year study period [20].A too short study period can create bias against a system which has more first time investment cost.

Cost benefit analysis of PACS was conducted in two hospitals in 2011 by the Institute of Medical Research and Technology Assessment, Ministry of Public Health. PACS was compared with partial PACS in the 300 bed Prasat Neurological Institute, and compared with film-based system in the 114 bed Ubonrachathani Cancer Hospital. It was found in both settings that PACS saved more cost than its alternatives [21].

From previous reviewed studies, it was noted that cost components and study assumptions of cost benefit analysis models are varied. This study aimed to develop an economic model to assess cost savings to assist hospitals that intended to implement PACS. The model will help hospital administrators answer whether a hospital should invest in PACS or not and when will such an investment be returned. In this paper, this model was tested by using data assuming small, medium and large sized hospitals. Cost saving, break-even point and sensitivity analysis were demonstrated outcomes.

## MATERIALS AND METHODS

Materials and methods were divided into two parts; economic model development and model evaluation.

### Development of economic model

The study applied cost-benefit analysis as a framework. The model, using provider's perspective, aimed to compare cost of three alternatives; PACS, partial PACS and film-based system. Cost items were based on reviewed studies and real work process learned from two practice settings; Prasat Neurological Institute and Ubonrachathani Cancer Hospital. Assumptions such as lifetime of PACS and PACS related supplies, discount rate, and growth rate of service utilization were gathered from previous studies. Two key informants from the Radiology Department of Prasat Neurological Institute made a final decision for assumptions best fit to Thailand's context.

### Model evaluation

The developed model was evaluated. Quantitative utilization data were acquired from the cost-benefit analysis reports conducted by the Institute of Medical Research and Technology Assessment. Examples of quantitative utilization data were radiation examination volume, number of imaging devices and radiographic imaging conventional equipment, and the numbers of

[1] Partial PACS refers to use of both film-based system and PACS system as the hospital cannot afford full capacity of radiologist and clinician workstation.

workstations. Data from Ubonratchathani Cancer Hospital and Prasat Neurological Institute were used to produce answers for small and medium size hospitals, respectively [21]. Quantitative utilization data for large size hospital was assumed to be 2 times of a medium size hospital utilization. Cost data were obtained from the Ministry of Public Health's price list [22], medical supplies price survey 2009 and 2013 [23, 24], and Mahasarakam hospital's term of reference document [25]. When cost for the same items varied, the lowest cost was used.

For a partial PACS, the volume of 3 cost items; diagnostic viewing station and result viewing station were reduced by 50%. The reduction in these 2 items also resulted in proportionally reducing PACS maintenance cost and electricity for running PACS.

Net Present Value (NPV) was the main outcome. NPV referred to the summation of total cost which took into account time value in a specified study period. Among the three alternatives; PACS, partial PACS and film-based system, the alternative that produced the smallest NPV was the system a hospital should implement. The amount of cost saved was calculated as a product of two comparators of differential NPV. Break-even point for each alternative was identified at the year the Accumulated Present Value (APV) was greater than zero.

Example of how to use NPV for decision making is provided below. The NPV was calculated using the following formula.

$$\mathrm{NPV} = \sum_{t=0}^{n} \frac{C_t}{(1+r)^t}$$

When $C_t$=cost at time t, $r$= discount rate, $n$= a project lifetime

If an ordinary office man has two choices: A) to pay 10,000 Baht/month for rent and spend 7,000/month on commuting between his apartment and his office or B) to pay 5,000 Baht/month for rent and buy a 420,000 Baht car (paying off 7,000 Baht/month with 0% interest rate for car, and fill the tank 6,000 Baht/month). Which alternative is the best for 5 years interval? The calculation below show how to make decision.

$$\mathrm{NPV_A} = \frac{(120{,}000+84{,}000)}{(1+0.03)^0} + \frac{(120{,}000+84{,}000)}{(1+0.03)^1} + \ldots\ldots + \frac{(120{,}000+84{,}000)}{(1+0.03)^5}$$

= 204,000 + 198,058 + 192,290 + 186,689 + 181,251 + 175,972

= 1,138,260 Baht

$$\mathrm{NPV_B} = \frac{(60{,}000+84{,}000+72{,}000)}{(1+0.03)^0} + \frac{(60{,}000+84{,}000+72{,}000)}{(1+0.03)^1} + \ldots\ldots + \frac{(60{,}000+0+72{,}000)}{(1+0.03)^5}$$

= 216,000 + 209,709 + 203,601 + 197,671 + 191,913 + 113,864

= 1,132,758 Baht

With the calculation, one should choose alternative B as it saves 5,502 Baht.

An APV is used for calculating break-even point. APV in year *i* is the accumulation of NPV from $0^{th}$ year to $i^{th}$ year. The formula for APV is:

$$\mathrm{APV} = \sum_{i=0}^{n} (\mathrm{PVA_i} - \mathrm{PVB_i})$$

The break-even point will be identified when differential PV of the two choices reaches zero. Using the previous example, APV of choice A and B in 5 year period are calculated below.

