Healthcare Service Network Analysis: Northern Region's Healthcare Service Network of Cleft Lip and Cleft Palate

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Abstract

This research focused on the analysis of healthcare network of cleft lip and cleft palate patients at Chiang Mai University Craniofacial One Stop Service Center as the treatment hub for the northern part of Thailand. The delay was founded during the treatment plan. Patient classification was carried out using K-mean technique. The results from the classification show that the best case patient is the case with the average distance to the treatment center (64.20 km) without complication symptoms. To improve the service of this network, the proposed solution is to increase the number of treatment centers. Two hospitals, Fang and Chomthong hospitals, were proposed as the potential hospitals in this network. The mathematical model was proposed for patient assignment. Twelve districts were assigned to Maharaj Nakorn Chiang Mai hospital and 6 districts were assigned to Fang hospital and Chomthong hospital. The average distances of three groups were 32.84, 55.55 and 62.28 km less than the best case distance at 64.20 km. When the real implementation is considered, both hospitals have to increase their capabilities by hiring more specialist for this service that incurs 2.64 million baht/year for Fang hospital and 2.16 million baht/year for Chomthong hospital. With the proposed solutions, the critical time of the treatment plan can be reduced from 2,663.6 to 2,504.5 days that was 5.97%.

Keywords: Why-Why analysis, PERT technique, K-means technique, mathematical model
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1. Introduction

Cleft lip and cleft palate are birth facial malformations, that is palate and lip of the baby do not join together properly. Cleft lip and cleft palate results in living, physical, eating, speech and breathing problems and may cause various diseases, for example dental and oral diseases. However, the effectiveness of the treatment depends on receiving standardized treatment continuously at the proper age of infants by a multidisciplinary team involved in the planning and providing treatment [1, 2].

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Chiang Mai University Craniofacial One Stop Service Center or CMU CF center is the treatment center at Maharaj Nakorn Chiang Mai hospital established in 2011 by combining plastic surgeons, neurosurgeons, otolaryngologists, ophthalmologists, anesthesiologists, orthodontists and nurses to establish a multidisciplinary team for the treatment of patients with cleft lip and cleft palate. This center plays a role in providing the treatment service for cleft lip and cleft palate patients since the womb until growing up to allow the patient to have a good quality of life at any age, until normally living and working with other people [1].

This research aims to study the treatment guidelines according to the treatment plans and analyze the patient's route to identify causes of delay along the treatment plan using the data of the 48 patients at CMU CF center as sample data. The highlights of this study are to (1) study the treatment path using CPM/PERT techniques to identify the critical route along the treatment plan, (2) apply one of data mining techniques for classifying patients leading to propose appropriate solutions, and (3) propose solutions using the mathematical model and provide the related aspects, for example investments and resource limitations, when considering the real implementation.

2. Materials and Methods

Program evaluation and review technique (PERT) is a technique adopted by organizations to analyze and present the activity in a project, and to illustrate the flow of events in a project. PERT is a method to evaluate and estimate the time required to complete a task within deadlines [3]. PERT technique was applied widely in many areas, such as in planning the processes of electrical power systems and electrical communication systems in order to reduce time of each activity as addressed in [4]. PERT technique was used to calculate the estimated times of each activity when uncertainty was included.

Data mining is the process of sorting through large data sets to identify patterns and to establish relationships among big data for solving problems. Data mining tools allow enterprises to predict future trends [5]. K-means clustering is a method commonly used to automatically partition a data set into k groups. It proceeds by selecting k initial cluster centers and then iteratively refining them as follows; instance (d_i) is assigned to its closest cluster center and cluster center (C_j) is updated to be the mean of its constituent instances [6]. Data mining was widely applied in healthcare problems. For example, a decision support system for analyzing the risk of chronic disease in case of diabetes and hypertension was presented in Jongkasikit [7] using decision tree and k-nearest neighbor techniques. The proposed model from this research was tested with 10-fold cross validation. The results showed that applying decision trees technique generated the most accurate results.

Facility location problem is to find locations for new facilities such that the conveying cost from facilities to customers is minimized [8]. One application of this problem was presented in Thanakorn and Phongsathon [9]. The distribution centers were located in order to achieve the lowest costs of transportation. The mathematical model of single facility location problem was applied Then the optimal solution was compared with the location selection by center of gravity technique. The results from the mathematical model were superior in term of decreasing shipping distance.

