

**ANALYSIS AND DESIGN OF APPROPRIATE LOCATIONS OF
REGIONAL BLOOD CENTERS AND THEIR DISTRIBUTION
PATTERNS**

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**A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENT FOR
THE DEGREE OF MASTER OF ENGINEERING
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FACULTY OF GRADUATE STUDIES
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Thesis
entitled

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REGIONAL BLOOD CENTERS AND THEIR DISTRIBUTION
PATTERNS**

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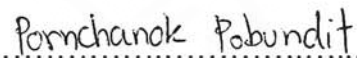
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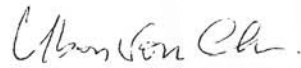
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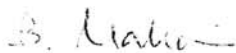
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ANALYSIS AND DESIGN OF APPROPRIATE LOCATIONS OF REGIONAL BLOOD CENTERS AND THEIR DISTRIBUTION PATTERNS

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ABSTRACT

The blood distribution network in Thailand consists of one National Blood Center (NBC) and twelve Regional Blood Centers (RBCs). The RBCs are supposed to be responsible for procuring and supplying blood for provinces under their charter. However, the NBC has to distribute blood to support these RBCs because they are still unable to procure a sufficient amount of blood to meet the demand. Blood transportation from the NBC to the RBCs usually takes a long time due to long distances, which also leads to difficulty in controlling blood quality. This situation results in a cost of about 2.7 million Baht/year to the NBC. Therefore, this research aimed to study, analyze, and re-design the logistics of blood distribution at the regional level in Thailand by using the location-and-allocation optimization-based model. There are seven different cases. One major result regarding the location of the next planned RBC revealed that a very cost-effective place would be in Saraburi province, in contrast to the planned RBC in Ayutthaya. The total blood transportation cost is 4.32 million Baht/year. This new pattern can help reduce blood distribution cost of the NBC by 64%, while allowing the NBC to respond to blood demand at the regional level more efficiently. However, this pattern requires that all RBCs must have a sufficient blood supply.

KEY WORDS: BLOOD / BLOOD LOGISTIC / REGIONAL BLOOD CENTERS /
LOCATION / ALLOCATION / MATHEMATICAL MODEL

314 pages

การวิเคราะห์และออกแบบความเหมาะสมของที่ตั้งภาคบริการโลหิตแห่งชาติและรูปแบบการกระจายโลหิตที่เหมาะสม

ANALYSIS AND DESIGN OF APPROPRIATE LOCATIONS OF REGIONAL BLOOD CENTERS AND THEIR DISTRIBUTION PATTERNS

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บทคัดย่อ

โครงข่ายการกระจายโลหิตประกอบไปด้วยศูนย์บริการโลหิตแห่งชาติและ 12 ภาคบริการโลหิต โดยภาคบริการโลหิตมีหน้าที่จัดหาและกระจายโลหิตให้กับจังหวัดที่รับผิดชอบ แต่ปัจจุบันศูนย์บริการโลหิตต้องจัดส่งโลหิตไปช่วยเหลือ เนื่องจากภาคบริการโลหิตไม่สามารถจัดหาโลหิตได้เพียงพอ ซึ่งเป็นการจัดส่งที่มีระยะทางไกล, ใช้เวลานานและยากที่จะควบคุมคุณภาพโลหิต ปัจจุบันเหล่านี้ส่งผลต่อการเพิ่มต้นทุนของศูนย์บริการโลหิตถึง 2.7 ล้านบาท/ปี ดังนั้นงานวิจัยนี้มีวัตถุประสงค์เพื่อศึกษาทำเลที่ตั้งภาคบริการโลหิตและรูปแบบของการกระจายโลหิตที่เหมาะสมในระดับภูมิภาคของประเทศไทย โดยใช้ตัวแบบจำลองทางคณิตศาสตร์สำหรับหาทำเลที่ตั้งและการกระจาย เป็นเครื่องมือในการวิเคราะห์ ผลลัพธ์ 7 กรณีศึกษาหลัก จัดตั้งภาคบริการโลหิตแห่งใหม่ ที่จังหวัดสระบุรี แทนที่จะเป็นจังหวัดอยุธยาตามแผนเดิมที่วางไว้ ซึ่งต้นทุนการกระจายโลหิตทั้งประเทศ คือ 4.32 ล้านบาท/ปี ซึ่งสามารถลดต้นทุนการกระจายโลหิตของศูนย์บริการโลหิตได้ถึง 64 % และยังสามารถตอบสนองความต้องการโลหิตในภูมิภาคได้มากขึ้น โดยมีเงื่อนไขที่สำคัญคือ ภาคบริการโลหิตทุกแห่งต้องมีโลหิตเพียงพอ

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CHAPTER I

INTRODUCTION

1.1 Background and importance of the problem

Every year, the National Blood Center (NBC), Thai Red Cross Society, is supposed to collect a large amount of blood to distribute it among hospitals. Unfortunately, the amount of blood collected is lower than the demand, (Nuchprayoon, 2010) because of several reasons and the limited number of blood donors. The donated blood is examined and filtered through the quality checking process, as some diseases can be transmitted via blood. In 2006, the NBC, found 0.28% of Syphilis, 0.12% of HIV-Ab, 0.001% of HIV-Ag, 0.09% of Anti-HCV, and 0.36% of HBsAg out of 203,210 donors (National Blood Center, Thai Red Cross Society, 2007). Blood with these diseases must be eliminated. Each day, the blood centers cannot deliver enough amount of blood demanded by hospitals all over the country. The Ministry of Public Health therefore has given authority to the NBC to be responsible for blood donation services in the whole country so that blood donations throughout the country meet the same standard. Hence, the NBC has a policy to setup 12 Regional Blood Centers (RBCs), which are located dispersedly throughout Thailand and a special regional blood center at Phuket province. These RBCs were established with the same responsibilities as the NBC, which include collecting, selecting, storing, and distributing blood to central hospitals and community hospitals that need it.

Locations of these 12 RBCs and the special RBC at Phuket province were distributed according to administrative boundaries determined by the Ministry of Interior (Ministry of Interior, 2003). There locations are as follows.

Regional Blood Center	1	located at Ayutthaya province
Regional Blood Center	2	located at Lopburi province
Regional Blood Center	3	located at Chonburi province
Regional Blood Center	4	located at Ratchaburi province
Regional Blood Center	5	located at Nakhonratchasima province
Regional Blood Center	6	located at Khonkaen province
Regional Blood Center	7	located at Ubonratchathani province
Regional Blood Center	8	located at Nakhonsawan province
Regional Blood Center	9	located at Phitsanulok province
Regional Blood Center	10	located at Chiang Mai province
Regional Blood Center	11	located at Nakhonsithammarat province
Regional Blood Center	12	located at Songkhla province
Regional Blood Center	Special	located at Phuket province

Note that the Regional Blood Centre 1 has not started its service. Locations and blood distributions of the RBCs are shown in Figure 1.1. It can be seen that their pattern of blood distribution is of the hub-and-spoke pattern, with the National Blood Centre acting as the headquarter. Currently, the NBC is responsible for providing blood to hospitals in Bangkok, while the 12 RBCs and Phuket RBC are responsible for hospitals in their respective regions.

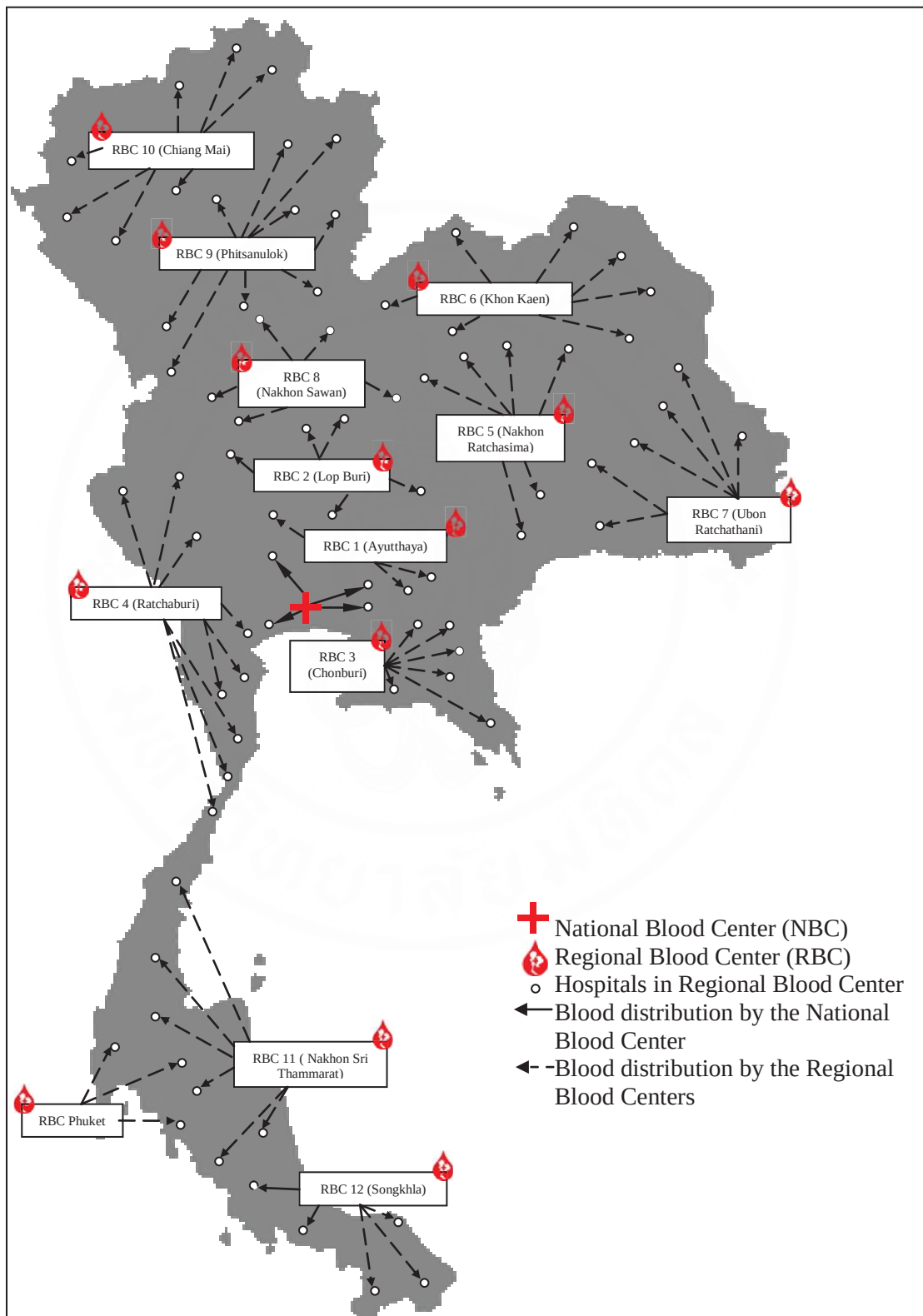


Figure 1.1 Locations of the National Blood Center and Regional Blood Centers and their blood distributions

In the fiscal year 2006, the NBC collected 467,312 units of blood from 295,187 donors, (National Blood Centre, Thai Red Cross Society, 2007). Meanwhile, hospitals in Bangkok that were branches of the NBC and provided blood donation services could collect the additional 132,393 units of blood. Therefore, there were totally 599,705 units of donated blood in 2006. Based on the number of registered population in Bangkok of 5,695,956 in 2006 (Department of Provincial Administration, 2007), the proportion of donors in Bangkok was 10.53 percents. The 67 percent of donated blood was distributed to patients in Bangkok. The rest of 33% in transported to supply patients in other provinces. Some of this amount was distributed via RBCs. Some of them were distributed directly to hospitals, which include hospitals in provinces nearby Bangkok. The original intention of the NBC was to enable these RBCs to collect and provide sufficient blood for patients in their responsible areas. However, RBCs could not really provide adequate blood for their responsible patients. Therefore, the NBC had to send blood to these RBCs. It was very difficult to control the quality of blood during transportation since blood must be kept at controlled temperature all the time. During transportation, varying conditions of surrounding environment may affect the temperature control system. Therefore, long-distance transportation through unpredictable environmental conditions poses a high risk to blood quality. Condition of patients can become even worse if they receive low quality blood. In addition, because of having to distribute blood to regional centers, operational cost of the NBC becomes higher.

Figure 1.2 presents the characteristic of blood distribution at present. It can be seen that blood distribution at the national level has become more complex. The NBC was supposed to distribute blood only to hospitals in Bangkok's area, and let RBCs take care of blood demand from hospitals in other their respective responsible provinces. However, at present, pattern of blood distribution is more complex because the NBC has to supply some blood to RBCs and provincial hospitals as well.

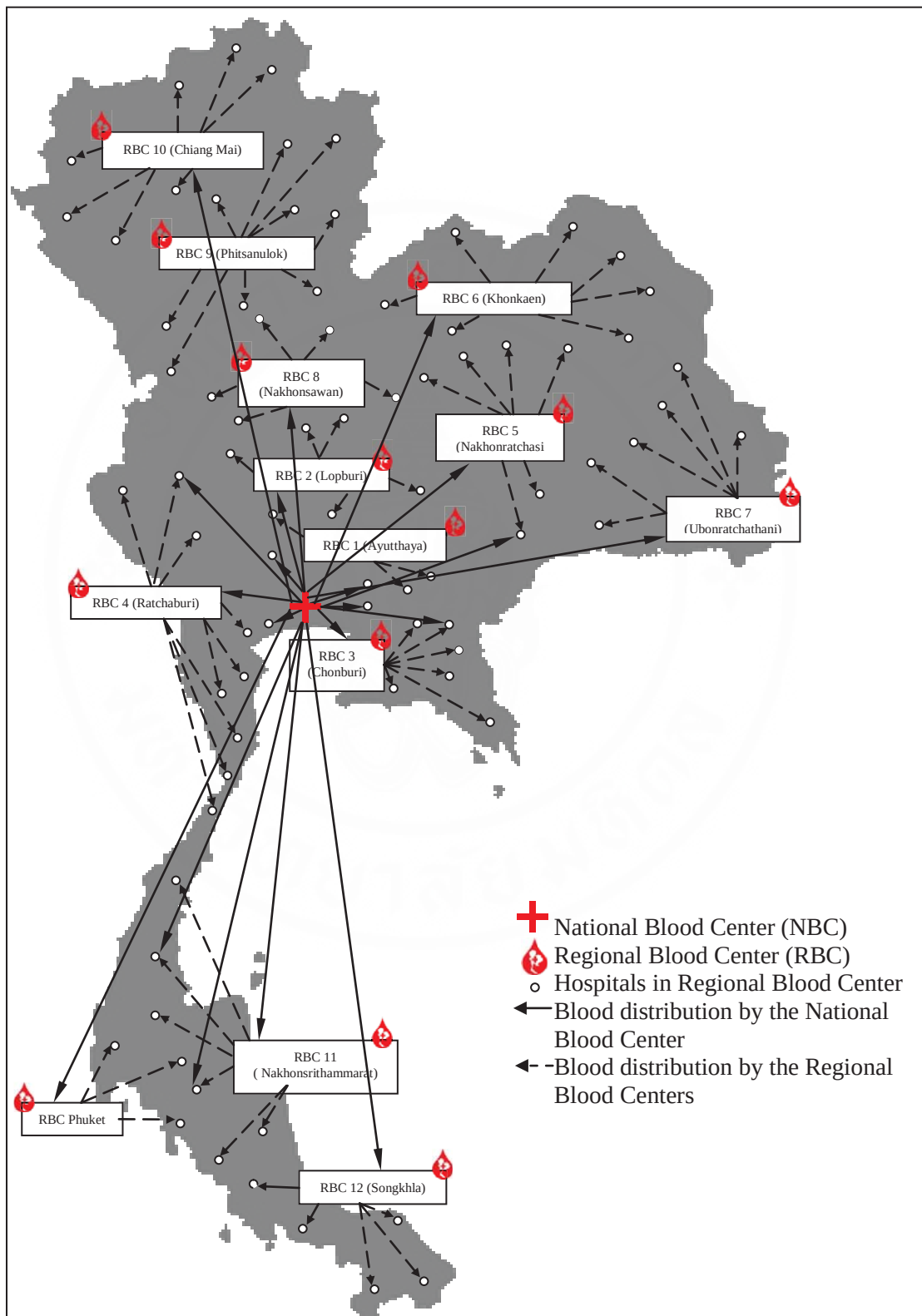


Figure 1.2 Complexity of blood distribution pattern in Thailand at present

It is now obvious that there are problems regarding blood distribution at the national level. With the current pattern of blood distribution, blood quality can be lower than standard. The transportation cost is too high because of long distances between the NBC and RBCs all over the country. In addition, it creates more tasks for personnel of the NBC. Blood quality is hard to be controlled. These problems arise probably because of inappropriate logistics of the blood distribution. Having to bring blood to regional centers and provincial hospitals, the cost for blood transportation is very high. It is possible that number of RBCs might be insufficient. Some additional RBCs might need to be established in the future. It is also possible that locations and blood distribution patterns of RBCs might be improper. It is therefore suggested that analyses should be conducted in order to assess the appropriateness of the number and locations of RBCs. Careful studies should be taken to find the better solutions to provide sufficient blood and efficient blood distribution.

1.2 Objectives

This research has set up the following two objectives.

- 1) To study supply chain of blood in Thailand in order to understand processes and procedures of blood distribution from the main center to regional centers and hospitals in provinces throughout Thailand.
- 2) To study and analyze for the optimum numbers and locations of the RBCs, by which the blood collection and distribution is improved.

1.3 Scope of the research

Scope of this research has been determined as below.

The research will study about blood distribution at the national level; with the emphasis on the distribution from the NBC to RBCs. Blood distribution within Bangkok will not be emphasized.