APV at $0^{th}$year = ($PVA_0$-$PVB_0$)

= 204,000 - 216,000 = -12,000

$APV_A$ at $1^{st}$ year = ($PVA_0$-$PVB_0$) + ($PVA_1$-$PVB_1$)

= (204,000 - 216,000) + (198,058-209,709)

= -23,651

APV at $2^{nd}$ year = -34,962

APV at $3^{rd}$ year = -45,943

APV at $4^{th}$ year = -56,605

APV at $5^{th}$ year = 5,503

From the APV calculation, it can be concluded that alternative B will reach break-even point between year 4 and 5 when compared to alternative A.

The study was approved by the ethics committee of the Faculty of Pharmaceutical Sciences, Chulalongkorn University in March, 2013. (Protocol number 13-33-010)

## RESULTS

Results have been illustrated in two parts; economic model development and model evaluation.

### Development of economic model

Three alternative models; PACS, partial PACS, and film-based system, were developed based on provider's perspective. Direct and indirect costs were included. The economic model for PACS composed of 11 direct cost items and 3 indirect cost items. The economic model for film-based system composed of 14direct cost items and 5 indirect cost items. The economic model for partial PACS combined items from film-based system and PACS. (Table 1) Benefits of PACS were "freed up film storage room", "freed up radiology department staff", "no lost film" and "no damaged film". These items were appeared as cost items in film-based system.

*PACS lifetime*

In previous studies, the PACS lifetime were

**Table 1** Model structure, cost, and source for PACS, partial PACS and film-based system in three sized hospitals

| Cost structure | Cost | P | pP | F | Source[¶] |
|---|---|---|---|---|---|
| **Direct cost** | | | | | |
| A) Direct material cost | | | | | |
| 1. Computed radiography (CR) | 2.5-3.8M/ 1 unit | ✓ | ✓ | | [21, 22, 25] |
| 2. CR cassettes | 25- 35K/ 1 unit | ✓ | ✓ | | [21, 22, 25] |
| 3. Server | 1.3M (S), 5.7M(M), 11.5M (L) | ✓ | ✓ | | [21, 22, 25] |
| 4. Diagnostic viewing station | 0.5-1.8M/ 1 unit | ✓ | ✓ | | [21, 22, 25] |
| 5. Result viewing station | 30 – 39K/ 1 unit | ✓ | ✓ | | [21, 22, 25] |
| 6. PACS and RIS software | 3.0M (S), 3.5M (M), 3.5M (L) | ✓ | ✓ | | [21, 22, 25] |
| 7. Redundant array of independent disks (RAID) | 30K/ 2TB | ✓ | ✓ | | [21, 22, 25] |
| 8. Network | 1.5M (S), 1.7M (M), 3.5M (L) | ✓ | ✓ | | [21, 22, 25] |
| 9. Electricity for running PACS (e.g. server and viewing stations, etc) | 0.4M (S), 0.6M (M), 0.9M (L)/ year | ✓ | ✓ | | [21] |
| 10. PACS maintenance cost | 8% of first time investment/ year | ✓ | ✓ | | [21] |
| 11. Film | 1.2M (S), 5.0M (M), 10.0M (L)* | | ✓ | ✓ | [21, 23, 24] |
| 12. Film cassettes with screen | 6.2- 13.5K/ 1 unit | | | ✓ | [21, 23, 24] |
| 13. Film processor | 0.4-0.8M/ 1 unit | | ✓ | ✓ | [21, 22] |
| 14. Film printer | 0.6-1M/ 1 unit | | ✓ | ✓ | [21, 22] |
| 15. Film envelope | 40K (S), 85K (M), 170K (L)* | | ✓ | ✓ | [21] |
| 16. Color sticker | 13K (S), 40K (M), 81K (L)* | | ✓ | ✓ | [21] |
| 17. Office tool of film-based system | 4.8K (S), 33K (M), 66K (L)* | | ✓ | ✓ | [21] |
| 18. Film processor's maintenance cost | 5% of film processor cost | | ✓ | ✓ | [21] |
| 19. Film printer's maintenance cost | 5% of film printer cost | | ✓ | ✓ | [21] |
| 20. Film developer | 1,200/ 1 gallon | | ✓ | ✓ | [21, 23, 24] |
| 21. Film storage room | 1,000 baht/$m^2$/year | | ✓ | ✓ | [21] |
| 22. Film print process room | 1,000 baht/$m^2$/year | | ✓ | ✓ | [21] |
| 23. Electricity for film printer and film processor | 48K (S), 74K (M), 148K (L)/ year | | ✓ | ✓ | [21] |
| B) Direct labor cost | 300K (IT), 113K (R), 73K (FRP), 73K (FC)/ 1 person/ year* | ✓ | ✓ | ✓ | [21] |
| **Indirect cost** | | | | | |
| 1. Electricity for things other than PACS or film-based system | | | | | [21] |
| 1.1 air-conditioner of server room | 25K/ year | ✓ | ✓ | | [21] |
| 1.2 air-conditioner of film storage room | 15K (S), 30K (M), 60K (L)/ year | | ✓ | ✓ | [21] |
| 1.3 film viewing lamp | 7K (S), 20K (M), 41K (L)/ year | | ✓ | ✓ | [21] |
| 2. Office tool of PACS | 36.5K (S), 10.0K (M), 20.0K (L)* | ✓ | ✓ | | [21] |
| 3. CD to transfer medical image | 1K (S), 5K (M), 10K (L)/ year | ✓ | ✓ | | [21] |
| 4. Lost film | 1.5% of film cost of each year | | ✓ | ✓ | [21] |
| 5. Damaged film | 1.7% of film cost of each year | | ✓ | ✓ | [21] |
| 6. Film viewing lamp | 2K (S), 3K (M), 6K (L)** | | ✓ | ✓ | [21] |