In field of healthcare service management, performance measurements are usually time-base and normally uncertainty. PERT is appropriate to measure treatment time especially activities on a critical paths of treatment plans that can influence completion time of the treatment. Because of the complication of patients, patient classification is needed to propose different solutions for each group of patients, K-mean technique was applied in this research for classifying patients based on their characteristics. Then the proposed solutions were provided based on the

mathematical model of facility location problem for increasing capability of healthcare service of cleft lip and cleft palate treatment service network.

The methodology of this study was as follows:

1) Preliminary Study: The standard treatment protocol for cleft lip and cleft palate was studied on patients aged 0-5 years including activities, time (age) fences, and multidisciplinary team. Patient's route was presented using PERT and CPM techniques to identify the treatment critical path and total treatment time along the standard protocol.

2) Data Collection and Analysis: The data of 48 patients, aged between 3-7 years, without complications, residing in Chiang Mai province, were collected. Based on available data, K-means technique was applied to classify groups of patients. Then problem identification was carried out based on results of K-means.

3) Model Formulation and Optimization: Location problem was applied to this research for locating additional healthcare service centers for the patients residing in Chiang Mai. The proposed model was solved using Lingo optimizer. The optimal solution from the case study was interpreted and compared with the current situation.

4) Result Discussion: The optimal solution was discussed in term of real implementation considering available resources and additional investment for improving this healthcare service network.

3. Results and Discussion

3.1 Cleft lip and cleft palate standard protocol

The standard treatment protocol for patients (0 - 6 months) was presented in Table 1. At each age, specific treatments are needed by multidisciplinary specialists. Any delay occurring within the treatment plan is affected to the treatment effectiveness and time plan.

Table 1. The standard treatment protocol for patients (0 - 6 months)

Age (months)	Treatment plan of cleft lip and cleft palate	Multidisciplinary teams
0-4	Preliminary diagnosis to patients	Plastic Surgeons
	Providing advice and knowledge in patient care	Officer of CF Center
	Congenital abnormally evaluation	Pediatrics
	Micrognathia and Airway obstruction evaluation	Plastic Surgeons
	Feeding evaluation	Nurse
	Cleft lip nose deformity and Alveolar cleft evaluation	Plastic Surgeons
	Insertion tools for adjusting nose structure (Nasoalveolar molding: NAM)	Dentists
	Inserting Palatal Obturator	Dentists
5	Cheiloplasty or Cleft lip repair	Plastic Surgeons
	Follow Up #1 after Cleft lip repair 7- 14 days	Plastic Surgeons
	Inserting Nasoform	Dentists
6	Follow Up #2 after Cleft lip repair 1 month	Plastic Surgeons

From Table 1, it can be seen that the treatment processes for cleft lip and cleft palate requires multidisciplinary team with expertise in various fields including plastic surgeons, otolaryngologists (ENT), ophthalmologists, radiologists, pediatricians, anesthesiologists and dentists. In addition, patients are required to undergo treatment in every treatment process, which will result in patients continuing to receive treatment until the end of treatment plan. Patients living in Chiang Mai are admitted to CMU CF center. Treatment path analysis of cleft lip and cleft palate patients aged 0-5 years admitted to this center is presented in Figure 1. Critical path and the treatment duration from CPM/PERT technique were summarized as shown in Table 2.

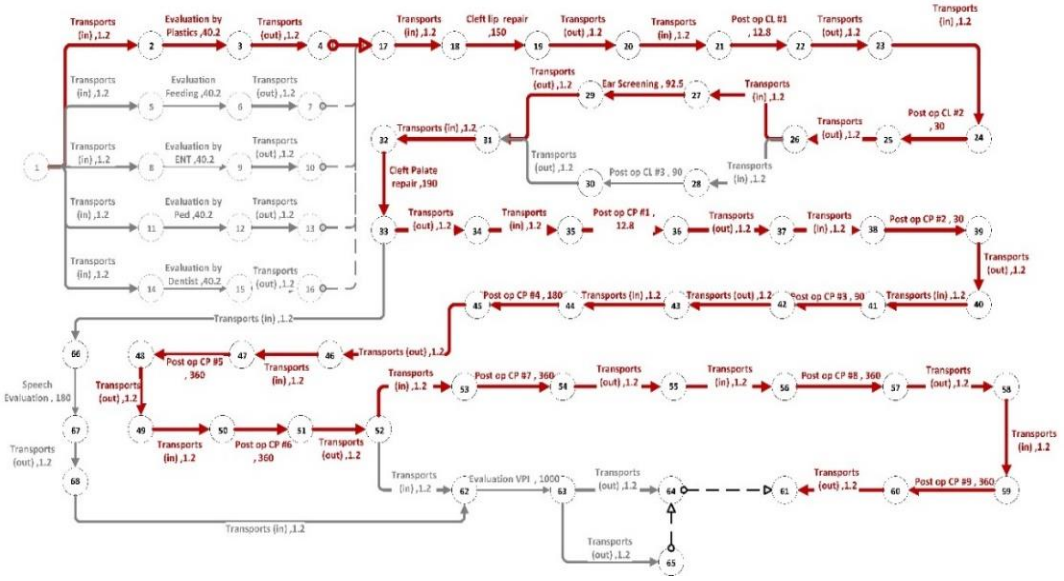

Figure 1. The network identifying the critical path of treatment for cleft lip and cleft palate during aged 0-5 years