This chapter has discussed about background and importance of problems on the blood distribution in Thailand at present. Content in this chapter also covers blood composition, diseases that require blood for treatment, blood selection, the current pattern of blood distribution, and necessity to analyze for the optimum numbers and locations of RBCs. The next chapter will review relevant theories and researches that have studied on relevant topics, such as blood quality, cost of blood distribution, and locations of blood centers, in order to obtain knowledge and guidelines required to conduct this research.

CHAPTER II

LITERATURE REVIEW

This chapter discusses about theories and researches relating to the topic of this research. The main purpose of studying relevant theories and researches is to gain fundamental knowledge for conducting the research. It is also expected that the literature review will lead to the clear understanding on relevant issues and importance of analyzing locations of the RBCs. There are three main sections in this chapter. The first section is about Issues of blood supply chain, which describes about the nature of blood and activities or factors that can affect blood. The second section is about the structure of blood transfusion services, which will provide clear understanding on the current pattern of blood distribution. Finally, the last section is about problems of location/allocation regional blood centers, which is the main interest of this research.

2.1 Issues of blood supply chain

By studying the blood supply chain in Thailand as discussed in the previous section, the researcher can now clearly understand the processes that lead to the production of various blood products. In addition, problems that arise during these processes have also been realized. The problems are the main motivation of this research. Problems of other relevant researches conducted previously are also interesting. Therefore, this section discusses about relevant researches conducted on various aspects of blood.

1) Donors and blood volumes

The starting point of blood is the blood donors. Without blood donors, there will be no blood products to be supplied to patients, since blood cannot be produced by any body's organs (Nuchprayoon, 2010). Therefore, strategies to retain and to reward blood donors are needed in order to motivate them to donate blood (Leigh et al, 2007). In Thailand, donors are rewarded with token badges and some

discounts while being treated in hospitals (Red Cross Society, 2010). However, sometimes there are unexpected events that impact the number of donors and quantity of blood demand (Currie et al, 2004; Greinacher et al, 2007). For example, the political rally in May 2010 could greatly affect quantity of stored blood. The number of donors at the NBC reduced significantly whereas blood demand remained the same. Therefore, the NBC had to find solutions to persuade more donors. The NBC also dispatches its vehicles out to provide blood donation service outside the headquarter office (Sakundumrongpanit, 2011). The big earthquake in Indonesia that led to the devastating tsunami on December 26, 2004 is also unforgettable. The tsunami caused many deaths and injuries in several countries, including Thailand. Blood demand at that time became rising rapidly. Sri Lanka, which was greatly damaged, had to improve their system of blood procurement (Kuruppu, 2009). Thailand was supported by Finland to set up the Special Regional Blood Centre in Phuket province. The main duty of the special center is to procure and provide blood to victims from the natural disaster in nearby provinces (Nation Blood Center, Thai Red Cross society, 2010). However, the number of donors sometimes decreases due to the misunderstanding and misbeliefs about the blood donation and blood transfusion (Nwagbo et al, 1997). This leads to insufficient blood supply. Some countries had to import blood for domestic use, such as Italy, Scotland, South Africa, etc. (Rock et al, 2000). Proper blood donation must consider balance between security of blood donation and quantity of blood demand (Currie et al, 2004; Custer et al, 2005). Keeping this balance is a problem of blood distribution services in many countries, such as England. It is difficult to keep blood donation safe and meet requirements. There are many factors that control quality of blood checking and storing processes (Reynolds et al, 2001). In order to improve blood donation services, further studies on quality of blood donation are needed.

2) Quality in blood supply system

The blood supply chain represents flow of processes starting from collecting blood from donors, screening, testing, separating blood components, storing, distributing to hospitals, and ending at the patients who will receive the blood (Ryttila and Spens, 2006). Quality controls are needed for the whole stages in the blood supply chain. Quality is needed for checking blood group. The tests for blood

transmitted diseases; namely, syphilis, HIV, Hepatitis B, and Hepatitis C by using Nucleic acid Amplification Testing (NAT) technique (Japanese Red Cross Society, 2007) also require high quality of work. Barcode technique is used to enhance the quality of blood storing process so that the database of blood storage can be automatically updated when giving blood away (Turner et al, 2003; Li et al, 2005; Li et al, 2006; Spyropoulos et al, 2009). When distributing blood to hospitals, temperature in the container needs to be controlled continuously in order to maintain blood quality. The NBC randomly monitors the temperature of blood containers by using the data logger device during the transportation of blood to RBCs. The logged temperature data is used to improve blood distribution services (Chiewsilp et al, 2007). However, the warning system of blood services in Thailand does not operate automatically. Some countries have applied sensors and Radio-Frequency IDentification (RFID) for monitoring blood temperature. Their systems can automatically warn officers upon abnormality detection at the blood bags by sending Short Message Service (SMS) via Global System for Mobile Communications (GSM). These warning systems are efficient in preventing deterioration of blood quality during the delivery to hospitals (Kim et al, 2007; Lv et al, 2009). The Austrian Red Cross Society has analyzed blood transportation by simulating conditions of timetable arrangement of emergency ambulances, and checked transportation quality by using speed monitoring devices (Koch and Weigl, 2003). Blood temperature can be more efficiently controlled if the transportation takes only little time. Therefore, the American Red Cross Society has improved the schedules and routes for their blood distribution services in the Mid-Atlantic area, which is Virginia State and North Carolina State, for the optimum quality control (Jacobs et al, 1996). In Turkey, a research was conducted to study blood management system by considering locations of their RBCs, stations for collecting blood from donors, and the number of vehicles used for blood donation (Sahin et al, 2005). However, no research in Thailand has been conducted regarding the appropriate numbers and locations of RBCs, while this is a topic of interest in many other countries that also have similar system of blood distribution (World Health Organization, 2007). Those countries were successful in solving their problems of blood administration by better locating their RBCs. Therefore, this topic is an interesting research problem at the national level.

2.2 Structure of blood transfusion services

There are various patterns of blood transfusion services, from centralized to decentralized systems. In order to select a proper pattern or structure of blood services for a country, the political structure and laws enforcement in that country have to be considered (World Health Organization, 2007). Patterns of blood distribution services have been categorized into four types (Britten, 1992) as follows.

1) Centralized blood services model

This is the pattern that the main blood centre of the country is responsible for blood services of the whole country. There may be, or may be no, regional blood centers. The advantage of this system is the ability of the national centre to control quality of blood services. Equipment and tools used throughout the country can be controlled to meet the same standard. Problems are solved by the national centre. This model is suitable for countries with moderate size.

2) Decentralized blood services model

This pattern is appropriate for countries that govern in a state system. These countries may have a great variety of cultures and traditions. This model of blood service administration facilitates all blood centers to manage their services according to their unique conditions. The centers can coordinate with hospitals in their states conveniently. The centre will take care of blood collection, blood separation, blood testing, blood storing, and blood distributing for hospitals in its responsibility.

3) Co-location of small blood centre with hospital

This pattern is appropriate for small countries. Hospitals will work together to assist each other regarding blood services. Good approaches, data, skills, and equipment can be shared among hospitals in the country.

4) Mixed blood service model

This pattern is the combination of two patterns previously described, i.e., centralized and decentralized blood services model. Since both systems have some advantages and some disadvantages, combining both patterns together can help to reduce problems. With fully decentralized system, blood centers may compete for better quality, but they may work without cooperation. Therefore, mixing decentralized system with centralized system can allow flexible management on blood services.

In Thailand, the structure of blood transfusion services consists of the NBC, as the main center, and 12 Regional Blood Centers as well as the Provincial Red Cross Offices providing services in regional areas. The NBC also has facilities for blood donation such as stations for donating blood, vehicles for mobile blood donation, etc. (National Blood Center, Thai Red Cross Society, 2007). Other countries may have different structures of blood transfusion services due to differences in size, population, social, laws, and political background. Selected examples of structures of blood transfusion services in several countries are listed in Table 2.1.

Table 2.1 Structure of blood transfusion service in certain countries

Country	Area (km ²)	Population	Structure of blood transfusion service	References
Thailand	198,115	63,878,267	1 National Blood Center (NBC) 12 Regional Blood Centers (RBCs) 6 branches of blood services in Bangkok and 152 in regional. 77 Provincial Red Cross Chapters 300 hospitals-based blood banks in Bangkok and 700 in regional, Blood stations, Mobile unit	NBC (2007); Sakundum rongpanit (2011)
Albania	28,648	3,126,153	1 Nation Blood Transfusion Center (NBTC) 4 subsidiary blood banks in Tirana 26 hospital-based blood establishments at district level	WHO (2007)
Bulgaria	111,000	7,845,841	1 National Center of Haematology and Transfusiology (NCHT) 4 Regional Centers of Haematology and Transfusiology (RCHT) 23 Departments of transfusion haematology in multi-profile hospitals 56 hospital transfusion facilities	WHO (2007)
Croatia	56,542	4,437,460	33 transfusion departments/blood banks 20 from 34 perform full range of blood chain activities 1 national plasma fractionation center	WHO (2007)

Table 2.1 Structure of blood transfusion service in certain countries (cont.)

Country	Area (km²)	Population	Structure of blood transfusion service	References
Canada	9,984,670	32,601,360	41 permanent collection sites 20,123 blood donor clinics to donate whole blood, platelets or plasma 732 healthcare facilities served (1 in 3)	Canadian Blood Services (2007)
Finland	338,145	5,274,820	1 Helsinki Blood Transfusion Center (BTC) 4 Regional Blood Transfusion Center (RBTCs) Mobile unit Temporary stations	Ryttilä and Spens (2006)
Japan	377,930	127,288,416	7 Principal Blood Centers 60 Regional Blood Centers 139 blood collecting stations 1 plasma fractionation center 1 Center for Nucleic acid Amplification Testing (NAT) 309 Blood Mobiles	Japanese Red Cross Society (2007)
Montenegro	13,812	620,145	1 Blood Transfusion of the Clinical Center of Montenegro. 9 Blood transfusion in various hospitals Blood service is all hospital based.	WHO (2007)

Table 2.1 Structure of blood transfusion service in certain countries (cont.)

Country	Area (km²)	Population	Structure of Blood Transfusion Service	References
Republic of Macedonia	25,713	2,045,262	1 The National Institute for Transfusion Medicine (NITM) 2 hospital-based transfusion department 4 health care center transfusion unit 19 from 25 perform full range of blood chain activities.	WHO (2007)
Republic of Moldova	33,800	3,606,800	1 National Transfusion Center (NBTC) 2 Regional Blood Center (RBC) 21 hospitals blood transfusion sections 23 hospitals blood transfusion cabinets	WHO (2007)
Romania	238,500	21,673,328	1 National Institute of Blood Transfusion (NIBT) 8 Regional Blood Centers 33 the subsidiary blood establishments 4 hospital blood centers in Bucharest 330 hospital-based blood banks	WHO (2007)
Serbia	77,474	749,800	1 Nation Blood Transfusion Center (NBTC) 2 Regional Blood Transfusion Center (RBTC) 44 blood transfusion centers within various health care facilities	WHO (2007)

Table 2.1 Structure of blood transfusion service in certain countries (cont.)

Country	Area (km²)	Population	Structure of Blood Transfusion Service	References
			70 blood transfusion department/laboratories within hospitals, clinics and institutes 1 Plasma Fractionation Center is located in the National Blood Transfusion Institute.	
Sri Lanka	25,332	19,000,000	1 The National Blood Transfusion Service (NBTS) 1 National Blood Center (NBC) in Colombo 9 Regional Blood Center of provinces 70 hospital-based blood banks	Kuruppu (2009)
Taiwan	36,000	22,605,000	6 Blood Centers 12 Blood Stations throughout the country Mobile unit	Taiwan Blood Service (2007)
Turkey	780,580	73,193,000	1 Turkish Red Crescent (TRC) 23 Blood Centers Blood station Mobile unit	Sahin et al. (2005)

2.3 Location/Allocation problem

To find the proper number and locations of facilities, such as hospitals, schools, fire stations, police stations, mills, or department stores, many factors should be considered. Capital, labor, utilization space, topography, climate, security, transportation and communication, etc. are all important factors for locating facilities. This section will describe in detail about approaches that can be applied to analyze for the proper numbers and locations of RBCs in Thailand.

2.3.1 Nature of problem

Location is an important factor for logistics management since locations of facilities are the nodes that link processes in the supply chain (Sule, 2001). The problem of location analysis is not limited to be applied with only industrial mills or product distribution centers. Location management can be applied to many other purposes, such as finding proper locations to provide primary care to patient with maximum coverage (Reid et al, 1986; Ndiaye and Alfares, 2006). To design the number and locations of facilities properly, some factors, such as time, capital, efficiency, etc., may be needed for decision making. Similarly, the analysis on locations of RBCs should also consider various factors, such as construction cost, transportation cost, time for transportation, cost of operation, quantity of blood demand, and availability of blood supply from the NBC. The research problem about locations of RBCs may not be a new research topic for the world, but it is very challenging to conduct such a research in Thailand. With the proper location arrangement of RBCs, it is expected that living quality of blood-demanding patients in Thailand will be better. Conclusively, previous studies conducted about locations of facilities had objectives to solve these four categories of problems (Daskin, 1995).

- 1) How many facilities should be sited?
- 2) Where should each facility be located?
- 3) How large should each facility be?
- 4) How should demand for the facilities' services be allocated to the facilities?

Achievement of outcomes from these objectives depends on factors and procedures of the location analysis. Good approach can lead to good results. The next section will discuss about approaches to analyze for proper locations in detail.

2.3.2 Solution approach

Normally, to analyze for a proper location, the selected location should have the minimum cost of operation. Locations of facilities can lead to advantages or disadvantages of their operation. Factors to be considered when selecting a location may be different due to the objectives. Solutions for solving facility location problem can be categorized into two main approaches, ie., qualitative and quantitative approaches (Sule, 2001).

The qualitative approach is easy to understand. Factors to be considered for this approach include transportation cost, labor cost, land, topography, climate, security, laws, and taxes. Some researchers conducted their researches by using the Centre of Gravity (CoG) principle for their analyses. The principle employs the Newton's Law of Gravity for the calculation to analyze locations of facilities. Some research used this principle for studying locations of product distribution centers (Thai and Grewal, 2005; Cetin and Sarul, 2009).

The quantitative approaches are more complex. These approaches analyze locations by using mathematical models. Examples of models used for these approaches include static versus dynamic location problems, deterministic versus probabilistic model, single- versus multiple- product model, single-versus multiple-objective problems, capacitated versus uncapacitated facilities model, and hierarchical versus single-level models, etc. (Daskin, 1995; Owen and Daskin, 1998). The following lists are examples of problems that can be solved with these quantitative approaches.

1) Covering problem

This problem is used to determine the locations that can respond to demand of customers by considering the limitation on time and distance. Coverage area of the facility can be determined from solving this problem. There are two models commonly used to solve this problem; namely, the Maximum-Covering Location

model, and the Set-Covering Location model (Reid et al, 1986; Sahin et al, 2005; Cetin and Sarul, 2009).

2) Center problem

This problem is used to determine the location in emergency cases. The objective of using this problem is to reduce cost and travelling distances between the points of demand and the point of service as much as possible. In other words, the model is aimed to minimize the maximal distance (Owen and Daskin, 1998).

3) Median problem

This problem is used to specify the optimal location within the network. The problem is solved by trying to manage and bring demands to the located facilities. The main objective of using this approach is to minimize the total weighted distance between the facilities and the demand points (Sahin et al, 2005).

4) Fixed Charge Facility Location problem

This problem is highly complex. The problem is used to solve for multiple facility location. This problem is commonly found in real life. For example, industrial mills or product distribution centers normally do not exist in just one location. The problem is more complicated to be solved since there are additional variables. The possible patterns of locations can also vary. The problem can be analyzed to determine the numbers and locations. The main objective of this approach is to minimize the total cost that incurred from both fixed costs and transport costs. The problem can be further categorized into two types namely Uncapacitated Fixed Charge Facility Location problem and Capacitated Fixed Charge Facility Location problem (Daskin,1995; Nozick and Turnquist, 1998; Nozick and Turnquist, 2000; Klose and Drexl, 2005).

2.3.3 Related researches

There are several researches that have conducted on location/allocation problems. These researchers studied various aspects regarding locations of industries, medical facilities, as well as blood service systems in several countries. Objectives and model used in these researches are summarized and briefly explained in Table 2.2.

Table 2.2 Summary of related research on location/allocation problem

No.	References	Objective	Model
1	Reid et al (1986)	Determine the medical supply center for preparing to delivery primary health care services in Ecuador	Set covering
2	Jacobs et al (1996)	Improve blood collection and distribution from existing facilities pattern in the Mid-Atlantic American Red Cross (ARC) region	Integer programming , ie., collection model and distribution model)
3	Nozick and Turnquist (1998)	Optimal design of logistics systems bases on inventory, transportation, construction and opening cost	The fixed-charge facility location model
4	Taniguchi et al. (1999)	Find the optimal size and locations of public logistic terminal	Queuing theory, nonlinear programming and Genetic Algorithm
5	Nozick and Turnquist (2000)	Design for logistics systems and find optimal distribution center.	The fixed-charge facility location model
6	Thai and Grewal (2005)	Show conceptual framework for selecting the location of distribution center	Center of gravity (CoG) principle and mathematical model to optimize the total distribution cost or total transportation cost
7	Sahin et al (2007)	Restructure the blood service of Turkish Red Crescent which consider the optimal number of regional blood center, blood center, blood station and mobile units.	Hierarchical location problem with the three sub problems; ie., Problem 1: pq-median location model Problem 2: Set covering model Problem 3: Integer programming model
8	Ndiaye and Alfares (2008)	Find optimal number and locations of health care facilities for nomadic groups in the Middle East.	Binary integer programming model
9	Cetin and Sarul (2009)	1) How many blood banks will be located within capacity and covering all areas? 2) Minimize the total fixed cost of location blood bank and total distribution distances.	Set covering model Center of gravity method Binary nonlinear goal programming

Based on the literature review, it was found that there were many studies that analyzed patterns of locations of industrial mills and distribution centers. However, there were very few researches that conducted on the location of blood distribution centers. In Thailand, researches about location/allocation of regional blood centers could hardly been found. Therefore, it is interesting to analyze for the most proper number and pattern of RBCs in Thailand that can provide blood services to meet country-wide blood demands. The appropriate locations of RBCs can lead to more operational efficiency. The cost of transportation can be reduced, and the quality of blood can be controlled more efficiently. This will benefit living quality of all patients that require blood for their treatment.