Abbreviation:
P= PACS, pP= partial PACS, F= Film-based system
K= 1,000, M= 1,000,000
S= small, M=medium, L=large sized hospital
IT= Information technology staff, R= Receptionist, FRP= Film room personnel, FC= Film carrier
Note:
*At year zero
**At year zero and sixth year
[¶] References 21st – 25th were from procurement information from public sources.

assumed differently e.g. five years in one study[1], seven years in one study [26], eight years in one study [2], nine years in two studies[17, 21], and10 years in two studies[7, 8].Technology obsolescence was raised as an important issue which affects PACS lifetime.

For this study, two expert radiologists were consulted. Both of them unanimously selected nine years lifetime. This is because PACS was highly expensive and it was nearly impossible to purchase newer system in a shorter time period. In addition, they both believed that an upgraded version of PACS system may not provide significant change compared to the huge investment required.

*Lifetime of PACS related hardware and CR reader*

Most of PACS related hardware (e.g. workstations for radiologists, workstations for clinicians, and servers) were assumed to have four years lifetime. These items were assumed to be replaced in the 5th year. Only computed radiography (CR) item was assumed to have nine years life time. Depreciation rate was applied for all items according to their lifetime assumption [27].

**Table 2** Cost of implementing PACS assuming 9 year lifetime in a small hospital, Year 2012 – 2021

| Cost | Year | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **0** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** |
| **Direct cost** | | | | | | | | | | |
| *Direct material cost* | | | | | | | | | | |
| 1. CR (1) | 2,700,000 | | | | | | | | | |
| 2. CR cassettes | 26,502 | 28,622 | 30,912 | 33,385 | 36,056 | 38,940 | 42,055 | 45,420 | 49,053 | 52,978 |
| 3. Server (2) | 1,300,000 | | | | | 1,300,000 | | | | |
| 4. Diagnostic viewing station (3) | 2,700,000 | | | | | 2,700,000 | | | | |
| 5. Result viewing station (24) | 936,000 | | | | | 936,000 | | | | |
| 6. PACS and RIS software | 3,000,000 | | | | | | | | | |
| 7. RAID | 26,650 | 28,782 | 31,085 | 33,571 | 36,257 | 39,158 | 42,290 | 45,673 | 49,327 | 53,273 |
| 8. Networking system | 1,500,000 | | | | | | | | | |
| 9. Electricity for running PACS (e.g. server and viewing stations, etc) | 427,521 | 427,521 | 427,521 | 427,521 | 427,521 | 427,521 | 427,521 | 427,521 | 427,521 | 427,521 |
| 10. PACS maintenance cost | 975,132 | 975,132 | 975,132 | 975,132 | 975,132 | 975,132 | 975,132 | 975,132 | 975,132 | 975,132 |
| *Direct labor cost* | | | | | | | | | | |
| 1. Information technology staff (1) | 300,000 | 315,000 | 330,750 | 347,288 | 364,652 | 382,884 | 402,029 | 422,130 | 443,237 | 465,398 |
| 2. Receptionist (1) | 112,620 | 118,251 | 124,164 | 130,372 | 136,890 | 143,735 | 150,922 | 158,468 | 166,391 | 174,711 |
| **Indirect cost** | | | | | | | | | | |
| 1. Electricity for things other than PACS | | | | | | | | | | |
| 1.1 air-conditioner of server room (2) | 25,140 | 25,140 | 25,140 | 25,140 | 25,140 | 25,140 | 25,140 | 25,140 | 25,140 | 25,140 |
| 2. Office tool of PACS | 3,650 | 3,942 | 4,257 | 4,598 | 4,966 | 5,363 | 5,792 | 6,255 | 6,756 | 7,296 |
| 3. CD to transfer medical image | 1,100 | 1,100 | 1,100 | 1,100 | 1,100 | 1,100 | 1,100 | 1,100 | 1,100 | 1,100 |
| **Annual Cost** | 14,034,315 | 1,923,490 | 1,950,061 | 1,978,107 | 2,007,714 | 6,974,973 | 2,071,981 | 2,106,840 | 2,143,657 | 2,182,550 |
| **Present Value** | 14,034,315 | 1,867,466 | 1,838,119 | 1,810,248 | 1,783,828 | 6,016,673 | 1,735,252 | 1,713,053 | 1,692,223 | 1,672,743 |
| **Net Present Value** | 34,163,920 | | | | | | | | | |