Table 2. Treatment path analysis of cleft lip and cleft palate patients aged 0-5 years

Detail	Amount
Critical Time (Days)	2,663.3
The Number of Activities Of The Treatment Processes	22
The Number of Onward Travel Activities	23
The Number of Return Travel Activities	23
The Traveling Expenses (Baht/Person)	30,921.2

From Table 2, patients with cleft lip and cleft palate have a critical treatment duration of 2,663.3 days, with a total of 22 treatment activities, 23 onward travel activities and 23 return travel activities. The traveling expenses is 30,921.2 baht per patient.

3.2 Patient classification using K-means

From data collection, 64.10% of patients with cleft lip and 96.67% of patients with cleft palate were behind the treatment protocol. To identify the cause of delay, data of sample patients with available parameters including the starting age of receiving treatment (days), traveling distance (km) from residential to CF, case's complication (yes/no), and residential area (Chiang Mai/ others), were used in patient classification.

Applying k-means technique via Rapid Miner program, the appropriate number of groups (K) was 5 at the elbow point as shown in Figure 2. Five groups of patients were presented in Table 3.

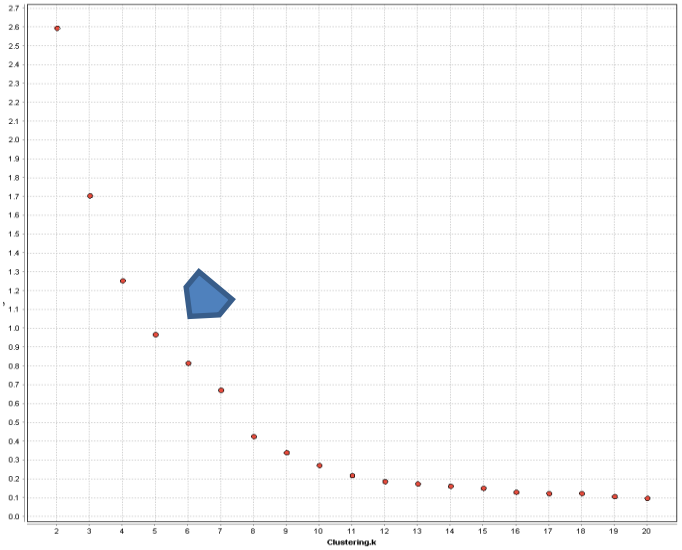

Figure 2. Relationship graph between the number of groups and the average within centroid distance

Table 3. Patient classification of 5 groups

Group	Average age starting to receive treatment (days)	Average travel distance (km.)	Complications	Domiciles
Group 0	237.38	237.62	No	Other provinces
Group 1	21.76	64.204	No	Chiang Mai
Group 2	64.50	163.71	No	Other provinces
Group 3	25.83	110.76	Yes	Chiang Mai and others
Group 4	178.064	136.10	No	Chiang Mai

The first visit for starting the treatment based on the protocol should be within 30 days after childbirth. Thus the 1st and 3rd groups were satisfied with this condition. Comparing these two groups, the third group is the case with complications, so patients need to contact quickly with CF center, while the first group is patients living near CF center. The first group was used as the

best case. From the classification, without complication as group 0, 2, and 4, traveling distance has an effect on delay on the first visit for the treatment. Considering only patients living in Chiang Mai, the 4th group was considered for the improvement.

3.3 The proposed solution

Patients in group 4 live in suburb area of Chiang Mai province, thus the distance between their homes and CF center is rather far. The best case is the group 1 having satisfied starting time of the treatment (within 30 days) with the average distance to CF center as 64.2 km. The location problem was applied to assigned patients at additional possible treatment centers. The mathematical formulation was explained below.

Set:

- i Districts in Chiang Mai province
- j 3 network-centric Hospitals, namely Maharaj Nakorn Chiang Mai Hospital, Fang Hospital, Chomthong Hospital (Proposing by the CF team members considering capability of the hospital in each district)

Parameter:

- D_{ij} Travel distance from district i to network hospital j (km)
- C_{ij} Traveling cost from district i to network hospital j (baht/time)

Decision Variable:

X_{ij} is decision variable used for assigning patients of each district to network-centric hospitals, which is equal to 1 when the patients are sent from District i to District Network Hospital j, and is equal to 0 when no patient is selected.