This chapter reviewed literature regarding blood and its distribution. Current situation of blood transfusion services in Thailand has been studied to gain knowledge and understanding about existing problems of blood distribution. The structures of blood transfusion services in Thailand and several other countries have also been studied and summarized. Finally, problems regarding location/allocation of facilities and blood centers have been presented. These knowledge and understandings will be very useful for designing the methodology in this research. It will be discussed in the next chapter.

CHAPTER III

RESEARCH METHODOLOGY

The analysis to solve the problem regarding the optimal numbers and locations of RBCs at the national level involves a lot of data and variables. This great amount of data can lead to confusion and error. Therefore, this chapter will describe about details and procedures that are appropriate for conducting the research. The chapter comprises four main sections. The first section describes framework of this research about the target of mathematical model that will be used in each case. The second section will present details of data used. The third section is about hardware and software tools used for processing the data and solving the problem. Finally, the fourth section explains overall research procedures.

3.1 Research framework

This research divides the analysis into four main parts. The first part presents the current blood distribution cost for comparison with the cost analysis in various cases. The second part analyzes the optimal blood distribution pattern by using the transportation model. The third part discusses about the design of a new blood distribution pattern by fixing location of current RBCs and considering blood supply. The last part analyzes locations and numbers of RBCs in the case of no priori conditions on the availibiling of currents RBCs.

3.1.1 Understanding the existing regional blood distribution

This is to study the overall procedure of regional blood distribution. The data were collected by observing the daily operation and interviewing the disbursement, packaging, and delivery staff. The analysis provides the necessary understanding about the logistics process at current practice. The actual cost can be estimated as the basis for subsequent comparisons.

3.1.2 Analyzing the optimal distribution pattern based on existing configuration

When we know current blood distribution cost, in this section, we analyze the optimal total cost by using the transportation model to solve the problem. The involving factors are the delivery distance and blood volume. It is assumed that there is sufficient supply of blood so that the cost of blood transportation can be minimized because of the short distance delivery. Given the current locations of the NBC and 13 RBCs, with unlimited blood supply, this case determines the optimal transportation pattern with minimum cost. The expected results show the network of blood distribution and the amount of blood that should be collected for hospitals in the respective areas. The details of the transportation model (Daskin, 1995) are explained below.

Parameters

S_i = Blood supply at RBC i (unit)

D_j = Blood demand at demand point j (unit)

C_{ij} = The unit cost of transporting blood from RBC i to demand point j which measured by distance (kilometer)

Decision Variables

X_{ij} = The amount of transported blood from RBC i to demand point j (unit)

Mathematical Formulation

$$\text{Minimize} \quad \sum_i \sum_j C_{ij} X_{ij} \quad (1)$$

$$\text{Subject to} \quad \sum_j X_{ij} \leq S_i \quad ; \forall_i \quad (2)$$

$$\sum_i X_{ij} \geq D_j \quad ; \forall_j \quad (3)$$

$$X_{ij} \geq 0 \quad ; \forall_{i,j} \quad (4)$$

The objective function (1) minimizes the total transportation cost. Constraint (2) stipulates that the total amount of blood transportation from any RBC i must be less than or equal to its total supply. Constraint (3) ensures that each demand point j receives at least as much as it requires. Finally, constraint (4) is the nonnegativity condition.

This research has added a dummy location in the set of demand points for balancing because the total blood supply from all RBCs (S_i) are more than the total blood demand (D_j). Therefore, the model can always find the optimal solution to the problem.

3.1.3 New network design

In this section, the study is separated into two cases. The first case is to analyze the location of RBCs regardless of the amount of blood supply that can be collected (unlimited capacity) using the Uncapacitated Fixed-Charge Facility Location model. The second case considers the limited blood collection (capacity) using the Capacitated Fixed-Charge Facility Location problem model (Daskin, 1995). The results show the optimal number and locations of RBCs in Thailand as well as the corresponding distribution patterns based on the condition of each model. Afterwards, the cost of blood distribution will be compared with the current cost, to see how much it may be reduced. The elements in each mathematical model can be explained below.

1) Uncapacitated Fixed Charge Facility Location problem

Parameters

f_j = fixed cost of locating an RBC at candidate site j

h_i = blood demand at point i

d_{ij} = transportation distance from demand point i to the RBC j

α = transportation cost per unit distance per unit blood demand

Decision variables

X_j = 1 if we locate an RBC at candidate site j or 0 if not

Y_{ij} = fraction of demand at demand point i that is served by an RBC at site j

Mathematical formulation

Objective function

$$\text{Minimize} \quad \sum_j f_j X_j + \alpha \sum_i \sum_j h_i d_{ij} Y_{ij} \quad (1)$$

Subject to

$$\sum_j Y_{ij} = 1 \quad \forall i \quad (2)$$

$$Y_{ij} \leq X_j \quad \forall i, j \quad (3)$$

$$X_j = 0, 1 \quad \forall j \quad (4)$$

$$Y_{ij} \geq 0 \quad \forall i, j \quad (5)$$

The objective function (1) minimizes the total cost which is the sum of the fixed RBC costs and the total demand point-weighted distance multiplied by the cost per unit distance per unit blood demand. It is subject to the constraints (2) – (5).

Constraint (2) stipulates that each demand point i be served. Constraint (3) says that demands at demand point i cannot be assigned to the RBC at candidate site j unless we locate an RBC at node j . Constraints (4) are the integrality constraint. Nonnegativity is specified in constraint (5).

2) Capacitated Fixed Charge Facility Location problem

This model is similar to the previous problem, but considering also the limitation of blood supply that can be collected. Some elements are added into the mathematical model, ie.,

Added parameter

k_j = capacity of an RBC at candidate site j if located there

Added constraints

$$\sum_i h_i Y_{ij} \leq k_j X_j \quad \forall j \quad (6)$$

The additional constraints (6) ensures that the amount of blood supplied from any point j is limited to the its capacity of k_j .

3.1.4 New network design given the existing current configuration with the additional new RBCs

It is in fact difficult and impractical to close the existing RBCs and rebuild them at the ideal locations suggested by previous analyses due to very high transaction cost, such as land, buildings, instrument and personnel. In this analysis, it is assumed that the current RBCs must be there whereas the new RBCs may be added to the network, if necessary. The analysis is done by using the Fixed-Charge Facility Location models. The model will consider two cases, ie., limited blood supply and unlimited blood supply. The details of the mathematical model are already explained in 3.1.3.

Once the research framework is already designated, the overall aspect of the study can be seen clearer, more systematically. It also identifies the necessary data to be collected for each mathematical model in finding the solutions. The data will be explained in the next section.

3.2 Data

Data is an important part of all research. The research can have progress as planned if the collected data are accurate and clear. The analysis requires data for processing with the mathematical model. Generally, data can be categorized into two types namely:

1) Primary data

It refers to data that are not available to be used since they have not been surveyed, or have been surveyed but have not been systematically collected. Researchers have to survey and collect data by themselves. For this research, the primary data consists of:

- Locations and coordinates of the NBC, all 12 existing RBCs and one planned RBCs
- Patterns of blood transportation by mode such as car, van, bus, airplane, etc

- Costs of blood transportation for each transportation mode
- Routes of blood transportation
- Costs for construction and administration of RBCs in each province

2) Secondary data

It refers to data that have been surveyed and collected in databases, books, journals, researches, international articles, instruction manuals, etc. Secondary data used in this research include:

- National and international articles
- Statistics on blood demand at each RBC
- Distances of blood transportation throughout Thailand
- Population in each province
- Number of hospitals that the NBC and RBCs serve at present
- Estimated land price in all provinces throughout Thailand
- Statistic on the quantity of blood that each RBC and each province

acquired, which represents figures of blood supply

3.3 Analytical tools

There are two categories of tools used in this research, ie., hardware and software. Hardware basically refers to computers used for preparing and storing data for the analysis. Software tools mainly refer to all computer program used for processing data with different functions. Details of these tools are discussed below.

3.3.1 Hardware

1) A laptop computer was used for collecting and preparing data for the analysis. The CPU of the computer is AMD Turion™ X2 RM-74 @ 2.2 GHz. Its main memory (RAM) is 2 GB. The operating system is Windows XP Professional Version 2002 Service Pack 3.

2) A desktop computer was used for analyzing the data. The computer system consists of Intel Core 2 Quad 2.66 GHz for its CPU. Its RAM is 4 GB. It runs on Windows VISTA operating system.

3.3.2 Software

1) A GIS software package (ArcGIS 9.3)

ArcGIS 9.3 is a GIS software package with an ability to analyze network of routes by using its embedded Network Analyst Extension. This research used ArcGIS 9.3 to find the shortest distances between RBCs, and from the centers to bus stations, airports, and hospitals throughout the country. The set criteria were shortest distances and least utilized time. The unit of distance was set as meter, meanwhile the unit of time was minute.

2) Google Earth

In addition to ArcGIS 9.3, Google Earth was used because the data of bus stations and some hospitals were not readily available to be used with ArcGIS 9.3. Google Earth was used to find locations of those facilities. However, since the file system of Google Earth is .kml, which cannot be used with ArcGIS 9.3 that requires Shapefile (.shp) data, the next software was also needed for data transformation.

3) DNR Garmin version 5.04.0001

DNR Garmin was the software used to convert .kml files from Google Earth into .shp files (Shapefiles) so that the data can be opened by in ArcGIS 9.3.

4) Microsoft Excel 2007

Microsoft Excel 2007 was used for preparing data and calculates some parameters for the analysis, such as transportation cost by mode, construction cost of RBCs and supply of blood in each province.

5) Microsoft Access 2007

This is relational database management software with capabilities to store data, design data queries, and create reports. However, this research used Microsoft Access for preparing and storing database of preliminary data that will be processed by Visual basic 2005 software.

6) Visual Basic 2005

Due to the fact that the formulation based on abovementioned mathematical modeling contains many constraints, this software is used for writing mathematical formulation. The mathematical expression is then fed to be solved for the optimal solution by LINDO software.

7) LINDO Release 6.1

LINDO is the software used for solving the mathematical model to find the optimal number and locations of RBCs. LINDO takes data that was derived in Microsoft Excel 2007 for the analysis. LINDO Release 6.1 is capable to handle 200,000 variables, 64,000 constraints, 20,000 integer variables and 2,000,000 nonzero.

8) IBM ILOG OPL IDE 6.3

IBM ILOG OPL IDE 6.3 is a advanced software package for solving the high level optimization problem. It can also solve the mathematical model to find the optimal number and locations of RBCs. IBM ILOG OPL IDE 6.3 can handle much larger number of variables than LINDO Release 6.1. There were some cases that the number of variables and constraints used in this research was over the limitation of LINDO Release 6.1. Therefore, IBM ILOG OPL IDE 6.3 was used instead of LINDO Release 6.1 in those cases.

3.4 Overall procedures of the research

Appropriate arrangement of procedures is important for the success of this research. Each procedure has different activities that should be conducted in the proper order. In brief, the procedures were summarized into five parts as explained below.

1) Determining research problems

The first procedure is to study the blood supply chain. The chain starts from the downstream at the blood donors and flow to the patients at the upstream. Past research in the country and from overseas were reviewed in order to understand the blood distribution process worldwide. In addition, observation, interviews, and questionnaire techniques were adapted for collecting primary data from officers in the National Blood Centre of Thai Red Cross Society.

Based on the review, it was found that the current blood distribution in Thailand can be divided into two areas. The first area covers Bangkok Metropolitan region (BMR). The second area is for the rest of country. Every morning, the blood supply room of the NBC will give away blood to two major groups of clients. The first

group is hospitals in BMR, which send their vehicles and drivers to pick up blood and blood products regularly. The second group is RBCs and hospitals in provinces throughout Thailand. For this group of clients, the NBC packs blood products in the containers, and then drives the van to drop them at the public bus station or airport for transporting to RBCs and provincial hospitals. As a result, blood distribution to regional areas incurs extra transportation cost for the NBC. In fact, RBCs were established in 12 main provinces throughout the country with an intention to assist the NBC in collecting blood from donors and providing blood to patients in their responsible areas. However, the RBCs currently cannot obtain sufficient amount of blood as required by their responsible hospitals. Therefore, the RBCs have to request for help on blood supply from the NBC regularly.

Due to the problem discussed above, the researcher suspects that the number of RBCs might be insufficient. In addition, their locations might be inappropriate. The insufficient number and improper locations may be the causes that make these existing centers unable to collect sufficient blood for their clients. Thus the researcher attempts to apply the Location/Allocation mathematical model to find the optimal number and locations of RBCs in Thailand. The intention of this research is to propose solutions for reducing or eliminating unnecessary blood transportation cost.

2) Defining scope of the research

The research will emphasize on blood distribution services at the national level provided by the NBC for RBCs and provincial hospitals. Details regarding blood distribution to hospitals in BMR will not be discussed herein. The Location/Allocation mathematical model will be used to find new sites for locating RBCs more properly. The suggested locations should help to reduce transportation cost and ensure blood quality because the transportation distance and time will be shortened.

3) Data collection

The data collection process starts from studying general characteristics and work process of the NBC, and RBCs in order to obtain information for designing data collection forms and preparing tools for data collection. After the preparation process is completed, required data can be collected.

Regarding primary data, the process of data collection starts from observing and interviewing officers of the NBC. These officers included the person who took orders from clients, the person who checked records of blood provision, the packaging person, and driver. The researcher also surveyed the routes and places of destination by going together with the blood delivery van of the NBC. The places of blood distribution were photographed, and their environments were recorded in detail. Prices of blood products in various sizes of container and different mode of transportation were recorded in order to assess corresponding by mode.

Regarding secondary data, the statistics of blood usage and the list of hospitals in the NBC network were collected from the NBC. Digital map and road network shapefiles were obtained from the Transport Fundamental Geographic Data Set (Transport FGDS). These files are maintained by the Permanent Secretariate Office of the Ministry of Transport. The dataset was last updated in March 2007. Population data at the provincial level was obtained from the website of Department of the Provincial Administration (DOPA). Land prices in each province were derived from the website of the Treasury Department.

4) Data analysis

After collecting all required data, the next step is to develop a mathematical model for analyzing to find the appropriate number and locations of RBCs. The model is developed based on these assumptions.

- It is assumed that all provinces in Thailand are candidate sites for the establishment of RBCs. However, transportation and operational costs in these provinces can be different due to several reasons such as distance, land price, material prices, labor, etc.
- Distances between provinces, bus stations, and airports can be calculated and used for estimating the transportation cost. The distance was calculated by using the GIS software (ArcGIS 9.3).
- Land and construction costs for new RBCs can be estimated by using land price data and historical cost incurred to the NBC in the past. The result is the fixed cost of locating RBCs in the respective provinces.
- Blood demand in each province can be estimated using statistical data.

- Blood supply in each province can be estimated based on the population together with statistical data from previous researches.

- The mathematical model for analyzing the optimal number and locations of RBCs can be developed by using all data mentioned above. The model is of optimization type with the objective function to minimize the total cost of the logistics system, which include fixed and transportation costs. Since the solution to this problem is both the location and distribution pattern, thus the Location/Allocation model is applicable.

- The locations of existing RBCs and new locations designated by the model can be compared. The efficiency of the current blood distribution network in Thailand can be examined.

- The final assumption is that the existing RBCs cannot be moved or removed, and the new center can be added to reduce the total cost of blood distribution.

5) Concluding and reporting the results

This is the final step of conducting the research. It is about drawing the research conclusion. Figure 3.1 shows the flow chart of overall procedures for conducting the research.