Note: A number for each cost item is shown in parenthesis

**Table 3** Cost of film-based system assuming 9 year lifetime in a small hospital, Year 2012 – 2021

| Cost | Year | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **0** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** |
| **Direct cost** | | | | | | | | | | |
| *Direct material cost* | | | | | | | | | | |
| 1. Film | 1,202,496 | 1,324,669 | 1,459,255 | 1,607,516 | 1,770,839 | 1,950,757 | 2,148,954 | 2,367,287 | 2,607,804 | 2,872,757 |
| 2. Film cassettes with screen | 10,222 | 11,040 | 11,923 | 12,877 | 13,907 | 15,020 | 16,221 | 17,519 | 18,921 | 20,434 |
| 3. Film processor (2) | 900,000 | | | | | 900,000 | | | | |
| 4. Film printer (1) | 900,000 | | | | | 900,000 | | | | |
| 5. Film envelope | 40,730 | 43,988 | 47,507 | 51,308 | 55,413 | 59,846 | 64,633 | 69,804 | 75,388 | 81,419 |
| 6. Color sticker | 13,577 | 14,663 | 15,836 | 17,103 | 18,471 | 19,949 | 21,545 | 23,269 | 25,130 | 27,140 |
| 7. Office tool of film-based system | 4,800 | 5,184 | 5,599 | 6,047 | 6,530 | 7,053 | 7,617 | 8,226 | 8,884 | 9,595 |
| 8. Film processor's maintenance cost (2) | 45,000 | 45,000 | 45,000 | 45,000 | 45,000 | 45,000 | 45,000 | 45,000 | 45,000 | 45,000 |
| 9. Film printer's maintenance cost (1) | 45,000 | 45,000 | 45,000 | 45,000 | 45,000 | 45,000 | 45,000 | 45,000 | 45,000 | 45,000 |
| 10. Film developer | 105,840 | 105,840 | 105,840 | 105,840 | 105,840 | 105,840 | 105,840 | 105,840 | 105,840 | 105,840 |
| 11. Film storage room (36 $m^2$) | 36,000 | 36,000 | 36,000 | 36,000 | 36,000 | 36,000 | 36,000 | 36,000 | 36,000 | 36,000 |
| 12. Film print process room (12 $m^2$) | 12,000 | 12,000 | 12,000 | 12,000 | 12,000 | 12,000 | 12,000 | 12,000 | 12,000 | 12,000 |
| 13. Electricity for film printer and film processor | 48,000 | 48,000 | 48,000 | 48,000 | 48,000 | 48,000 | 48,000 | 48,000 | 48,000 | 48,000 |
| *Direct labor cost* | | | | | | | | | | |
| 1. Receptionist (2) | 225,240 | 236,502 | 248,327 | 260,743 | 273,781 | 287,470 | 301,843 | 316,935 | 332,782 | 349,421 |
| 2. Film room personnel (3) | 219,120 | 230,076 | 241,580 | 253,659 | 266,342 | 279,659 | 293,642 | 308,324 | 323,740 | 339,927 |
| 3. Film carrier (1) | 73,040 | 76,692 | 80,527 | 84,553 | 88,781 | 93,220 | 97,881 | 102,775 | 107,913 | 113,309 |
| **Indirect cost** | | | | | | | | | | |
| 1. Electricity for things other than film-based system | | | | | | | | | | |
| 1.1. air-conditioner of film storage room (1) | 14,850 | 14,850 | 14,850 | 14,850 | 14,850 | 14,850 | 14,850 | 14,850 | 14,850 | 14,850 |
| 1.2. film viewing lamp | 7,200 | 7,200 | 7,200 | 7,200 | 7,200 | 7,200 | 7,200 | 7,200 | 7,200 | 7,200 |
| 2. Lost film | 18,037 | 19,870 | 21,889 | 24,113 | 26,563 | 29,261 | 32,234 | 35,509 | 39,117 | 43,091 |
| 3. Damaged film | 20,442 | 22,519 | 24,807 | 27,328 | 30,104 | 33,163 | 36,532 | 40,244 | 44,333 | 48,837 |
| 4. Film viewing lamp | 2,000 | | | | | | 2,000 | | | |
| **Annual Cost** | 3,943,595 | 2,299,094 | 2,471,141 | 2,659,136 | 2,864,621 | 4,889,286 | 3,336,992 | 3,603,782 | 3,897,902 | 4,219,821 |
| **Present Value** | 3,943,595 | 2,232,130 | 2,329,287 | 2,433,486 | 2,545,179 | 4,217,541 | 2,794,679 | 2,930,205 | 3,077,040 | 3,234,142 |
| **Net Present Value** | 29,737,283 | | | | | | | | | |