Mathematical Model:

$$\text{Minimize} \quad \sum_{i=1}^{m} \sum_{j=1}^{n} D_{ij}X_{ij} + 2C_{ij}X_{ij} \qquad (1)$$

Subject to

$$\sum_{j=1}^{n} X_{ij} = 1 \quad \forall i \qquad (2)$$

$$X_{ij} \in \{0,1\} \quad \forall\, i, j \qquad (3)$$

Equation (1) is the objective that combined two objectives together to minimize (i) the total distance and (ii) the traveling cost, considering patients in different districts to the network-centric hospitals. To combine these two objectives, the first objective is assigned to multiply by 1 when the second objective is assigned to multiply by 2 (suggestion form CF team members for prioritizing two objectives). Equation (2) is to assign patients in each district to only one network-centric hospital. Equation (3) is binary constraint for X_{ij}.

In this research, the Lingo program was used to find the optimal solution. The patient assignment was presented in Table 4.

Table 4. Patient assignment to each network-centric hospital

Maharaj Nakorn Chiang Mai Hospital		**Fang Hospital**		**Chom Thong Hospital**	
District	Distance (km)	District	Distance (km)	District	Distance (km)
Mueang	3	Fang	0	Chom Thong	0
Doi Saket	20.1	Mae Ai	30.1	Mae Chaem	78
Mae Taeng	59.8	Phrao	89.7	Hod	67.5
Mae Rim	32	Wiang Haeng	121	Doi Tao	77.8
Samoeng	80.5	Chai Prakan	22.1	Om Koi	132
San Pa Tong	27.1	Chiang Dao	70.1	Doi Lo	18.4
San Kamphaeng	27.8				
San Sai	14.3				
Hang Dong	14.7				
Saraphi	15				
Mae Wang	60.1				
Mae On	39.7				
Average	**32.84**		**55.55**		**62.28**

From Table 4, there were three groups based on each network-centric hospital. Twelve districts were assigned to Maharaj Nakorn Chiang Mai hospital and 6 districts were assigned to Fang hospital and Chom Thong hospital. The average distance of three groups were 32.84, 55.55, and 62.28 km. Comparing with the best case from patient classification, group 1 with average distance as 64.20 km., the optimal solutions were under the best case average distance as shown in Figure 3.

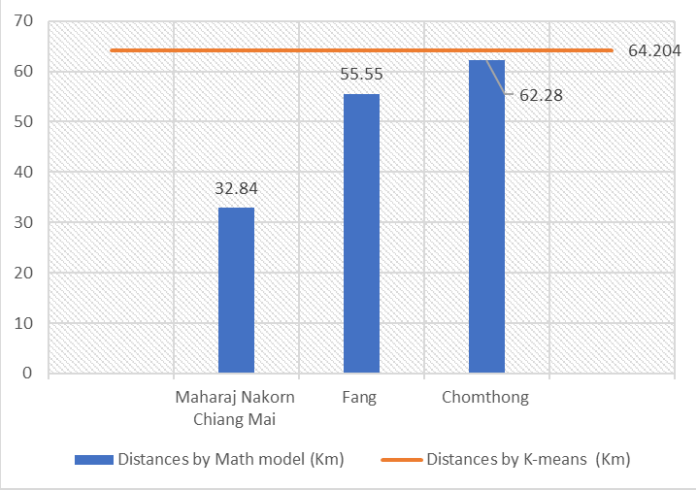

Figure 3. Average traveling distance comparison

Afterwards, treatment path analysis for the optimal solution was carried out to evaluate the duration of treatment as shown in Figure 4.