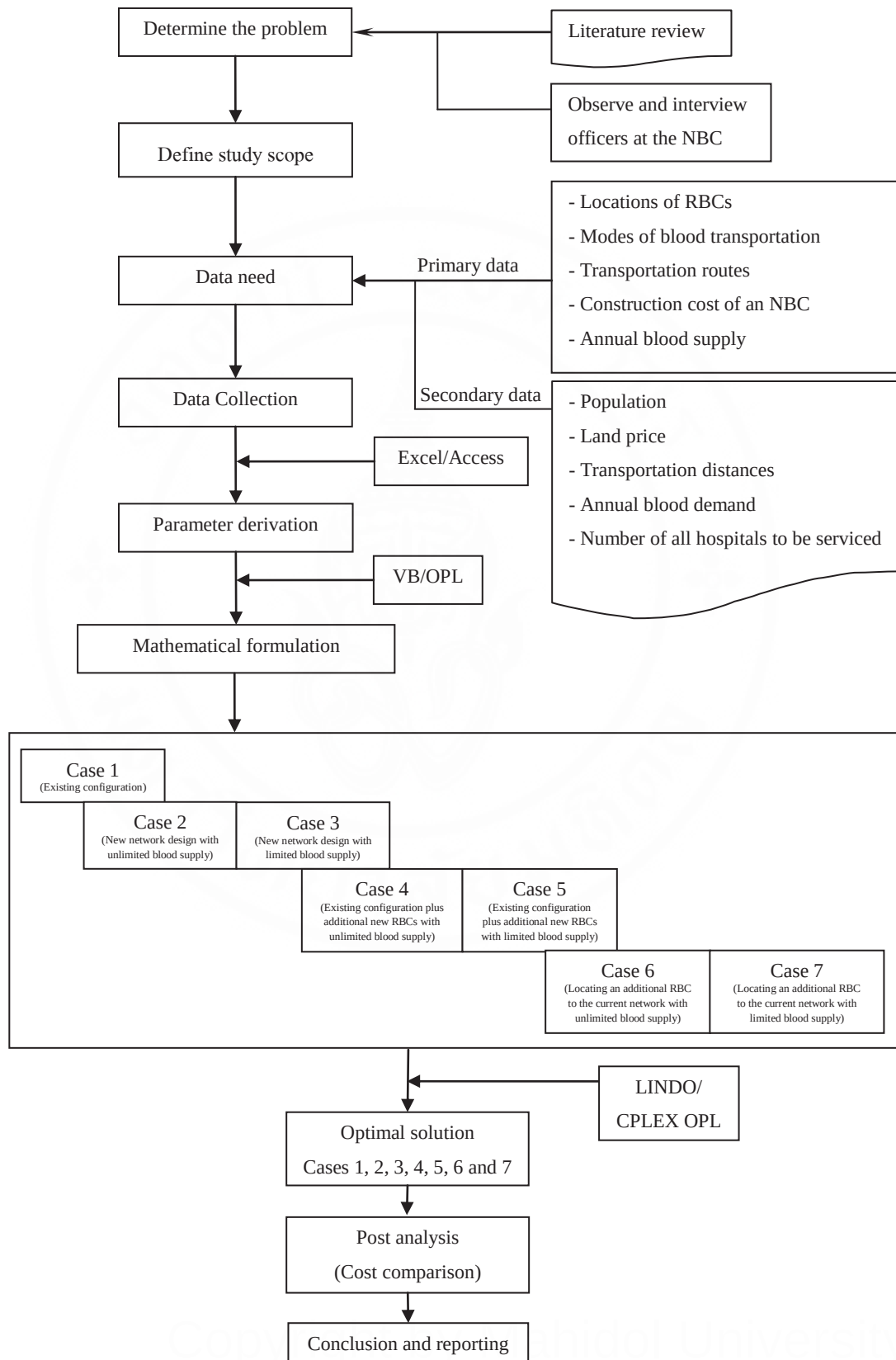


Figure 3.1 Overall procedures for conducting the research

CHAPTER IV

REGIONAL BLOOD SUPPLY CHAIN

The previous chapter has discussed in details about the research methodology. This chapter is going to explain about general of blood supply chain. There are many sections to be discussed in this chapter, including data collection, current practice of blood supply system, description of regional blood distribution, transportation distance, volume of blood delivery, the details of blood delivery cost analysis and the estimation of the current blood distribution cost.

4.1 Data collection

Data collection was carried out for understanding the operation, current practice and problem of regional blood supply chain in Thailand. Despite a brief explanation in previous section, detail on data collection is clarified in two sections. The first section is primary data collection. The analysis requires data for understanding operation and blood distribution processing. It was collected by the unstructured interview with the NBC's staff for general details (Figure 4.1), observing blood delivery steps by going together with NBC's van (Figure 4.2), recording the volume of blood (Figure 4.3) and taking the photos of blood distribution procedures (Figure 4.4) from the NBC to RBCs. The field observation is conducted during seven days of 8, 10, 14, 19, 20, 24, and 28 August, 2010. On the first day of August 8, it is the overall observation to get acquainted with the process. The data were therefore completely collected for 6 days.

The second section is about secondary data collection. They are basically document data. The set of data includes fixed cost of building RBCs, blood request form, blood distribution form, blood demand and blood supply in each province from

historical record in annual report of NBC/RBCs, books, journals, researches, international articles, instruction manuals, and the current blood distribution route, etc.



Figure 4.1 Interviewing officers about blood packing procedure



Figure 4.2 Going together with the blood delivery van of the NBC



Figure 4.3 Recording volume of blood delivery



Figure 4.4 Taking photos of blood distribution procedure

4.2 Current practice of blood supply system in Thailand

From data collection section, the first step is to understand overall processes of blood distribution service from the upstream (blood donors) to the downstream (patients). The current blood procurement system in Thailand is centered at the NBC. The NBC is a non-profit and independent organization. Its main responsibility is to provide blood distribution services with safe and standardized blood products to meet requirements of patients all over the country. In 2006, the NBC could procure blood as much as 467,312 units from 295,187 blood donors (NBC, 2007). It showed an increasing trend of blood procurement over previous years. Each bag of blood has to pass through many technical processes before being sent to the patients (Prastacos, 1984; Sapountzis, 1984; Ryttila and Spens, 2006; NBC, 2007; Canadian Blood Service, 2007; Japanese Red Cross Society, 2007; Delen et al, 2009). Conclusively, there are four main procedures; namely, recruitment and collection, testing, processing and storage, delivery of blood and blood components and patient use as shown in Figure 4.5.

4.2.1 Recruitment and collection

All blood donors firstly have to be screened by having them filled their personal data in the Blood Donor Application Form (Appendix A). Then the donor will meet the doctor to check blood pressure and blood concentration, and to discuss about his/her health (Chiewsilp, 2010). After the doctor has agreed that the patient is ready for blood donation, his/her name will be registered as a blood donor. Then he/she will lie down to have his/her blood drawn to the blood bag. There are two types of containers for storing the blood drawn from blood donors; namely, tube and bag. The tube is used to keep blood for being checked to determine the blood group and blood diseases, which requires four tubes for each sample. The tubes are labeled differently with red, gray, pink, and purple colors. The bag is used to store blood that will be separated into various blood components. There are two sizes of commonly used bags; namely, 350 ml. and 450 ml. The 350-ml bags are for donors whose weight is within the range of 45 to 50 kilograms. The 450-ml bags are used with donors heavier than 50 kilograms. The two types of blood containers have to go through technical processes together.

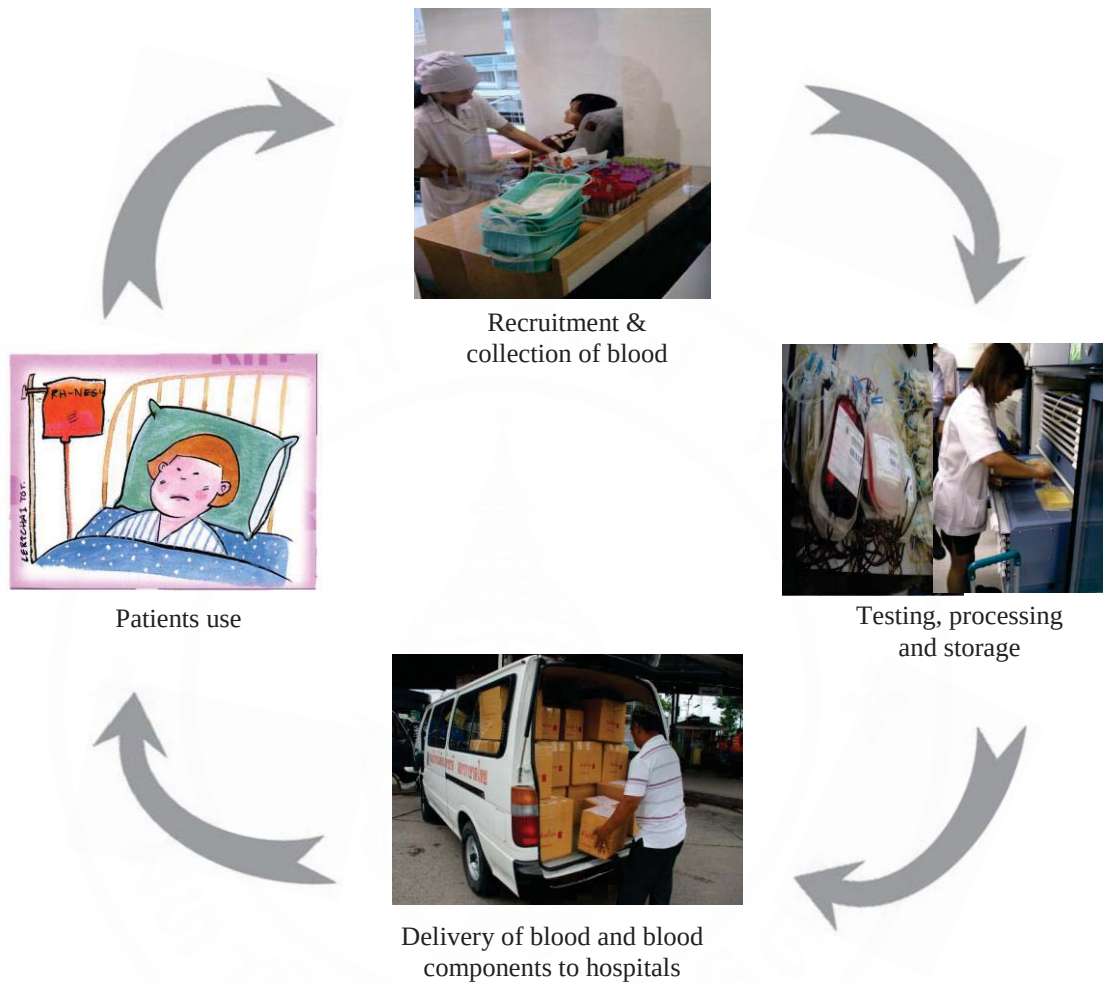


Figure 4.5 Blood supply chain system

4.2.2 Testing, processing and storage

Having blood drawn into both types of blood containers, the blood tubes will be submitted to the Blood Group Testing Unit and the Viral Testing Unit. These units will check for diseases that may be transmitted with blood transfusion (NBC, 2007). Details of the checking are as follows:

- The clotted tube is used to examine blood groups (ABO, Rh⁺).
- The CPD tube is used to check for antibody.
- The clotted tube is used for checking various blood diseases; namely, HIV-Ab, HIV-Ag, Anti-HCV, HBsAg and syphilis.
- The EDTA tube is used by the center for Nucleic acid Amplification Testing and Quarantine (NAT-Testing).

Meanwhile, the blood bags will be sent to the Plasma and Blood Section, who will separate the blood into three main components. The three components are red blood cell, platelets, and plasma. Each component can be further separated into many minor products. Main products produced daily at the NBC are:

- Packed Red Cell (PRC)
- Leukocyte-Poor Packed Red Cell (LPRC)
- Leukodepleted Packed Red Cell (LDPRC)
- Platelet Concentrate (PC)
- Leukocyte Poor Platelet Concentrate (LPPC)
- Fresh Frozen Plasma (FFP)
- Leukodepleted Fresh Frozen Plasma (LDFFP)
- Cryoprecipitate (Cryo)
- Cryo-Removed Plasma (CRP)

The Notification of Blood Results Unit will inform the donor about results on blood tests. If the test results do not meet the criteria, all products from that donor will be rejected. After the blood has been verified to meet standardized quality, it will be kept at appropriate temperature according to the standard for each blood component (Chiewsilp et al, 2007). The stored blood component is then ready in the blood bank for distribution to patients. The standard temperatures for blood components are as follows;

- Red blood cell is stored at the temperature range of 2 - 10 °C.
- Platelet is stored at the temperature between of 20 - 24 °C. The bags of platelets also require continuous movement during transportation (by keeping in the shaking tray).
- Plasma is stored at the temperature below – 18 °C.

4.2.3 Delivery of blood and blood components to hospitals

At present, blood distribution service in Thailand start at the centers, either NBC or RBCs. In Bangkok Metropolitan Region (BMR) the center is at the NBC. In other regions, blood distribution is provided to provincial hospitals by the RBCs or by the NBC via RBCs. The transportation may be by several modes; namely, NBC's van, public bus, airplane and public carrier.

4.2.4 Using blood components

Blood demand of patients is the final step of the blood supply chain. Blood from the NBC is stored in the blood banks of hospitals. When a patient needs to use some blood, the doctor must permit the blood usage first. The doctor will fill in the form with details of patient, type of blood, quantity, date of usage, and blood sample. The form will then be submitted to the blood bank of the hospital. The ordered blood must be tested by the cross-matching technique to verify that the patient's blood is compatible with the donor's blood so that the blood transfusion will be safe for the patient's life.

In summary, the blood distribution system in Thailand consists of several procedures. The flow of procedures starts from screening blood donors, then drawing blood from donors, testing the blood, separating blood into components, storing the blood, delivering blood products, and using blood with the patient. For ease of understanding, the procedures are illustrated in Figure 4.6.

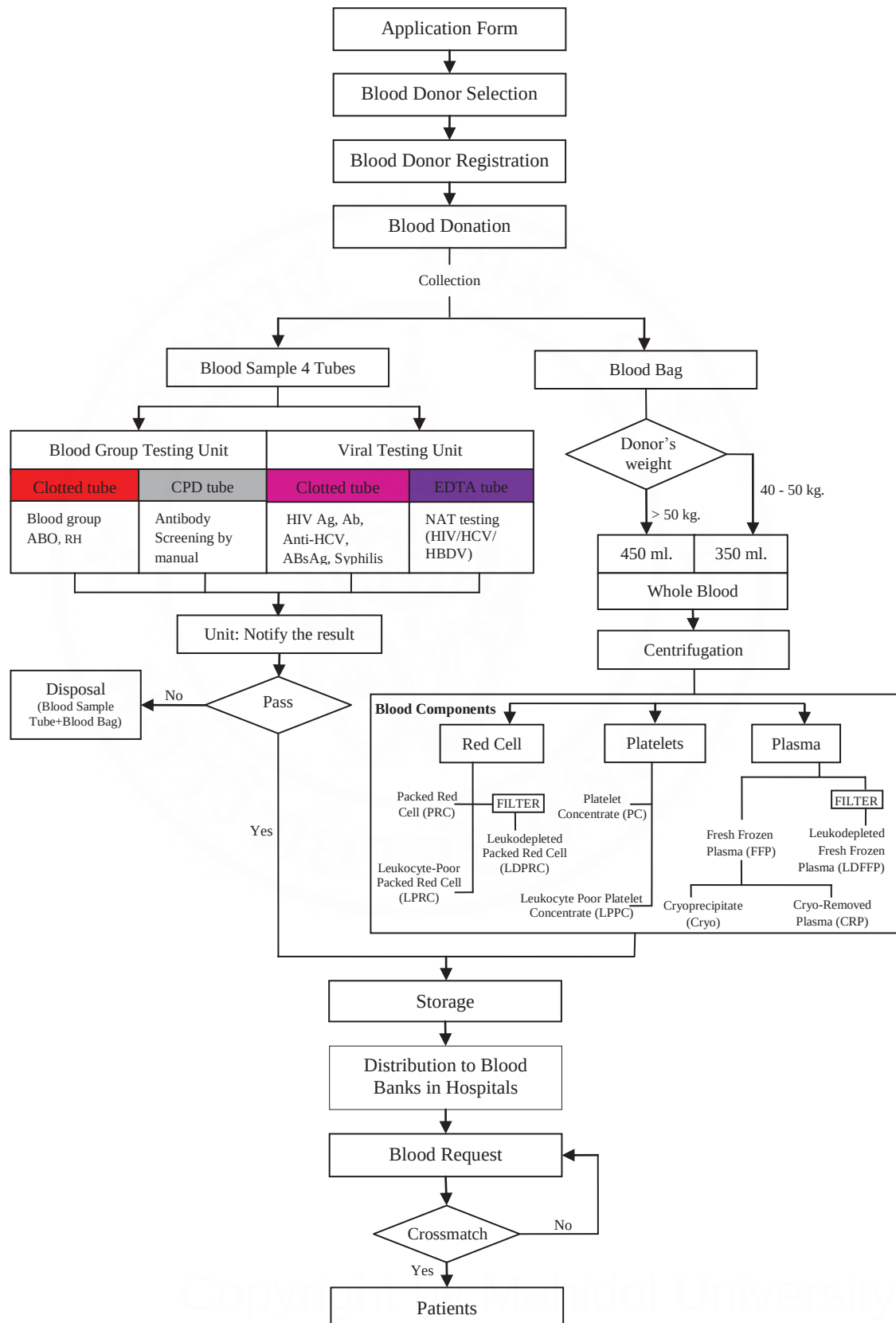


Figure 4.6 Flow of blood supply system in Thailand

4.3 Description of regional blood distribution

This section explains two main things. The first topic is about the locations of 12 existing RBCs and their service areas. The RBC's working function is the same as the NBC in Bangkok. The second topic is the description of current regional blood distribution procedures. The contents explain about blood request, blood delivery, blood document forms, blood packing in different components and blood distribution forms. Current blood distribution has two ways of delivering, land and air. This section is described for estimating current blood distribution cost in the next section.

4.3.1 Locations and service areas of the NBC and RBCs

The NBC is located at Henri Dunant Road, Bangkok. Its main duty is to provide blood, blood components, and blood products sufficiently according to the demand of patients. The blood and blood products provided to all regional areas from the NBC must meet the national standards regarding safety and quality. The NBC also has extra service for specific patients with certain diseases (NBC, 2007). The blood distribution pattern in Thailand is categorized as a decentralized blood service model. This model comprises the NBC, as the center of blood services, 12 RBCs, the special RBC in Phuket, and Provincial Red Cross Chapter in all provinces. In addition, there are some places and mobile services with specific function of providing services for blood donation. These current RBCs' locations are simply followed the administrative districts designated by the Ministry of Interior (Ministry of Interior, 2003) for the sake of easy budgeting and personnel management. It is also convenient for organizations in charge to operate RBCs accordingly. These reasons, however, may not be very beneficial to the blood service and, consequently, lead to several problems. Notably, the blood supply from these RBCs cannot fulfill the demand for blood in their own service provinces. The locations of the NBC, RBCs, and their current servicing provinces (NBC, 2007) are shown in Table 4.1 and Figure 4.7.