Note: A number for each cost item is shown in parenthesis

**Table 4** Cost of implementing partial PACS assuming 9 year lifetime in a small hospital, Year 2012 – 2021

| Cost | Year | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **0** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** |
| **Direct cost** | | | | | | | | | | |
| *Direct material cost* | | | | | | | | | | |
| 1. CR (1) | 2,700,000 | | | | | | | | | |
| 2. CR cassettes | 26,502 | 28,622 | 30,912 | 33,385 | 36,056 | 38,940 | 42,055 | 45,420 | 49,053 | 52,978 |
| 3. Server (2) | 1,300,000 | | | | | 1,300,000 | | | | |
| 4. Diagnostic viewing station (2) | 1,800,000 | | | | | 1,800,000 | | | | |
| 5. Result viewing station (12) | 468,000 | | | | | 468,000 | | | | |
| 6. PACS and RIS software | 3,000,000 | | | | | | | | | |
| 7. RAID | 26,650 | 28,782 | 31,085 | 33,571 | 36,257 | 39,158 | 42,290 | 45,673 | 49,327 | 53,273 |
| 8. Networking system | 1,500,000 | | | | | | | | | |
| 9. Electricity for running PACS (e.g. server and viewing stations, etc) | 368,189 | 368,189 | 368,189 | 368,189 | 368,189 | 368,189 | 368,189 | 368,189 | 368,189 | 368,189 |
| 10. PACS maintenance cost | 865,692 | 865,692 | 865,692 | 865,692 | 865,692 | 865,692 | 865,692 | 865,692 | 865,692 | 865,692 |
| 11. Film | 1,202,496 | 1,324,669 | 1,459,255 | 1,607,516 | 1,770,839 | 1,950,757 | 2,148,954 | 2,367,287 | 2,607,804 | 2,872,757 |
| 12. Film processor (2) | 900,000 | | | | | 900,000 | | | | |
| 13. Film printer (1) | 900,000 | | | | | 900,000 | | | | |
| 14. Film envelope | 40,730 | 43,988 | 47,507 | 51,308 | 55,413 | 59,846 | 64,633 | 69,804 | 75,388 | 81,419 |
| 15. Color sticker | 13,577 | 14,663 | 15,836 | 17,103 | 18,471 | 19,949 | 21,545 | 23,269 | 25,130 | 27,140 |
| 16. Office tool of film-based system | 4,800 | 5,184 | 5,599 | 6,047 | 6,530 | 7,053 | 7,617 | 8,226 | 8,884 | 9,595 |
| 17. Film processor's maintenance cost (2) | 45,000 | 45,000 | 45,000 | 45,000 | 45,000 | 45,000 | 45,000 | 45,000 | 45,000 | 45,000 |
| 18. Film printer's maintenance cost (1) | 45,000 | 45,000 | 45,000 | 45,000 | 45,000 | 45,000 | 45,000 | 45,000 | 45,000 | 45,000 |
| 19. Film developer | 105,840 | 105,840 | 105,840 | 105,840 | 105,840 | 105,840 | 105,840 | 105,840 | 105,840 | 105,840 |
| 20. Film storage room (36 $m^2$) | 36,000 | 36,000 | 36,000 | 36,000 | 36,000 | 36,000 | 36,000 | 36,000 | 36,000 | 36,000 |
| 21. Film print process room (12 $m^2$) | 12,000 | 12,000 | 12,000 | 12,000 | 12,000 | 12,000 | 12,000 | 12,000 | 12,000 | 12,000 |
| 22. Electricity for film printer and film processor | 48,000 | 48,000 | 48,000 | 48,000 | 48,000 | 48,000 | 48,000 | 48,000 | 48,000 | 48,000 |
| **Direct labor cost** | | | | | | | | | | |
| 1. Information technology staff (1) | 300,000 | 315,000 | 330,750 | 347,288 | 364,652 | 382,884 | 402,029 | 422,130 | 443,237 | 465,398 |
| 2. Receptionist (2) | 225,240 | 236,502 | 248,327 | 260,743 | 273,781 | 287,470 | 301,843 | 316,935 | 332,782 | 349,421 |
| 3. Film room personnel (3) | 219,120 | 230,076 | 241,580 | 253,659 | 266,342 | 279,659 | 293,642 | 308,324 | 323,740 | 339,927 |
| 4. Film carrier (1) | 73,040 | 76,692 | 80,527 | 84,553 | 88,781 | 93,220 | 97,881 | 102,775 | 107,913 | 113,309 |
| **Indirect cost** | | | | | | | | | | |
| 1. Electricity for things other than PACS and film-based system | | | | | | | | | | |
| 1.1. air-conditioner of server room (2) | 25,140 | 25,140 | 25,140 | 25,140 | 25,140 | 25,140 | 25,140 | 25,140 | 25,140 | 25,140 |
| 1.2. air-conditioner of film storage room (1) | 14,850 | 14,850 | 14,850 | 14,850 | 14,850 | 14,850 | 14,850 | 14,850 | 14,850 | 14,850 |
| 1.3. film viewing lamp | 7,200 | 7,200 | 7,200 | 7,200 | 7,200 | 7,200 | 7,200 | 7,200 | 7,200 | 7,200 |
| 2. Office tool of PACS | 3,650 | 3,942 | 4,257 | 4,598 | 4,966 | 5,363 | 5,792 | 6,255 | 6,756 | 7,296 |
| 3. CD to transfer medical image | 1,100 | 1,100 | 1,100 | 1,100 | 1,100 | 1,100 | 1,100 | 1,100 | 1,100 | 1,100 |
| 4. Lost film | 18,037 | 19,870 | 21,889 | 24,113 | 26,563 | 29,261 | 32,234 | 35,509 | 39,117 | 43,091 |
| 5. Damaged film | 20,442 | 22,519 | 24,807 | 27,328 | 30,104 | 33,163 | 36,532 | 40,244 | 44,333 | 48,837 |
| 6. Film viewing lamp | 2,000 | | | | | | 2,000 | | | |
| **Annual Cost** | 16,318,295 | 3,924,521 | 4,116,342 | 4,325,222 | 4,552,765 | 10,168,733 | 5,073,058 | 5,365,863 | 5,687,476 | 6,038,454 |
| **Present Value** | 16,318,295 | 3,810,215 | 3,880,047 | 3,958,191 | 4,045,073 | 8,771,638 | 4,248,606 | 4,362,938 | 4,489,746 | 4,627,972 |
| **Net Present Value** | 58,512,721 | | | | | | | | | |