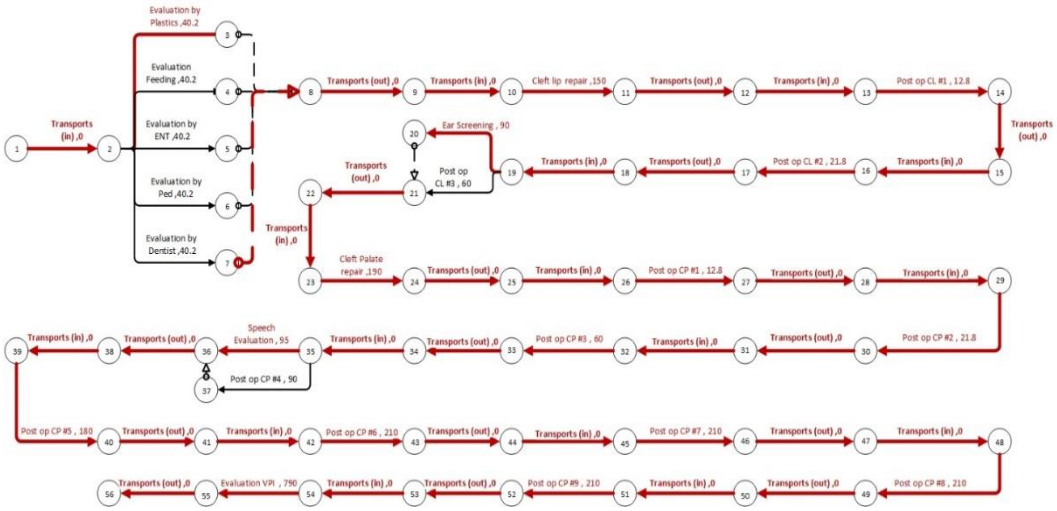

Figure 4. Treatment path analysis for the improvement

Proposing three network-centric hospitals, the treatment protocol was improved by using ECRS technique. The evaluation steps by plastic surgeons, nutritionists, otolaryngologists, pediatrician and dentists are at the same time as 40.2 days. These activities can make appointments at the same day to reduce the number of nodes on activities from 68 to 56 nodes.

The results of patient's path analysis compared between current situation and proposed solution were presented in Table 5.

Table 5. Patient's path analysis results comparison

Parameter	Current	Proposed	Percentage
Critical Time (Days)	2,663.6	2,504.5	↓ 5.97
The Number of Activities of the Treatment Processes	22	22	-
The Number of Onward Travel Activities to Maharaj Nakorn Chiang Mai Hospital	23	0	↓ 100
The Number of Return Travel Activities to Maharaj Nakorn Chiang Mai Hospital	23	0	↓ 100
The Traveling Expenses (Baht/Person)	30,921.2*	0	↓ 100

* From Tawanan [10], the cost of traveling to receive the treatment at Maharaj Nakorn Chiang Mai hospital was 1,344.41 Baht/time.

From Table 5, the critical time of the treatment was reduced from 2,663.3 days to 2,504.5 days or 5.97% without reducing the number of treatment activities. The traveling activities to the Maharaj Nakorn Chiang Mai hospital can be eliminated and the expenses can also be reduced approximately as 30,921.2 baht per person.

3.4 Discussion

The proposed solution is to locate more treatment centers not only Maharaj Nakorn Chiang Mai hospital, but also considering Fang hospital and Chom Thong hospital. To enhance the treatment's capability of both hospitals, some expense is needed. In this study, the cost for hiring specialists was estimated at 2,640,000 Baht/year for Fang hospital and 2,160,000 Baht/year for Chom Thong hospital. Table 6 presented the comparison among cost and benefit of the proposed solution.

From Table 6, total benefits from the proposed solution were approximately as 376,961.60 and 202,979.33 Bath/year for Fang and Chom Thong hospitals, respectively. Comparing with additional cost, there were 14.28% and 9.40% of additional costs for both hospitals. Although monetary benefit is small comparing with the cost, other benefits, for example social and people's well-being, should be considered in term of public service provided by the government.

Table 6. Cost-benefit comparison for the proposed solution

Hospitals	**Cost**	**Benefit (Bath/Year)**	
	Yearly Cost (Millon Baht)	Traveling Expenses	Surgery Income
Fang	2.64	45,773.60	331,188.00
Chom Thong	2.16	24,647.33	178,332.00

4. Conclusions

The cleft lip and cleft palate healthcare service network of the northern region of Thailand has been analyzed with one center at Chiang Mai University Craniofacial One Stop Service Center located at Maharaj Nakorn Chiang Mai hospital. The hospital provides the treatment since patients are newborn until they can live as normal people. Due to the data collection, the delay in the treatment standard protocol is obviously observed. After patient classification using K-mean technique, the results presented that long distance from resident area to the CMU CF center has an effect on the delay of the starting treatment plan causing the delay along the treatment protocol for patients without complication. Thus the solution is to propose additional treatment centers. Two potential hospitals are proposed by specialists as Fang and Chom Thong hospitals. The assignment of patients was carried out based on the proposed mathematical model. The optimal solutions presented that three groups of patients were assigned to each center when the averages of total distance to centers were below the best case of patient group from K-mean technique. The critical path for the treatment was reduced as 5.97%. For the real implementation, due to the limitation of additional hospitals, some cost incurs for enhancing their treatment capabilities.

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