Table 4.1 Description of the NBC and RBCs in Thailand

Blood Center	Year of establishment	Location	Servicing Provinces
National Blood Center	1952	Bangkok	Bangkok, Nonthaburi, Pathumthani, Samutprakan
Regional Blood Center 1	Isn't opened	Ayutthaya	Nonthaburi, Pathumthani, Ayutthaya, Angthong, Samutprakan
Regional Blood Center 2	2001	Lopburi	Chai Nat, Nakhonnayok, Lopburi, Saraburi, Singburi, Suphanburi
Regional Blood Center 3	1999	Chonburi	Chachoengsao, Chonburi, Rayong, Chanthaburi, Trat, Prachinburi, Sakaeo
Regional Blood Center 4	1998	Ratchaburi	Samutsakhon, Samutsongkhram, Nakhonpathom, Ratchaburi, Phetchaburi, Kanchanaburi, Prachuap Khirikhan
Regional Blood Center 5	1996	Nakhonratchasima	Nakhonratchasima, Buriram, Surin, Chaiyaphum, Mahasarakham, Sisaket
Regional Blood Center 6	1997	Khonkaen	Khonkaen, Udonthani, Sakonnakhon, Nongkhai, Nongbualamphu, Loei
Regional Blood Center 7	2003	Ubonratchathani	Ubonratchathani, Mukdahan, Roi Et, Yasothon, Nakhonphanom, Amnatcharoen, Kalasin
Regional Blood Center 8	2004	Nakhonsawan	Nakhonsawan, Uthaithani, Kamphaengphet, Sukhothai, Tak
Regional Blood Center 9	1996	Phitsanulok	Phitsanulok, Phichit, Phetchabun, Uttaradit, Phare, Nan
Regional Blood Center 10	1996	Chiang Mai	Chiang Mai, Lamphun, Lampang, Chiang Rai, Mae Hong Son, Phayao
Regional Blood Center 11	1997	Nakhonsithammarat	Chumphon, Suratthani, Ranong, Nakhonsithammarat, Phangnga, Phuket, Krabi
Regional Blood Center 12	2000	Songkhla	Songkhla, Satun, Trang, Phatthalung, Pattani, Yala, Narathiwat
Special Regional Blood Center	2007	Phuket	Coverage in the Andaman Sea provinces Phuket, Krabi, Trang, Phang Nga, Ranong and Satun

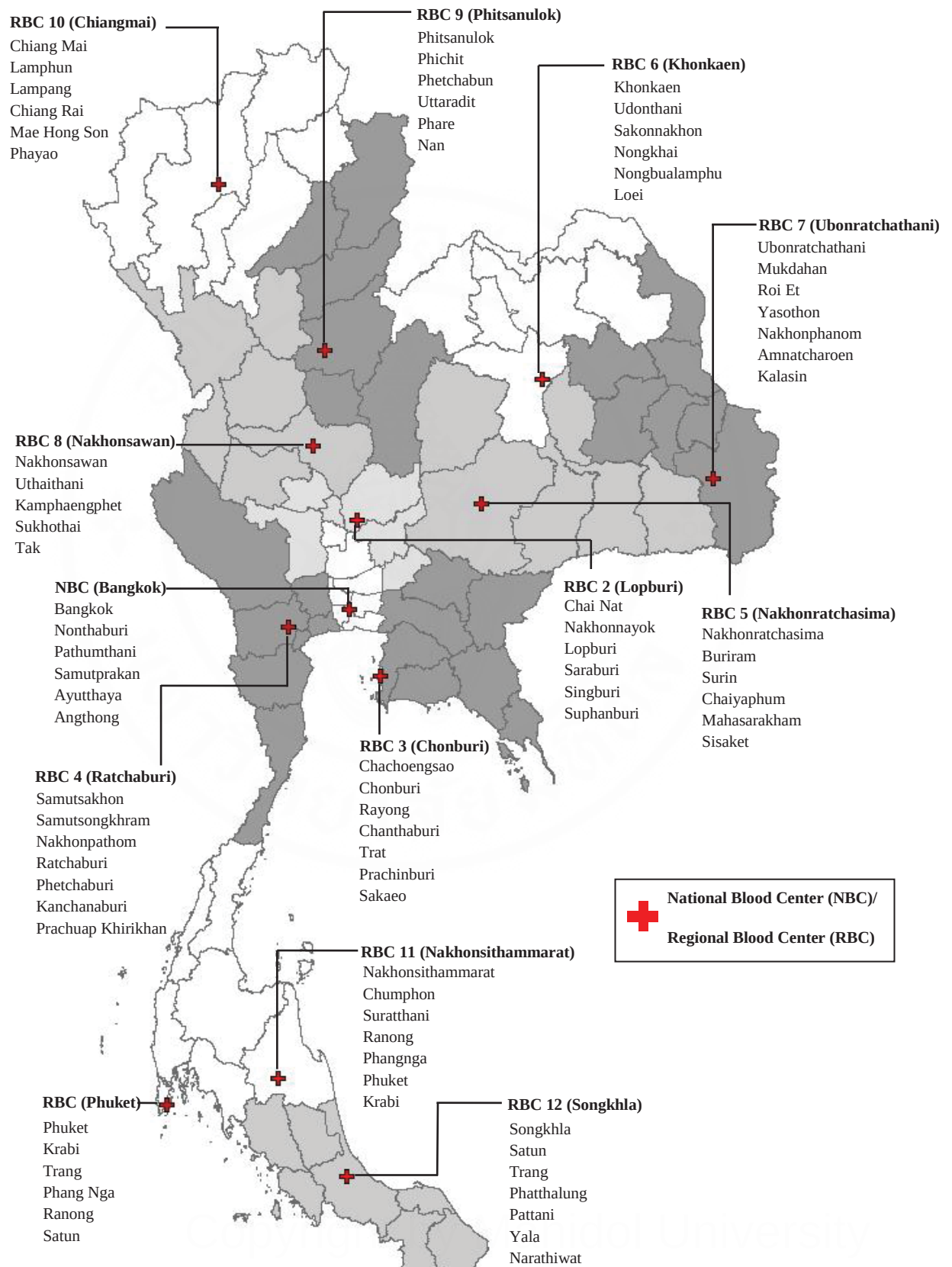


Figure 4.7 Current locations and their servicing provinces of the NBC and RBCs

4.3.2 The operation of blood distribution

The current blood distribution pattern from the NBC to other regions incurs very long distance. It is too expensive. Perhaps, the quality control of blood is an even bigger issue since blood is a highly sensitive product. Various types of blood products do require different temperature control. It is really hard to consistently keep the temperature at check over the long distance without incurring high cost. All these issues raise the questions of whether the analyzing and re-design locations of RBCs are the best for Thai society in Chapter 5. In this section, the current operation of blood distribution is divided to three steps. The first step is blood request. The second step is blood packing. And the third step is blood distribution. The details explained below.

1) Blood request

When RBCs or hospitals in the network need to use blood, they need to fax a blood request form to the NBC. There are two types of blood request forms. The first type is called Blood Request Form for Stock. This form is used when RBCs request blood in order to keep in their stock for future use at the provincial hospitals. The example of the form is shown in Figure 4.8. Details contained in the form include hospital's name, province, telephone number, fax number, membership number, date of blood request, blood type (for examples, Packed Red Cell (PRC), Leukocyte-poor Packed Red Cell (LPRC), Leukodepleted Packed Red Cell (LDPRC), Platelet Concentrate (PC), Leukocyte Poor Platelet Concentrate (LPPC), Fresh Frozen Plasma (FFP), Leukodepleted Fresh Frozen Plasma (LDFFP), Cryo-Removed Plasma (CRP), and Cryoprecipitate (Cryo)), blood group (such as A, B, O, AB), quantity of requested blood, name and position of the person who requests the blood.

The second type of blood request forms is called Blood Distribution Form, which is used by hospitals that request for blood directly from the NBC instead of RBCs in charge. The amount of blood that each RBC or hospital can get from the NBC depends on the availability of the blood during the day. For sharing blood, the NBC keeps a principle that all RBCs and hospitals should receive blood equally.

เครื่องหมายโรงพยาบาล

ชื่อโรงพยาบาล.....

จังหวัด.....

หมายเลขโทรศัพท์.....

หมายเลขโทรสาร.....

หมายเลขสมาชิก.....

ใบขอใช้โลหิต ศูนย์บริการโลหิตแห่งชาติ สภากาชาดไทย

สำหรับ STOCK (ตรวจ NAT ทุกยูนิต)

วันที่.....

ชนิดส่วนประกอบโลหิต Group	Units			
	A+	B+	O+	AB+
LDWB				
PRC				
LPRC				
LDPRC				
Platelet Concentrate (PC)				
LPPC				
FFP				
LDFFP				
CRP				
Cryoprecipitate				

(ลงชื่อ)

(.....)

ตำแหน่ง.....

หมายเหตุ โปรดตรวจสอบความเรียบร้อยในใบขอใช้ให้ถูกต้องก่อนนำไปขอโลหิตจากศูนย์บริการโลหิตแห่งชาติ สภากาชาดไทย

Figure 4.8 Blood request form for stock

ถึง โรงพยาบาล..... ศูนย์แม่เหล็กโลหิต (ส.เม็ด)

กรุณาไปรับ ☒ โลหิต

	A	B	O	AB
WB				
PRC	2	8	5	
LPRC				1
LPPC				
PC				
FFP				
CRYO				

☐ น้ำยา Antiserum ☐ น้ำยา Screening Cell

☐ อื่น ๆ ได้แก่ 2 กล่อง

สถานที่รับของ ☒ บริษัทการบินไทย เที่ยวบินที่ TG 014

☐ บริษัท ทวีร์

☐ การรถไฟแห่งประเทศไทย ขบวนที่.....

☐ อื่น ๆ

ในวันที่ 27 ธ.ค. 53 เวลา 19:15 น.

จาก ศูนย์บริการโลหิตแห่งชาติ สภากาชาดไทย โทร. 0-2252-4106-9 , 0-2251-3045 9 ต่อ 1000, 1001, 1004

แบบตอบรับ (กรุณา FAX กลับทั้งใบ)

เมื่อได้รับโลหิต หรือผลิตภัณฑ์ที่ศูนย์ฯ ส่งให้แล้ว กรุณาใช้แบบฟอร์มนี้ FAX กลับศูนย์ฯ ด้วย เพื่อเป็นประโยชน์ในการพัฒนางาน โดย FAX กลับที่เบอร์โทร. 0-2252-8864

ได้รับโลหิต หรือผลิตภัณฑ์ที่ศูนย์ฯ ส่งให้เรียบร้อยแล้ว ในวันที่..... เวลา..... น.

จำนวนผลิตภัณฑ์ที่ได้รับ ☐ ครบ ☐ ไม่ครบ คือไม่ได้รับ.....

สภาพของผลิตภัณฑ์ ☐ ดี ☐ ไม่ดี เนื่องจาก.....

ระยะเวลาในการจัดส่ง ☐ รวดเร็ว ☐ ล่าช้า เนื่องจาก.....

สถานที่รับผลิตภัณฑ์ ☐ สะดวก ☐ ไม่สะดวก เนื่องจาก.....

ลงชื่อ..... ผู้รับ (ตัวบรรจง)

ตำแหน่ง.....

Figure 4.9 Blood distribution form

Having received the request form, the NBC prepares the information on Blood Distribution Form, as shown in Figure 4.9. This is an important document with many details regarding blood delivery. In brief, the details can be divided into two parts. The first part contains information about blood types and the amount of blood to be delivered to RBCs or hospitals, date of blood delivery, and the place for delivering blood box. The second part of the form contains information for the officers of RBCs or hospitals to check after they have received the blood box. Details in the second part include number of products, condition of products, time for delivery, and destinations for submitting the blood. After RBCs or hospitals have read and agreed with the details, they will sign in the form and fax it to the NBC so that the NBC knows status of the blood boxes.

2) Blood packing

The NBC distributes blood to RBCs and regional hospitals in the foam boxes. The boxes are sealed with tape and packed inside a paper box. Blood in the boxes is required to be kept at a certain temperature range. The NBC randomly put a data logger into the box to monitor the blood temperature all the way. The tracking of blood temperature using the data logger is shown in Figures 4.10 and 4.11. The amount of blood that each RBC and hospital receive from the NBC is not equal, and can be varied day by day according to the availability and requirements. Therefore, the NBC prepares three sizes of blood boxes; i.e., small, medium, and large. The amount of ice to be used to maintain the temperature of the blood during transportation also depends on blood quantity and blood components. Details about blood packing are shown in Table 4.2.



Figure 4.10 Tracking temperature using a data logger



Figure 4.11 Red blood cell with data logger

Table 4.2 Description of blood packing classified by blood type/quantity/box size

Blood component	Temp. (°C)	Quantity (Units)	Box size (Inch)	Number of ice bag (bags)	Paper between blood bag and ice bag (layers)
PRC, LPRC, LDPRC	between 2-10°C	1-8	8.5x12x8.5	1 kg. 2 bags	4 thick layers
		9-16	10x14.5x12.5	1 kg. 3 bags	4 thick layers
		24-32	14x19x14	2 kg. 3 bags	12 side layers 20 top layers
SDR	between 2-10°C	2-4	8.5x12x8.5	1 kg. 2 bags	4 thick layers
		6-12	10x14.5x12.5	1 kg. 3 bags	4 thick layers
		20-32	14x19x14	2 kg. 3 bags	12 side layers 20 top layers
PC	between 20-24 °C	1-12	8.5x12x8.5	100 g. 1 bag	70 thick layers
		13-24	10x14.5x12.5	100 g. 2 bags	top 100 bottom 108 layers
		25-40	14x19x14	100 g. 2 bags	top 100 bottom 100 layers
LPPC		1-2	8.5x12x8.5	100 g. 1 bag	70 thick layers
		3-4	10x14.5x12.5	100 g. 2 bags	top 100 bottom 108 layers
		5-7	14x19x14	100 g. 2 bags	top 100 bottom 100 layers
SDP		1	8.5x12x8.5	100 g. 1 bag	70 thick layers
		2-3	10x14.5x12.5	100 g. 2 bags	top 100 bottom 108 layers
		4-6	14x19x14	100 g. 2 bags	top 100 bottom 100 layers
FFP	<	25	14x19x14	Dry ice 8 Kg.	-
Cryoprecipitate	-18°C	100		Dry ice 10 Kg.	-

The NBC has conducted experiments to test the effectiveness of the methods and procedures for packing each blood components as shown in Table 4.2. The results reveal that the temperature could be controlled for only a certain period of time (Chiewsilp et al, 2007). If the blood has to be transported over a long distance

taking too much time for travelling, the blood quality may become degraded. This could result in the risk of patients.

3) Blood delivery

After the blood boxes have been checked and loaded into the NBC's van, they will be transported to one of these four intermediate stations for further transportation; namely, 22 Karakkadakhom circle, Mo Chit bus terminal, Don Muang airport, and Suvarnabhumi airport depending on the destination. In other words, blood transportation can be categorized into two main modes i.e., land and air transportation. Figure 4.12 shows the flow of blood for both modes. The main differences of these two modes are the station and the destination of blood transportation. For land transportation, the station for transferring blood is either van or bus terminal. Meanwhile the transfer station is an airport in the case of air transportation.

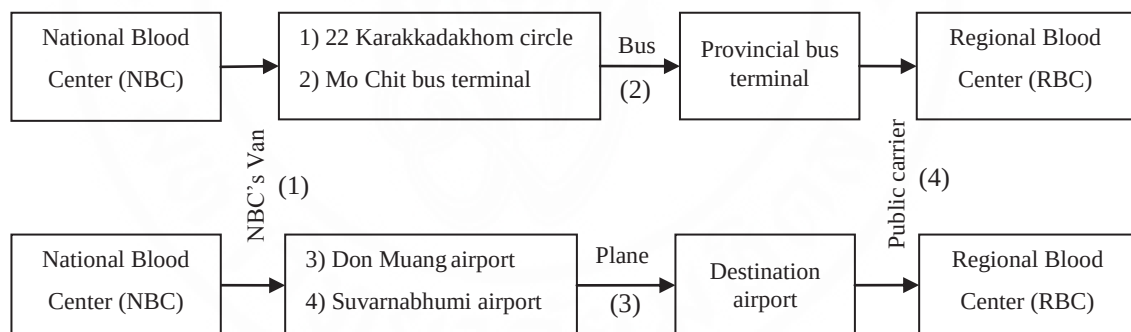


Figure 4.12 Mode of blood distribution from the NBC

- 22 Karakkadakhom circle

22 Karakkadakhom circle is the place where the passenger van station of Consu Transport Co., Ltd. is located. The station is at Soi Panjit, which is a community area with old buildings. The station set up chairs for customers to wait for the vans on the sidewalk, as shown in Figure 4.13. When the NBC's van has arrived and the blood boxes are unloaded, the transportation charge will be calculated. The NBC van driver will then pay the bill and take the receipt back to the NBC.



Figure 4.13 Van station at the 22 Karakkadakhom circle

- Mo Chit bus terminal

Blood box delivery at Mo Chit bus terminal comprises the processes of unloading blood boxes, checking for completion, paying the bill, and taking the receipt back to the NBC. The receipt contains information about the contact telephone number, the destination place, and the time when the bus will leave the station and arrive at the destination. Figure 4.14 shows the location where blood boxes are loaded onto the bus. According to the figure, it can be seen that the blood boxes are put together with the passengers' bags. This compartment in a bus may receive heat from the engine and the road surface. Such this heat can cause the ice in the foam boxes to melt more quickly, possibly resulting in deteriorated quality of blood inside the boxes.



Figure 4.14 Location of blood boxes on the bus

- Don Muang airport

Don Muang Airport is located on Viphavadee road. Before the blood boxes can be transported by airplanes, they have to pass through X-ray scanners, as shown in Figure 4.15, in order to security check for any harmful material inside. The blood boxes will then be billed and weighed at the counter. The staff at the airport will write information about the flight in the blood delivery form of the NBC and give to the driver. Once come back to the NBC, the form will be faxed to RBCs or hospitals of destination in order to inform them about the date and time of arrival of the blood boxes.