Note: A number for each cost item is shown in parenthesis

**Table 5** NPV for PACS, partial PACS and film-based system models for three sized hospitals

| Hospital size | NPV for | | | Conclusion |
|---|---|---|---|---|
| | PACS | Partial PACS | Film | |
| Small | 34,163,920 | 58,512,721 | 29,737,283 | film-based system < PACS < partial PACS |
| Medium | 64,184,444 | 140,127,064 | 88,700,786 | PACS < film-based system < partial PACS |
| Large | 117,163,401 | 269,470,373 | 177,401,571 | PACS < film-based system < partial PACS |

*Financial value adjustment*

Since the study assumed nine year lifetime, the amount of money tied up during this time period should be adjusted. It was found that six studies took into account time value of money [1, 2, 7, 8, 17, 21]. Only one study did not adjust time as a function of financial value [26]. NPV and 3% discount rate were conventionally specified in previously studies [2, 7, 11, 17, 21, 28]. For this particular study, NPV and 3% discount rate were assumed.

*Growth rate of service utilization*

Statistics from the Bureau of Policy and Strategy showed that the growth rate of service utilization increased approximately 8% annually [29]. In this study, CR cassette, storage, PACS related office supplies, film, film cassettes, film envelope, colored sticker, office tools of film-based system were assumed to have 8% growth as well. This 8% was used only for model evaluation in this paper. For a hospital that will use this model to support decision making, it is suggested that hospital should use its own historical data.

*Maintenance cost*

Maintenance cost was a vital part. For PACS, continuing budget for software upgrading and system maintenance were a significant part of the economic model. Mostly, software upgrading costs were included in maintenance cost [2, 21]. PACS maintenance cost was set at 8% of initial purchase cost. The initial purchase cost was the sum of CR, CR cassettes, server, diagnostic viewing station, result viewing stations, PACS and RIS software, RAID, and network costs.

For film-based system, the maintenance cost of the film processor was estimated 5% of the initial purchase cost [21].

*Inflation of goods and salary*

Existing data from previous studies from Ubonratchathani Cancer Hospital and Prasat Neurological Institute showed that the estimated film price inflation was 2% per year. This figure was used for this study.

The wage rate for all relevant personnel was estimated to increase 5% annually. This was based on the government wage schedule [30].

Price of other items such as computer-related hardware, electricity, compact disk (CD) to transfer medical image, film processor, film printer, film developer, film storage and film print process room, and film viewing lamp were assumed constant during the study [1, 2, 7, 8, 17, 21, 26]. This was because costs of such items stayed unchanged although technology progresses.

**Model evaluation**

Three developed models; PACS vs. partial PACS vs. film-based system, were evaluated using data from small, medium and large size hospitals. Results only from a small size hospital has been shown. NPV for PACS, partial PACS, and film-based system have been shown in Table 2, 3 and 4, respectively.

Table 2, 3 and 4 revealed that, for a small hospital, the NPV for PACS, film-based system, and partial PACS was 34.16, 29.73, and 58.51 million Baht, respectively. For a small hospital, film-based system had smallest NPV. It indicated that for a specified period, it utilized least resource compare to their counterparts. Thus, with this specific data from a small size hospital, a hospital administrator should invest in film-based system. A film-based system would save a hospital 4.42 million Baht when compared with PACS.

Some hospitals had limited budget, but would like to gradually implement PACS, while they still need to keep film-base system running. In this case, a hospital compared partial PACS and film. It was found that if a small hospital gradually implemented PACS, they would end up investing 58.51 million Baht in a 9 year lifetime, which was considered 28.77 million Baht more expensive than film-based counterpart. For this particular data from a small hospital, film-based system was recommended as it saved more cost than other alternatives.