Figure 4.15 X-ray blood boxes at Don Muang airport

- Suvarnabhumi International Airport

For transporting blood boxes by airplanes at Suvarnabhumi Airport, the NBC's van has to be parked at the car park of the domestic cargo terminal. Blood boxes will be put on pallets that are separated by each destination airport (Figure 4.16). An air waybill will be attached to each blood box (Figure 4.17). There are also other three types of labels to be attached to the blood boxes. The first label type informs about characteristics of goods inside the box, which is fragile and should be handled with caution. The second label type informs that the box contains fresh materials that can be degraded easily, thus it must be kept in a compartment with controlled temperature. Lastly, the third label type shows that the box has been passed the security check and valid for air transportation. All blood boxes have to be attached with these three labels, with an exception of the boxes of blood platelets. This is because blood platelets are required to be stored at temperature between 20-24 °C, and should not be frozen in order to prevent the death of cells. The blood boxes will be checked again to ensure that the weight and quantity are correct according to the

information faxed previously from the NBC. Upon completion, the Domestic Air Waybill will then be signed (Figure 4.18).



Figure 4.16 Separating blood boxes to destination airports by pallets

ไทย พัดคู่เลขที่ Air Waybill NO		217- 7288 7813	
จาก FROM	BKK	ถึง TO	CNX
จำนวนชิ้น PIECE NO	2	ผ่าน VIA	
รวมชิ้น TOTAL PIECES	002	13.60	TG0114
		TOTAL WEIGHT	

Figure 4.17 Number of air waybill

The domestic air waybill attached to the blood boxes contains these useful details; i.e., shipment number, terminal airport, destination airport, flight number, number of blood boxes, and their total weight. This air waybill is prepared in

advance after the airport has been informed via facsimile from the NBC. This is to speed up the blood delivery process.

217- 7288 7780		ใบรับส่งสินค้าและพัสดุภัณฑ์ภายในประเทศ DOMESTIC AIR WAYBILL				217- 7288 7780	
 บริษัท การบินไทย จำกัด (มหาชน) Thai Airways International Public Company Limited เลขทะเบียน: 89-38-5667 89 Vibhavadi Rangsit Rd., Bangkok 10900, Thailand เลขประจำตัวผู้เสียภาษี: 3 10 100063-4		สถานีปลายทาง Airport of Departure BKK		สถานีปลายทาง Airport of Destination KKC		เที่ยวบิน / Flight No. 45 วันที่ / Date 07AUG	
ผู้ส่งมอบสินค้า: ศูนย์บริการโลหิตแห่งชาติ สภากาชาดไทย กรุงเทพฯ โทร. 02-251-3111, 02-2524106-9, ต่อ 1004 (ห้องพัสดุ), ต่อ 1000, โทร. 0-4324 6807		ผู้รับมอบสินค้า: สำนักงานควบคุมการจราจรทางอากาศ ขอนแก่น โทร. 0-4324 6807					
ลงชื่อผู้ส่ง:  Signature of Shipper		ลงชื่อผู้รับ: _____ by Agent					
จำนวนชิ้น No. of Piece	น้ำหนักสุทธิ Actual Gross Weight Kg.	ชั้นของอัตรา Rate Class	น้ำหนักที่คิด Chargeable Weight	อัตราค่าระวาง Rate Charge	เงินสด Cash	เงินเชื่อ Credit	ชนิดของสินค้าและพัสดุภัณฑ์ Nature of Goods
1	17.7	PER SVC	0.0	0.00	X		
มูลค่าประกันภัย Amount of Insurance		ราคาประเมินเพื่อการขนส่ง Declared Value for Carriage		ค่าธรรมเนียม Valuation Charge		BLOOD	
ค่าธรรมเนียมปลายทาง Terminal Charge		ค่าพาหนะ Carriage Charge		ค่าธรรมเนียม Valuation Charge		ลงชื่อเจ้าหน้าที่บริษัทฯ หรือตัวแทน Signature of Issuing Carrier or its Agent NJ	
ค่าใช้จ่ายอื่น Other Charges						วัน เดือน ปี Executed on (Date) 07AUG10 /1248	
หมายเหตุ Remark		FLIGHT-45 AIRPORT		จำนวนเงิน (บาท) Total (Baht) 0		217- 7288 7780	

สำหรับผู้ส่ง ORIGINAL 3 (FOR SHIPPER)

Figure 4.18 Domestic air waybill

Having checked the information, the driver or the staff that comes with the blood box will sign on the Domestic Air Waybill. The staff will then inform the NBC about the flight. Officers at the NBC will fax the information to the RBCs or hospitals to prepare for picking-up the blood boxes at the destination airport.

Figure 4.19 shows the flow of the operation of current blood distribution from the NBC.

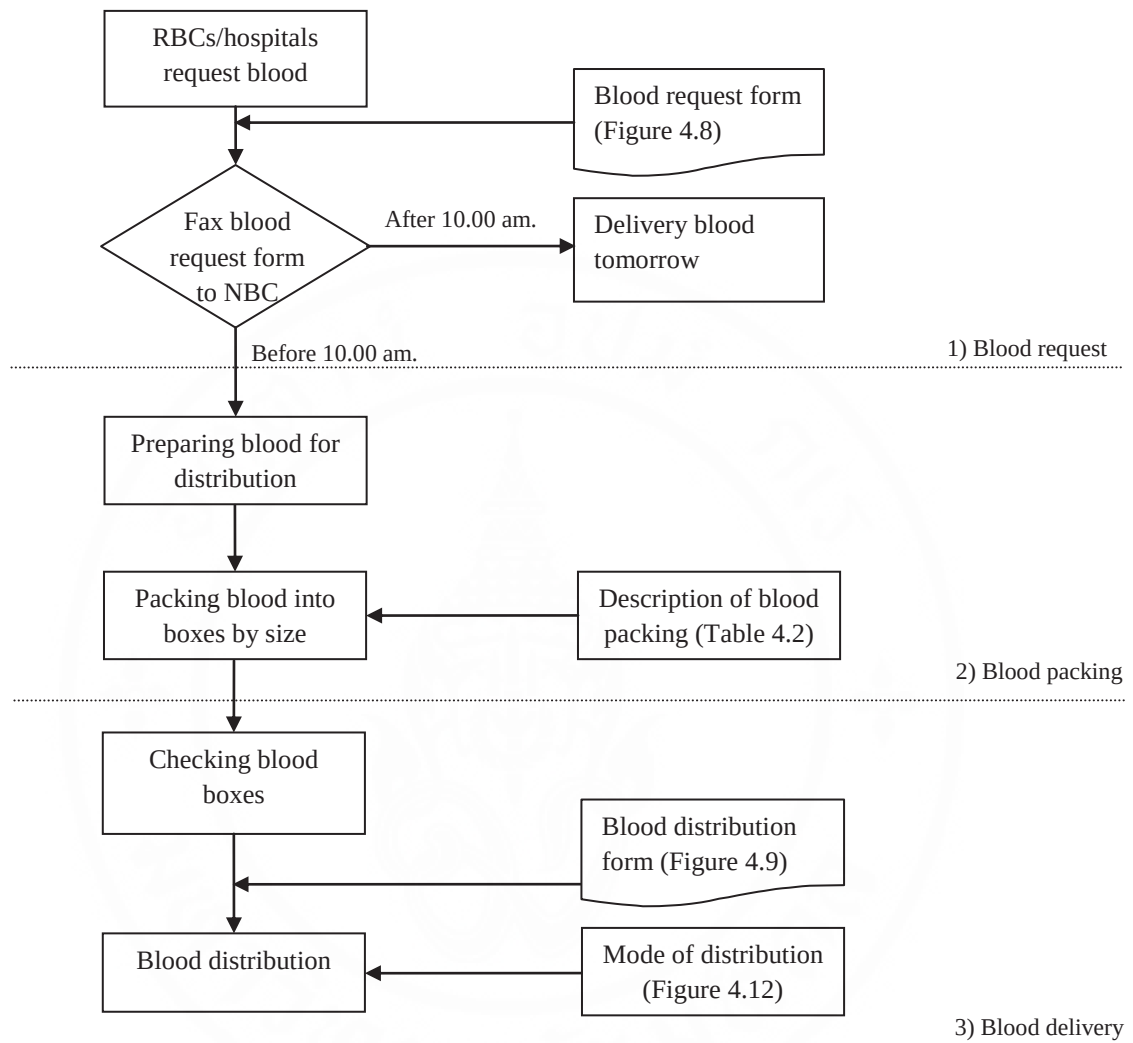


Figure 4.19 Summary of the operation of current regional blood distribution

4.4 Transportation distance

In this research, transportation distance is important in two regards. It is used for estimating cost of blood transportation and for calculating the parameters in the mathematical models. This section will present details regarding distance estimation. For example, NBC's van mode comprises two types of costs; namely, fixed cost and variable cost. The variable cost of this mode varies by distance. Similarly, the costs of other modes also vary according to transportation distance. Distance for transporting blood can be divided into two types. The first one is the land (or highway) distance, which refers to the distance for transportation by NBC's van

mode, public bus mode, and public carrier mode. The second type is the flight distance, which refers to the distance by air transportation or airplane mode.

4.4.1 Land distance

This research uses Arc Map 9.3 to calculate for land distances. The basic shapefile is made available from the Transport Fundamental Geographic Data Set (TFGDS) (Ministry of transport, 2007). This dataset was last updated in March 2007. The results from the calculation are the shortest distances from all nodes to all nodes. All nodes mean NBC, RBCs and hospitals that are located mostly in Muang districts. However, the calculated routes from the software might be inappropriate to be used in real practice because the shortest distance isn't always the route the driver takes. Therefore, data from the distance chart among provinces (Department of Highways, 2011) was used additionally in order to check the accuracy and validity of the routes. For the distance matrix calculation, this research divides the solutions into two cases

First, it is the case of places which their locations are available in the Landmark shapefile. This shapefile data was provided by the Department of Highways. It contains information of important places such as hospitals, schools, police stations, post offices, government offices, etc. Most of the interested distances between places of interest are distances between all nodes to all nodes. According to the current locations of RBCs, most of them are in the Muang district because large volume of blood is distributed to hospital centers. Arc Map 9.3 was therefore used to calculate for distances along the road network from all Muang districts to all Muang districts (see detail in Appendices B and C). The coordinates of Muang districts were obtained from the Landmark dataset. The distance matrix was then derived.

Second, it is for the case of places without previous existing coordinates. The Landmark shapefile does not contain all places of interest in this research. Such places of the latter case include all RBCs, bus terminal, etc. The coordinates of these places thus have to be input manually. Google Earth, which is an online GIS application, was used to mark the locations of these places. After obtaining locations of the places, which include all RBCs and bus terminals in all provinces, the data from Google Earth was converted to Shapefile format by using DNR Garmin software. The shapefiles were then ready for the analysis using ArcMap 9.3. The procedure of converting coordinate information using DNR Garmin is shown in Figure 4.20. The

specified projection as selected in the Datums/Projections option is Indian_1975_UTM_Zone_47N (Figure 4.21).

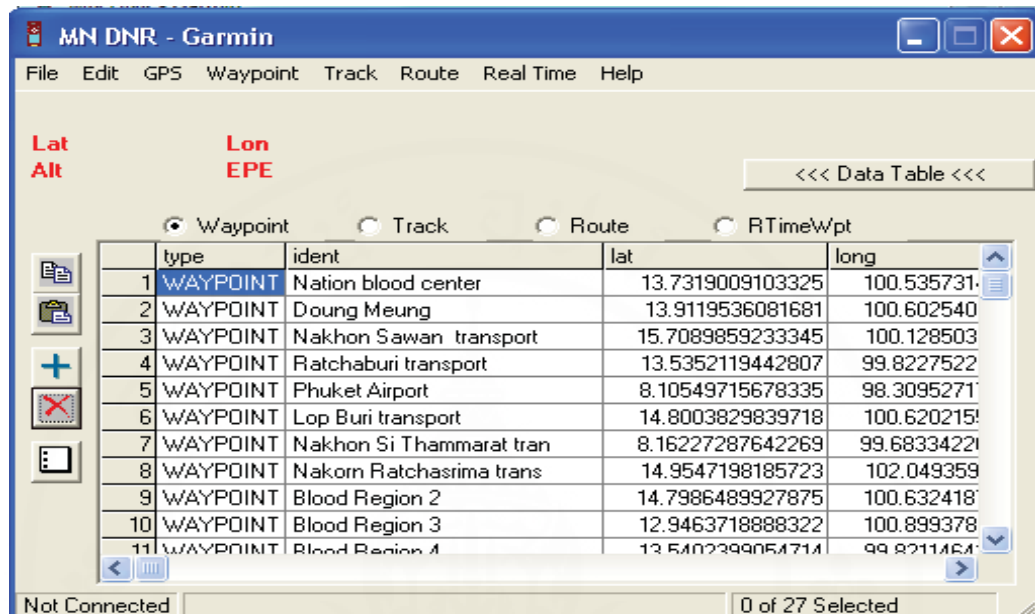


Figure 4.20 The procedure for changing data format by DNR Garmin

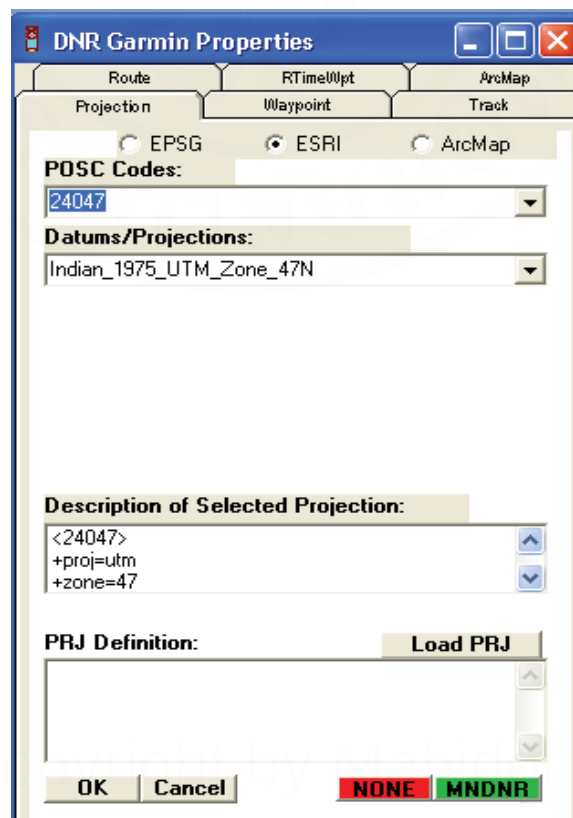


Figure 4.21 The procedure for selecting the map projection

The converted shapefile data were then used to calculate for the distance matrix with Arc Map 9.3 as explained in Appendix B. Table 4.3 shows the example of resulting distance matrix between all origins to all destinations. This distance is an important input for calculating the current distribution cost in Section 4.7.

Table 4.3 An example of distance matrix from all origin Muang districts to all destination Muang districts (km.)

Node	01	02	03	.	.	.	74	75	76
01	0	748	152	.	.	.	514	266	601
02	749	0	769	.	.	.	1,273	1,025	1,360
03	150	769	0	.	.	.	495	199	728
04	534	1,288	659	.	.	.	502	499	225
05	396	1,150	321	.	.	.	185	146	692
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
73	567	1,321	693	.	.	.	383	473	382
74	521	1,274	495	.	.	.	0	285	692
75	272	1,026	200	.	.	.	285	0	627
76	598	1,352	723	.	.	.	692	621	0

4.4.2 Flight distance

In this research, flight distance is used only to calculate transportation costs for airplane mode. Arc Map 9.3 is capable to measure distance only in the road network, not the air transportation network. There are ten destination provinces that are found in this research to use airplane mode for blood transportation; namely, Khonkaen (KKC), Chiangrai (CEI), Chiangmai (CNX), Phuket (HKT), Had Yai (HDY), Suratthani (URT), Udonthani (UTH), Nakhonsithammarat (NST), Phitsanulok (PHS) and Ubonratchathani (UBP). The flight distance data is obtained from the Department of Civil Aviation (Appendix D). The NBC uses the services of Thai Airways International Public Company Limited and Nok Air Company Limited for transporting blood to these destination provinces. Data on flight distance are shown in Table 4.4

Table 4.4 Flight distance from the origin to the destination airport

Origin airport	Destination airport	Flight distance (km.)
Suvarnabhumi	Khonkaen	387
Suvarnabhumi	Chiang Rai	678
Suvarnabhumi	Chiang Mai	566
Suvarnabhumi	Phuket	696
Suvarnabhumi	Had Yai	770
Suvarnabhumi	Suratthani	552
Suvarnabhumi	Udonthani	457
Don Muang	Nakhonsithammarat	607
Don Muang	Phitsanuklok	332
Don Muang	Ubonratchathani	483
Chiang Mai	Phuket	1,263
Chiang Mai	Udonthani	461

4.5 Quantity of blood delivery

The temperature required for storing each blood component is different. Blood demands of each province are also different. Therefore, there are three sizes of blood boxes for blood delivery; namely, small size (S), medium size (M), and large size (L). This research categorized data collection according to blood types, which are divided into four component; namely, Cryoprecipitate (Cryo), Fresh Frozen Plasma (FFP), Packed Red Cell (PRC) and Platelet. Data in Table 4.5 include details regarding types and quantity of blood boxes that are transported from the NBC to the destination RBCs and hospitals. The table shows the number of blood boxes by components that are sent to 21 provinces. The NBC sent a total of 255 blood boxes to destination RBCs and hospitals, which is equivalent to an average of 43 boxes/day. It is also noticeable that blood boxes are delivered on Tuesday more than any other days. Regarding provinces that require blood, these provinces can be categorized into two groups according to delivered blood quantity. The first group comprises provinces that require blood at large amount, and these are provinces where RBCs are located. The second group comprises provinces with low quantity of blood demand, generally they are hospitals. The data regarding number of blood boxes in Table 4.5 will be used for estimating transportation cost for the public bus mode and the airplane mode, as explained in Section 4.7.

Table 4.5 Quantity of blood boxes delivered during six days

No	Provinces	Type\ Size	10/08/10			14/08/10			19/08/10			20/08/10			24/08/10			28/08/10			Total blood (boxes)	
			S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	Type	Province
1	Lopburi	Cryo	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	23
		FFP	0	0	0	0	0	2	0	0	2	0	0	0	0	0	3	0	0	0	7	
		PRC	0	0	1	0	0	2	0	0	1	0	0	1	0	0	1	0	0	2	8	
		Platelet	1	0	0	1	0	0	1	0	0	2	0	0	1	0	0	0	1	0	7	
2	Chonburi	Cryo	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12
		FFP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
		PRC	0	0	1	1	0	0	0	1	0	0	0	1	0	1	0	1	0	1	7	
		Platelet	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	0	0	0	5	
3	Ratchaburi	Cryo	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	22
		FFP	0	1	0	0	0	0	0	0	1	0	0	0	0	0	2	0	0	2	6	
		PRC	0	0	1	0	2	0	0	0	1	0	0	1	0	0	1	2	0	1	9	
		Platelet	2	0	0	0	0	0	1	0	0	0	1	0	1	0	0	0	0	0	5	
4	Nakhonratchasima	Cryo	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14
		FFP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
		PRC	0	1	1	0	0	3	0	0	2	0	1	1	0	0	2	0	0	1	12	
		Platelet	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2	
5	Nakhonsawan	Cryo	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10
		FFP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
		PRC	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	1	0	1	7	
		Platelet	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	3	
6	Chaiyaphum	Cryo	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
		FFP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
		PRC	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	3	
		Platelet	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	

Table 4.5 Quantity of blood boxes delivered during six days (Cont.)

No	Provinces	Type\ Size	10/08/10			14/08/10			19/08/10			20/08/10			24/08/10			28/08/10			Total blood (boxes)	
			S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	Type	Province
13	Chiang Mai	Cryo	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	42
		FFP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	
		PRC	2	1	1	1	1	3	1	0	2	1	0	1	0	0	2	4	0	0	20	
		Platelet	4	1	0	3	0	0	2	1	0	2	1	0	3	0	0	1	2	0	20	
14	Songkhla	Cryo	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	2	15
		FFP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
		PRC	0	0	1	0	0	0	0	1	0	0	0	1	2	0	0	0	0	3	8	
		Platelet	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	0	0	0	5	
15	Phuket	Cryo	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
		FFP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
		PRC	1	0	0	1	0	0	1	0	0	0	0	0	0	1	0	0	0	0	4	
		Platelet	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
16	Udonthani	Cryo	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	27
		FFP	0	0	0	0	1	0	0	0	0	0	0	2	0	0	0	0	1	0	4	
		PRC	3	3	0	2	1	1	1	0	0	3	2	1	1	0	1	0	0	1	20	
		Platelet	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0	0	3	
17	Chiang Rai	Cryo	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14
		FFP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
		PRC	0	1	0	0	1	0	1	0	0	0	0	0	1	1	0	0	2	0	7	
		Platelet	2	0	0	1	0	0	1	0	0	0	0	0	2	0	0	1	0	0	7	
18	Suratthani	Cryo	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9
		FFP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	
		PRC	1	0	0	1	0	0	1	0	0	0	0	0	0	1	0	1	0	0	5	
		Platelet	1	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	3	

Table 4.5 Quantity of blood boxes delivered during six days (Cont.)

No	Provinces	Type\ Size	10/08/10			14/08/10			19/08/10			20/08/10			24/08/10			28/08/10			Total blood (boxes)	
			S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	Type	Province
19	Ubonratchathani	Cryo	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
		FFP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
		PRC	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	1	0	1	5
		Platelet	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2
20	Phitsanulok	Cryo	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11
		FFP	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	2	
		PRC	0	0	1	1	0	0	0	1	1	0	0	1	0	0	1	0	1	0	0	7
		Platelet	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	
21	Nakhonsitham-marat	Cryo	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	16
		FFP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	
		PRC	0	0	1	0	0	2	0	0	1	0	0	1	0	0	1	1	0	0	1	8
		Platelet	2	0	0	1	0	0	0	1	0	0	0	1	0	1	0	0	0	0	6	
Total blood by size (boxes)		26	12	10	19	6	17	18	8	16	17	9	14	17	7	21	16	6	16	255		255
Total blood by day (boxes)		48			42			42			40			45			38					

Blood quantity that NBC delivered to destination provinces, as shown in Table 4.5, has a unit of boxes/province. However, in order to calculate for blood transportation cost in Section 4.7, it is required that the unit must be in Baht/km./unit so that the values can be replaced as parameters in the mathematical model of Cases 1, 2, 3 and 4 (details of each parameter will be discussed in Chapter 5). The data in Table 4.6 are the weight average of blood boxes on six-day observation. The 20 hospitals and three RBCs are the example weight blood box in each size. It can be averaged 2.88, 5.50 and 10.37 kg. in the small, medium and large box, respectively. Thus, in this research are approximately 3, 5 and 10 kg. from each blood size. In the bottom of the table shows the quantity of blood bag that can be stored in each size of blood boxes. There are the Cryoprecipitate, Fresh Frozen Plasma, Packed Red Cell and platelet. Overall, different blood types are not much different regarding packing capacity, except only Cryoprecipitate (Cryo). Cryo is apparently different from other blood types because it is packed at only two quantities; namely, 100 units and 50 units. The data as shown in Table 4.7 present average blood quantity in blood bags delivered to each destination province, where the unit is “(blood) unit”.

Table 4.6 Quantity and weight of blood by product type and size of blood box

Data from observation		Example of blood box weight by destination hospitals																				Destination RBCs		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20			
10/	S	1.2	2.4	2.4	-	-	-	-	2.8	-	-	-	-	-	-	-	-	-	-	-	-	7	9	11
08/	M	-	-	-	-	-	-	-	-	6.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	L	-	-	-	9.0	9.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11.6	-	-	-
14/	S	-	-	-	-	-	-	-	-	1.2	3.6	2.0	3.0	-	4.0	2.2	-	-	-	-	2.0	2.4	-	-
08/	M	-	-	-	-	-	-	-	-	4.5	-	-	-	7.0	-	-	-	-	-	-	-	-	-	-
10	L	10.0	-	8.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19/	S	-	4.0	-	-	-	-	-	3.0	3.0	2.6	-	3.2	-	-	-	3.8	-	-	-	-	-	-	-
08/	M	-	-	-	-	-	-	-	-	-	-	4.0	6.0	-	-	-	-	-	-	-	-	-	-	7.0
10	L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12.0
20/	S	-	-	-	-	-	4.6	-	-	3.4	3.2	4.2	-	-	-	2.4	3.0	-	-	-	-	-	-	-
08/	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.0	-	-	7.0	-	-	-	-	-
10	L	-	-	9.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9.4	10.4	-	-	18.0	-
24/	S	-	-	-	-	-	-	-	-	-	2.0	-	-	-	4.0	-	1.8	-	-	-	-	-	-	-
08/	M	-	-	-	-	-	-	-	-	5.8	-	-	-	-	-	-	-	-	-	4.4	-	-	-	-
10	L	8.0	-	-	16.2	-	-	9.4	8.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
28/	S	-	-	-	-	-	-	-	-	-	4.8	-	-	-	-	1.3	-	-	-	-	-	-	-	-
08/	M	-	-	-	-	-	-	-	-	-	-	-	-	-	7.0	-	-	-	-	-	-	4.8	-	-
10	L	9.0	-	-	-	-	-	-	-	8.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Size box	Total weight box (kg.)	Average weight box (kg.)	Quantity of blood bag by blood type (units/box)			Platelet
			Cryoprecipitate (Cryo)	Fresh Frozen Plasma (FFP)	Packed Red Cell (PRC)	
Small (S)	83.50	2.88	N/A*	5	1 - 8	1 - 12
Medium (M)	71.50	5.50	50	14	9 - 16	13 - 24
Large (L)	165.90	10.37	100	25	24 - 32	25 - 40

Note: *Cryoprecipitate (Cryo) doesn't have the small box size. Minimum packing is 50 units.

Table 4.7 Quantity of blood units delivered during six days (Cont.)

[illegible]

Table 4.7 Quantity of blood units delivered during six days (Cont.)

No	Provinces	Type\Size	10/08/10			14/08/10			19/08/10			20/08/10			24/08/10			28/08/10			Total blood units		
			S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	Type	6 days	day
19	Ubonratchathani	Cryo	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	152	30
		FFP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
		PRC	0	0	0	0	0	0	0	0	30	0	0	30	0	0	30	8	0	30	128		
		Platelet	0	0	0	12	0	0	0	0	0	0	12	0	0	0	0	0	0	0	24		
20	Phitsanulok	Cryo	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	212	35
		FFP	0	0	0	0	0	0	0	0	50	0	0	0	0	0	0	0	0	0	50		
		PRC	0	0	30	8	0	0	0	16	30	0	0	30	0	16	0	8	0	0	138		
		Platelet	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24		
21	Nakhonsi thammarat	Cryo	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	100	447	75
		FFP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25	0	0	0	25		
		PRC	0	0	30	0	0	60	0	0	30	0	0	30	0	16	30	0	0	30	226		
		Platelet	24	0	0	12	0	0	0	24	0	0	24	0	12	0	0	0	0	0	96		
Total blood by size (units)		276	266	300	200	94	570	184	144	525	180	168	480	188	112	735	137	118	470	5,147	5,147	931	
Total blood by day (units)		842			864			853			828			1,035			725						

4.6 The details of blood delivery cost analysis

All transportation modes as mentioned above in Figure 4.12 require different approaches for cost estimation. NBC's van mode is estimated by considering fixed cost and variable cost. Public bus mode is estimated by considering the cost for transporting blood boxes, which is varied by transportation distances to the destination province. Airplane mode is estimated by considering weight of blood boxes, price of blood products, and transportation distances. Finally, public carrier mode is estimated by considering the cost that each RBC/hospital hires a public carrier to pick up the blood from the terminal station/airport. This section will explain about cost compositions in each mode that will be used for estimating cost of current blood distribution.

4.6.1 Delivery cost by the NBC's van

This cost estimation method is not only good for applying with NBC's van, but also can be applied for estimating cost of blood's supply within region as well. Cost of van usage of the NBC has to be calculated according to delivery stations. There are currently four stations for transferring blood to be transited. The NBC's van delivered blood to these four stations so that the blood boxes will be transferred to the destinations or next stations by another transportation mode. The four stations are 22 Karakkadakhom circle, Don Muang airport, Mo Chit bus terminal, and Suvarnabhumi airport. Cost calculation will have to be separated for each of these four stations. ArcMap 9.3 application software was used for calculating the distances of blood delivery (Appendix B). The costs are calculated from two parts; namely, fixed cost and variable cost (Department of Highways, 1988).

Costs categorized as fixed costs include motor-vehicle tax, insurance cost, vehicle inspection cost, driver's salary, victim protection act cost, maintenance cost and depreciation. The depreciation is based on the straight-line formular, ie., $(\text{vehicle price} - \text{salvage value}) / \text{lifetime}$. This section assumes that the NBC uses Toyota Commuter and has five year lifetime. The component of fixed cost data is shown in Table 4.8

Table 4.8 Structure of NBC's van fixed cost

Description	Cost		References
	Baht/year	Baht/day	
Motor-vehicle tax	2,000	5.48	Nurakkhe (1998)
Insurance cost	20,000	54.79	
Vehicle inspection cost	500	1.37	Singburi Provincial Land Transportation Office (2009)
Driver's salary	-	215	Department of Labour Protection and Welfare (2010)
Cost of victim protection act	940	2.57	Department of Land Transport (2011)
Maintenance cost	15,400	42.19	
Depreciation *	-	333.15	Toyota (2010), Department of Land Transport (2011)
Total NBC's van fixed cost		654.55	

Note: * Depreciation = (Vehicle price - Salvage value)/ Lifetime = (1,138,000 - 530,000)/5 = 121,600 Baht/year = 333.15 Baht/day

The second component of the transportation cost is the variable cost. It includes fuel cost, cost for tires, cost for brake, cost for battery, and the fees for using the toll way, the expressway, and the motorway. The diesel fuel price is 27.99 Baht/liter in August, 2010. Consumption rate of van is about 10.50 km./liter. Cost for each composition of this variable cost is presented in Table 4.9.

Table 4.9 Structure of variable cost of NBC's van

Description	Price	Unit	References
Tire cost	1.32	Baht/km.	Department of Land Transport (2011)
Oil cost	0.70	Baht/km.	
Brake cost	0.30	Baht/km.	
Battery cost	0.23	Baht/km.	
Diesel fuel cost	27.99	Baht/liter	Petroleum Authority of Thailand (2010)
Consumption rate	10.50	km./liter	Nurakkhe (1998)
Expressway fee	45	Baht/trip	-
Toll fee	60	Baht/trip	-
Motorway fee	25	Baht/trip	-

4.6.2 Delivery cost by public bus

The NBC delivers blood to several bus service companies at Mo Chit bus terminal. Cost assessment of blood transportation by the public bus based on the data collection during the period of six days in August 2010, is calculated by the size and number of blood boxes. Among 21 provinces that used land transportation for blood delivery, 11 provinces were found to transport blood by buses, which include Buriram, Chaiyaphum, Chonburi, Lopburi, Maehongson, Nakhonratchasima, Nakhonsawan, Nongkhai, Prachuapkhirikhan, Ratchaburi, and Sakonnakhon. Chonburi and Ratchaburi used van transit for blood transportation, but the costs were similar to the transportation by buses. Therefore, their costs were also considered as the cost of transportation by buses. Usually, small blood boxes are delivered directly to hospitals, which order only a few units of blood. Meanwhile large blood boxes are delivered to RBCs in order to store them for hospitals in their respective areas. The cost of blood boxes transported to certain provinces is presented in Table 4.10.

Table 4.10 Component of delivery cost by public bus to various destination provinces

Destination province	Component of delivery cost by public bus (Baht/box)		
	Small box (B_S)	Medium box (B_M)	Large box (B_L)
Buriram	200	250	300
Chaiyaphum	60	80	100
Chonburi	120	140	160
Lopburi	60	60	70
Mae Hong Son	250	250	250
Nakhonratchasima	60	60	60
Nakhonsawan	150	150	200
Nongkhai	200	250	300
Prachuap Khirikhan	150	150	150
Ratchaburi	60	60	60
Sakonnakhon	200	250	300

4.6.3 Delivery cost by airplane

Currently, blood costs data by air are exempted by two airline companies; namely, Thai Airways International Public Company Limited and Nok Airlines Company Limited. Therefore, the NBC always prefers to use air service for delivering blood rather than land services, especially for RBCs locating very far from the NBC. Besides having no transportation charge, air transportation is advantageous in speed and temperature control. For the cost calculation, however, this research also estimates air transportation cost because it is possible that the exemption from these two companies can be discontinued in the future. Details of data cost for airplane mode are separated for each of the two airlines.

1) Delivery cost by Thai Airways International Public Company Limited (THAI)

The NBC uses transportation service of Thai Airways when it wants to deliver blood boxes to the airports of Khonkaen, Chiangrai (and Phayao), Chiang Mai, Phuket (and Phang-nga), Songkhla, Suratthani, and Udonthani (and Nongbualampoo) Provinces. Thai Airways has two systems to calculate the transportation charge. The first is to calculate by weight whereas the second is to calculate by volume of the item. Costs calculated from these two systems are compared and the higher cost will be chosen. This is because sometimes small-size items are very heavy, and some light items are too large. Therefore, the company employs these two systems of calculation. However, for this research, the air transportation cost was calculated by weight only. This is because when comparing among the two systems, calculating by weight is more expensive than by volume. This research estimated the weight of blood boxes according to the number and weight of boxes. Table 4.11 shows component cost by Thai Airways International Public Company Limited. There are three parts; namely, other charge (fee for delivery charged per each destination airport), terminal charge and rate charge. The value depends on the distances and weight of blood units at each destination airport.

Table 4.11 Component cost of Thai Airways International Public Company Limited

Destination airport	Other charge (Baht/bill)	Terminal charge (Baht/bill)			Rate charge (Baht/kg.)
		0.10-1.00 (kg.)	1.01-30.00 (kg.)	30.01-100.00 (kg.)	
Khonkaen	20	30	40	50	13
Chiang Rai	20	30	40	50	22
Chiang Mai	20	30	40	50	18
Phuket	20	30	40	50	22
Had Yai	20	30	40	50	24
Suratthani	20	30	40	50	20
Udonthani	20	30	40	50	16

2) Delivery cost by Nok Airlines Company Limited (NOK)

Nok Airlines Company Limited provides transportation service for the NBC by delivering blood to airports in three provinces; namely, Nakhonsithammaratch, Phitsanulok, and Ubonratchathani. Data cost has three parts, i.e., other charge, terminal charge, and rate charge. Rate charge is divided into two parts. The first part is the minimum charge whereas the second part is variable charge by weight at destination provinces. The cost details are present in Table 4.12

Table 4.12 Component cost of Nok Airlines Company Limited

Destination airport	Other charge (Baht/bill)	Terminal charge (Baht/bill)	Weight (kg.)	Minimum charge (Baht)	Weight (kg.)	Charge (Baht/kg.)
Nakhonsithammarat	20	40	0.01-5	150	6-20	20
Phitsanulok	20	40	0.01-8	150	9-12	12
Ubonratchathani	20	40	0.01-6	150	7-14	16

4.6.4 Delivery cost by public carrier

Blood boxes sent from the NBC, transported either by buses or by airplanes, arrive at the bus terminals or destination airports and wait for being transported to RBCs or hospitals. RBCs and hospitals use various forms of transportation to pick up the blood boxes. They may send their own vehicles or hire a public carrier to pick-up the blood for them. Cost calculation varies by RBCs. For example, RBC 9 (Phitsanulok) hires a public carrier monthly, whereas RBCs 5, 6, 8 and 11 hire public carriers by trip. RBC 7 calculates the cost for transportation by considering number of boxes. Meanwhile, RBC 10, 12 sends its own vehicle to pick up the blood. Table 4.13 shows cost data of public carrier at the destination station/airport.