A summary of NPV for three sizes of hospitals has been shown in Table 5. It was found that PACS had the smallest NPV among other alternatives for both medium and large sized hospital. For a medium size hospital, PACS would save 24.51 million Baht compared to film-based system and save 75.94 million Baht compared to partial PACS, given 9 year lifetime was assumed. For large size

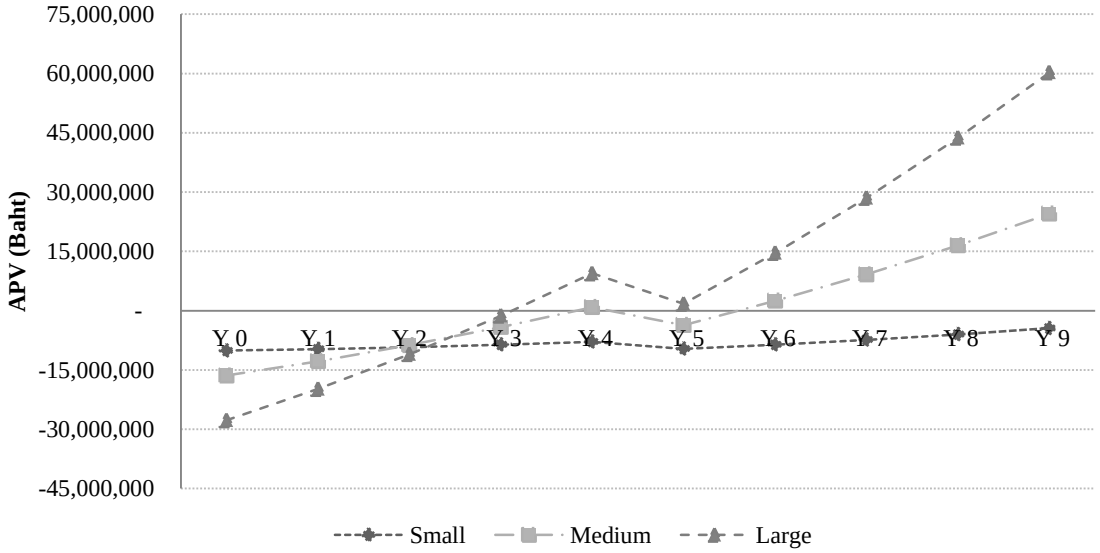
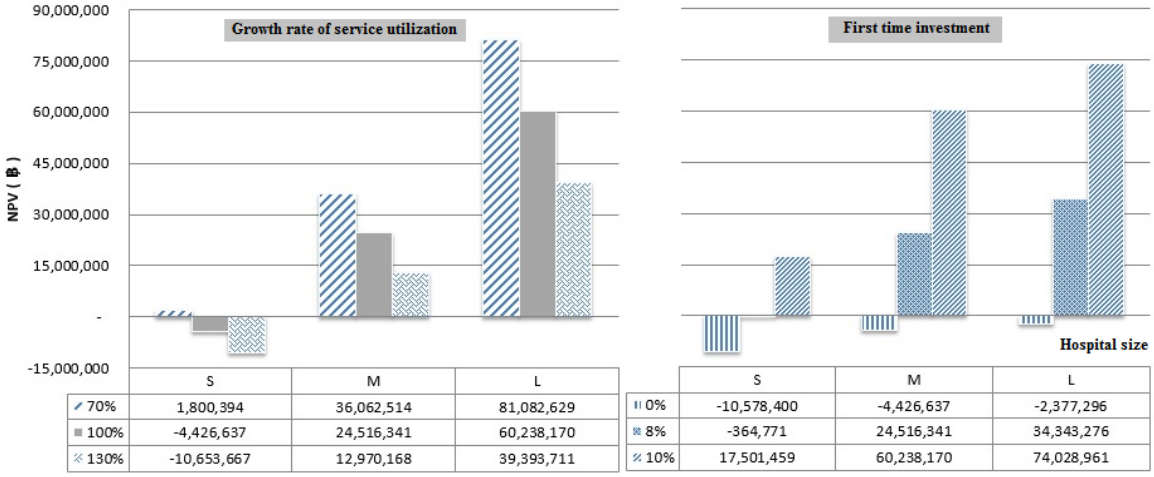



**Figure 1** Accumulated Present Value of all hospital sizes in three cost models




| | S | M | L |
|---|---|---|---|
| 70% | 1,800,394 | 36,062,514 | 81,082,629 |
| 100% | -4,426,637 | 24,516,341 | 60,238,170 |
| 130% | -10,653,667 | 12,970,168 | 39,393,711 |

| | S | M | L |
|---|---|---|---|
| 0% | -10,578,400 | -4,426,637 | -2,377,296 |
| 8% | -364,771 | 24,516,341 | 34,343,276 |
| 10% | 17,501,459 | 60,238,170 | 74,028,961 |

**Figure 2** Sensitivity analysis of first time investment and growth rate of service utilization

hospital, PACS would save 60.23 million Baht comparing to film-based system and saved 152.30 million Baht comparing to partial PACS.

It was worth noting that the NPV for partial PACS was larger than the NPV from the other two models in all hospital sizes. The information suggested that partial PACS may not be recommended for all hospital sizes.

A hospital not only needs to know whether PACS is worth investing, but also wants to know when the investment will be returned. To find out the break-even point, APV for PACS compared to film-based system was calculated. The break-even point is the point in time when the accumulated cost of PACS is equal to the accumulated cost of film-based system. Figure 1 shows the break-even point for PACS compared to film-based system for small, medium and large hospitals.

Figure 1 showed that, over a nine year lifetime, the APV of medium and large size hospital reached zero, while APV of small size hospital did not reach zero. The break-even point for PACS compared to film-based system was at the 4$^{th}$ year for a large and medium hospital. The value above zero in each year afterward showed the amount of cost saved from PACS when compared to film-based system. For example, for a large hospital at the 7$^{th}$ year and 9$^{th}$ year, PACS would save approximately 30 and 60 million Baht, respectively compared to film-based system. Please note that the negative slope of APV in the5$^{th}$ year was a result of replacing items such as workstation hardware and server.

Sensitivity analysis was further conducted by choosing 2 variables; first time investment and growth rate of service utilization as they had

significant impact on the NPV. These two variables were frequently selected for sensitivity analysis in previous studies [2, 7, 17].Results have been shown in Figure 2. In this study, 30% change in the first time investment was analyzed using 100% as a base case. Sensitivity analysis for first time investment had impact on a small hospital. It was found that if a hospital lowered its budget by 30%; e.g. by choosing lighter PACS packages, or reducing numbers of workstations, PACS would have smaller NPV when compared to film-based counterpart.

The growth rate of service utilization was another parameter selected because it affected many cost items such as server capacity or number of films. In this study, 0% and 10% growth rate were analyzed with 8% as a base case. It was found that if the growth rate of service utilization remained unchanged, medium size hospital should not invest in PACS as there was no gain on investment in a 10-year period.

## DISCUSSION

This study focused on a cost model development for PACS, partial PACS and film-based system using provider's perspective. Compared to other studies, the developed model included more indirect cost items such as cost of electricity for PACS, electricity for PACS related equipment, or PACS supporting office tools.

The limitation of this model was that it did not incorporate cost or benefit from other perspectives which could have changed an investment decision. Examples of benefit and cost from patient's perspective were benefit from satisfaction not to carry heavy load of film, or cost of retaking image when film was lost. Examples of costs from a societal perspective were costs to dispose of contrast media, film, chemicals and electronic device garbage. These items are real, but subjective. To measure them in monetary value, valid and reliable measurements need to be developed.

Another limitation was that cost items in the three developed models were tangible costs. Possible intangible items from provider's perspective that could have impact on NPV, but were not included in this study were cost incurred from faster and more accurate diagnosis, satisfaction with PACS, cost of better communication among health care providers, or better organization image.

Users of the model should be aware of resource sharing. In some hospitals, one work station was used for more than one system. The workstation accommodated not only PACS, but also Hospital Information System (HIS) and the like. Therefore, to input cost into the PACS model, one must appropriately quantify cost. If cost is not properly shared, NPV for PACS will be overestimated.

An issue that arose in many hospitals was how to calculate cost of film storage space. Equal space in a central of Bangkok and in a province or border province cost differently. However, Yaowarate et al, and Prasit et al., recommended that cost for space within a hospital can be estimated through actual rental of hospital space as if it was acquired from a lease holder [31, 32].

Although PACS is a digital image management system, PACS alone is not efficient enough. Integrating PACS with HIS makes fragmented medical information easier to access and enhance continuity of care. HIS will provide personalized information e.g. gender, date of birth, health insurance coverage, and medical history. For a better information system, linking PACS with HIS puts more cost on hospital.

Despite the fact that data from specialized hospitals were used in this study, cost items in the model were not affected. The NPV were largely depended on PACS software, the numbers of workstations and the like. These items were not related to specialty of hospital. To make decision to invest in PACS, one cannot generalize results from this study, but rather apply your own data to the model.

## CONCLUSION

In conclusion, this study developed an economic model to support decision making to implement PACS. The models were developed under provider's perspective with assumptions that fit with Thailand context. To reach a conclusion whether or not PACS should be implemented, a particular hospital should use its own data to run the model. This cost model is publicly posted and can be accessed online at http://goo.gl/ljubyO. The model that produced smallest NPV should be selected. Cost saved can be calculated by calculating differential NPV of the two alternative models. Break-even point can be identified when APV reaches zero line.

As the models were tested using data from three hospitals which could not be considered representative of each hospital size, this study suggested that partial PACS may not be recommended for all hospital sizes. PACS may not be worth investing in a small size hospital, but may be advised for medium and large size hospitals.

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