Table 4.13 Cost data of public carrier at the destination station/airport

Regional Blood Centers/hospitals	Type of carrier mode	Delivery cost (Baht/trip)
Regional Blood Center 5	Hired by trip	40
Regional Blood Center 6	Hired by trip	70
Regional Blood Center 7	Considering number of boxes	40
Regional Blood Center 8	Hired by trip	100
Regional Blood Center 9	Hired by monthly (4,000 Baht/month)	133
Regional Blood Center 10	Own vehicle to pick up the blood	74
Regional Blood Center 11	Hired by trip	600
Regional Blood Center 12	Own vehicle to pick up the blood	75
Udonthani hospital	Own vehicle to pick up the blood	48

4.7 Estimating the current blood distribution cost

This section is about using all collected data and derived information for analyzing the current blood distribution cost to regional areas. Currently, blood distribution from the NBC to RBCs comprises various modes of transportation including vans, airplanes, buses, public carriers, etc. The results thus show the transportation cost by mode. The resulting current blood distribution cost will be used as the parameters in mathematical models in Chapter 5

4.7.1 Transportation cost by the NBC's van

The NBC's van cost is divided into two parts, fixed and variable costs. The cost data are from Tables 4.8 and 4.9 respectively. Most of the variable costs depend on travel distance. According to the data collection, the routes used for daily blood delivery are not always the same depending mainly on the destinations. Transportation routes for Monday - Friday and for Saturday – Sunday are quite different.

On Monday through Friday, there are two routes. The first route starts out at the NBC, runs to 22 Karakkadakhom circle, Don Muang airport and Mo Chit bus terminal. The second route starts out at the NBC and runs to Suvarnabhumi airport.

On Saturday and Sunday, there are also two routes. The first route starts at the NBC, stops to deliver at Suvarnabhumi airport and then goes to Don Muang airport. The second route starts at the NBC to 22 Karakkadakhom circle and Mo Chit bus terminal.

This research estimates variable costs by considering the routes of Monday – Friday because the amount of work during these days is far greater than in Saturday and Sunday. The travel distance can be calculated by plotting the origin point (the NBC) and destination point (22 Karakkadakhom circle, Don Muang airport, Mo Chit bus terminal and Suvarnabhumi airport) and use Google earth program, then recheck again with mileage of the NBC's van. This is a round trip. Therefore, according to the collected data, the routes for transporting blood from the NBC to the four stations can be summarized as follow;

1) To 22 Karakkadakhom circle, the van driver takes Rama IV road from the NBC (A), enters 22 Karakkadakhom circle, and stops at Soi Panjit (B). Figure 4.22 shows routing from the NBC to 22 Karakkadakhom circle. The total travel distance is 7.12 kilometer/round trip.

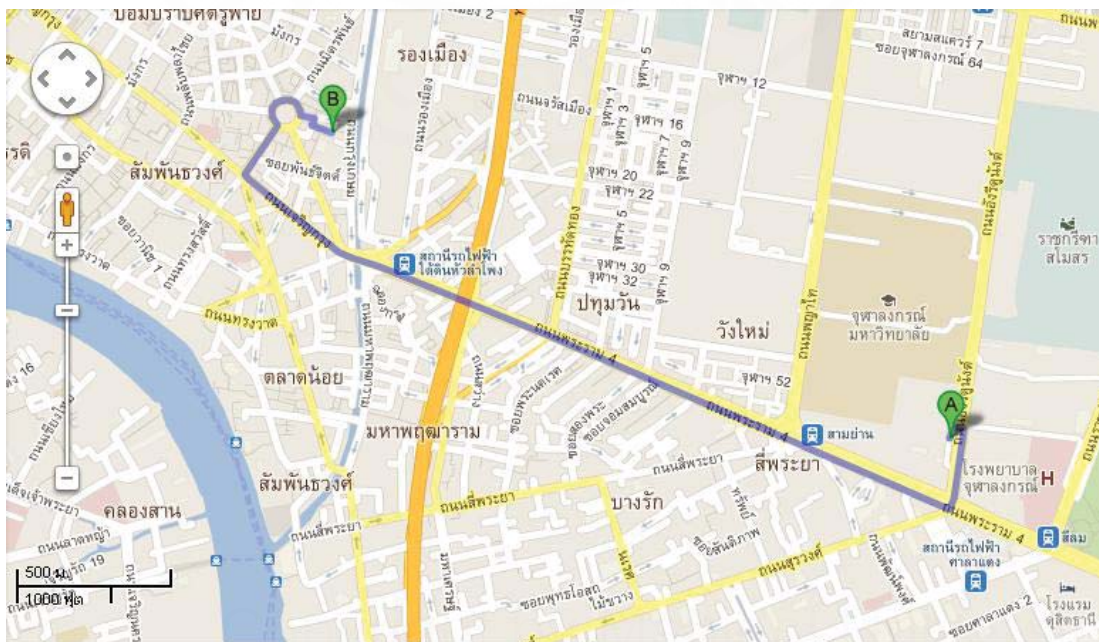


Figure 4.22 Routing between the NBC to the 22 Karakkadakhom circle

2) To Don Muang airport, the van driver takes Rama IV road from the NBC (A), enters the Expressway at Bon Kai toll plaza, then enters the Don Muang Tollway at the Dindaeng toll plaza, and arrives at Don Muang airport (B). Figure 4.23 shows routing between the NBC to Don Muang airport. The total travel distance is 49.26 kilometer/round trip

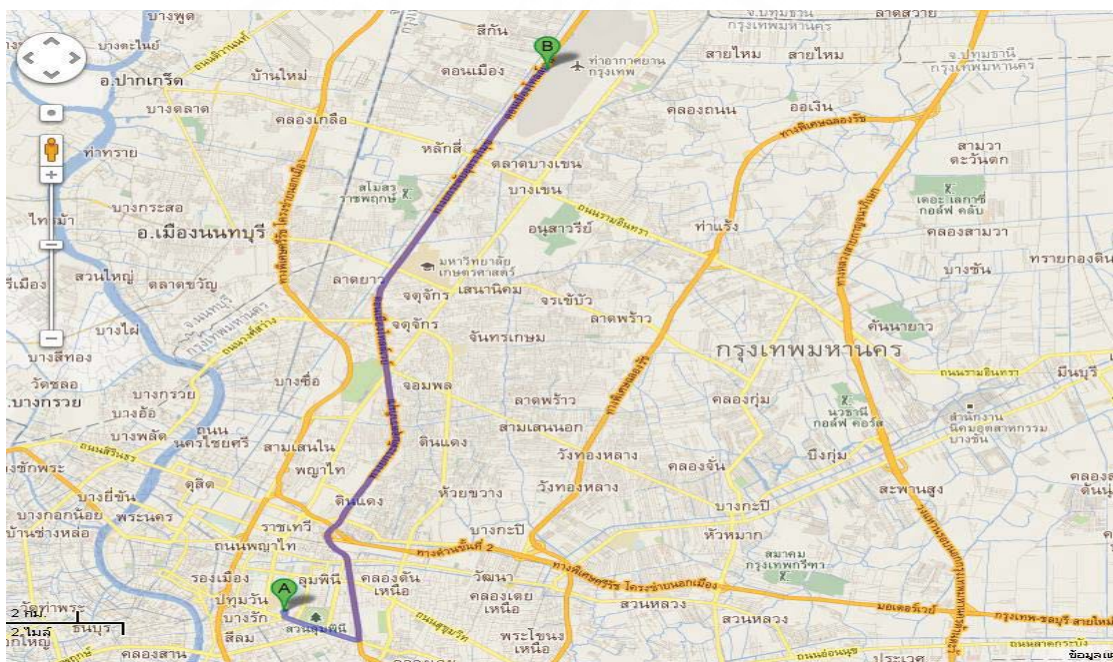


Figure 4.23 Routing between the NBC to Don Muang airport

3) To Mo Chit bus terminal, the van driver takes Rama IV road from the NBC (A), enters the Expressway at Bon Kai toll plaza, leaves the expressway at the Bang Sue exit, and arrives at Mo Chit bus terminal (B). Figure 4.24 shows routing between the NBC and Don Muang airport. The total travel distance is 36.02 kilometer/round trip.

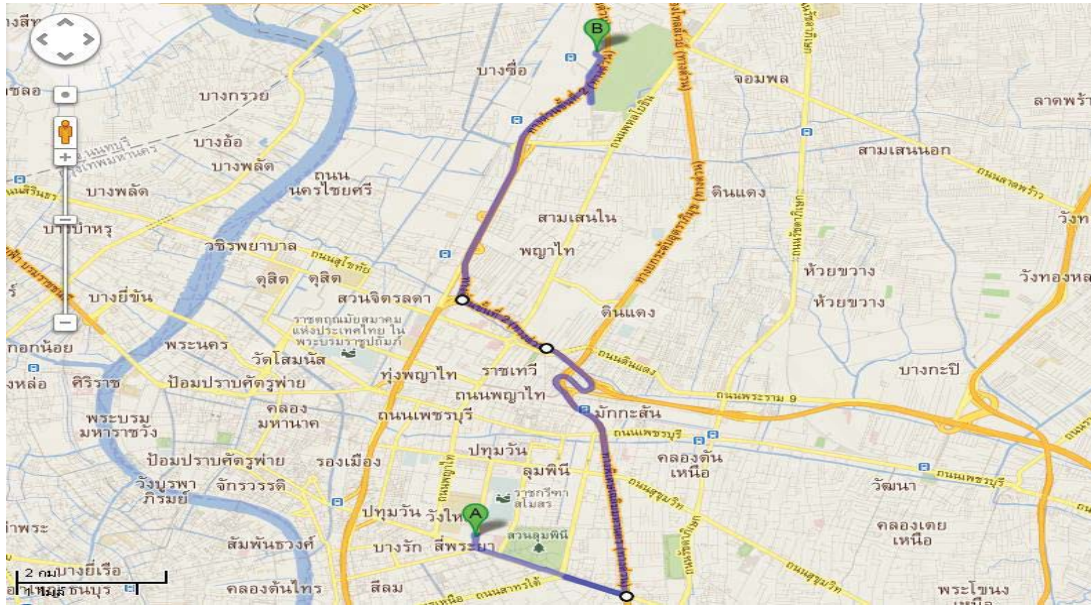


Figure 4.24 Routing between the NBC to Mo Chit bus terminal

4) To Suvarnabhumi airport, the van driver takes Rama IV road from the NBC (A), enters the expressway at Bon Kai toll plaza, enters the motorway at Srinakarin toll plaza, and arrives at Suvarnabhumi airport (B). Figure 4.25 shows routing between the NBC to Suvarnabhumi airport. The total travel distance is 59.86 kilometer/round trip.

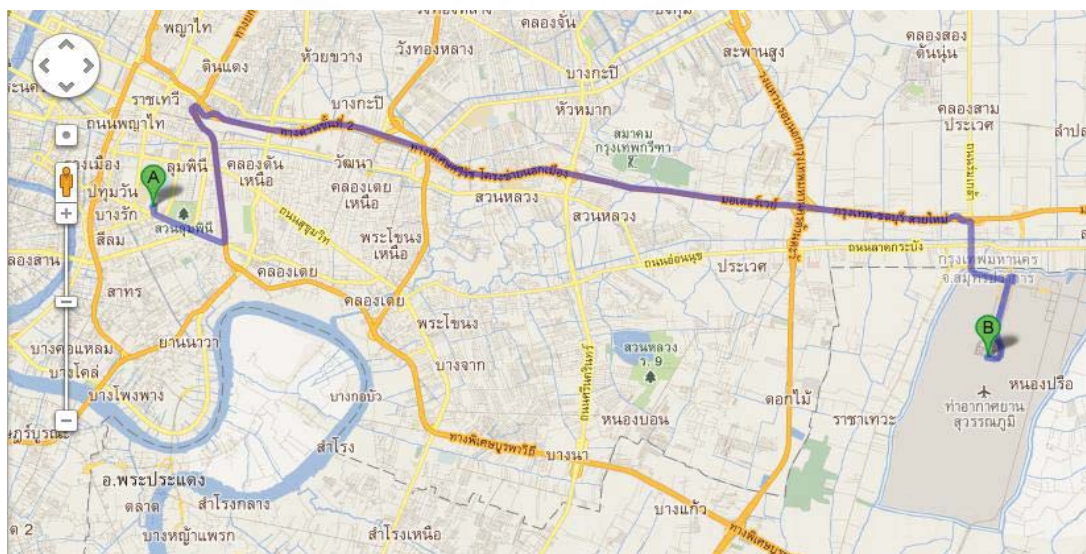


Figure 4.25 Routing between the NBC to Suvarnabhumi airport

Cost calculation for the total variable cost can be calculated from the below formula.

$$\begin{aligned} \text{Total variable cost} = & ((\text{tire cost} + \text{oil cost} + \text{break cost} + \text{battery cost} \\ & + (\text{diesel fuel cost} / \text{consumption rate})) \times \text{distance}) + \\ & \text{expressway fee} + \text{toll fee} + \text{motorway fee} \end{aligned}$$

So, the total variable cost of blood transportation from the NBC to the 22 Karakkadakhom circle is equal to;

$$\begin{aligned} \text{Total variable cost} = & ((1.32 + 0.70 + 0.30 + 0.23 + (27.99/10.50)) \times 7.12) + \\ & + 0 + 0 + 0) \\ = & 37.14 \text{ Baht/round trip} \end{aligned}$$

The total variable cost of blood transportation from the NBC to Don Muang airport is equal to;

$$\begin{aligned} \text{Total variable cost} = & ((1.32 + 0.70 + 0.30 + 0.23 + (27.99/10.50)) \times 49.26) \\ & + (45 + 45) + (60 + 60) + 0) \\ = & 466.93 \text{ Baht/round trip.} \end{aligned}$$

The total variable cost of blood transportation from the NBC to Mo Chit bus terminal is equal to;

$$\begin{aligned} \text{Total variable cost} = & ((1.32 + 0.70 + 0.30 + 0.23 + (27.99/10.50)) \times 36.02) \\ & + (45 + 45) + 0 + 0) \\ = & 277.87 \text{ Baht/round trip.} \end{aligned}$$

The total variable cost of blood transportation from the NBC to the Suvarnabhumi airport is equal to;

$$\begin{aligned} \text{Total variable cost} = & ((1.32 + 0.70 + 0.30 + 0.23 + (27.99/10.50)) \times 59.86) \\ & + (45 + 45) + 0 + (25 + 25)) \\ = & 452.21 \text{ Baht/round trip.} \end{aligned}$$

Table 4.14 summarizes the cost components, fixed and variable cost. In addition, travel distance, average blood units and the average unit transportation cost are also given.

Table 4.14 Cost of NBC's van to station and airport

Station/Airport	Cost		Distance (km./round trip)	Blood ¹ (units)	Cost ² (Baht/km./unit)
	Fixed (Baht/day)	Variable (Baht/round trip)			
22 Karakkadakhom	654.55	37.14	7.12	33	2.94
Don Muang airport	654.55	466.93	49.26	141	0.16
Mo Chit bus terminal	654.55	277.87	36.02	392	0.07
Suvarnabhumi airport	654.55	452.21	59.86	365	0.05

Note: ¹ Average from observed data during six days

² Cost/Distance/Unit

According to Table 4.14, the total costs of blood transportation from the NBC to the four stations were 2.94, 0.16, 0.07 and 0.05 Baht/km./unit respectively. The value depends on the distance and volume of blood units distributed through each station.

4.7.2 Transportation cost by public bus

The estimated transportation cost by public bus consists of three parts; namely, weighted average cost, distance and volume of blood. Cost is calculated by two steps of distance. For the distance of 100-300 km, transportation cost varies by distance, starting from 60 Baht up to 200 Baht. For the distance of more than 300 km, the transportation cost is fixed at 250 Baht, regardless of the distance. The first step, we calculate the weighted average cost based on volume of blood box and unit transportation cost (data from Tables 4.5 and 4.10) to destination provinces. Table 4.15 is composed of 12 columns. Column (1) is the destination province. Column (2) is number of delivery days from six-day observation from Table 4.7. Columns (3-8) are the unit transportation cost and quantity of blood boxes from Tables 4.10 and 4.7. Column (9) is the weighted average cost. Column (10) is the travel distance by public bus (data from Section 4.4.1). Column (11) is the number of blood units by trip (data from Table 4.7). The last column is the unit transportation cost by public bus. It is calculated by the weighted average cost per distance per blood unit. For example, cost to Burirum is $(250 / 383.08 / 18) = 0.036$ Baht/km./unit. The result is the average total transportation cost by public bus (and van transit) is 0.03 Bath/km./unit, as shown at the column (12)'s bottom line.

Table 4.15 Total transportation cost by public bus to destination provinces

Destination provinces (1)	Days ¹ (2)	Unit transportation cost (Baht/box) and quantity (boxes) based on six-day observation					Weighted average cost ² (Baht/trip/day) (9)	Distance ³ (km./trip) (10)	Quantity of blood (units/day) (11)	Unit transportation cost (Baht/km./unit) (12)
		B _S (3)	Q _S (4)	B _M (5)	Q _M (6)	B _L (7)	Q _L (8)			
Buriram	3	200	1	250	1	300	1	383.08	18	0.036
Chaiyaphum	3	60	3	80	1	100	0	384.08	15	0.015
Chonburi	6	120	7	140	2	160	3	128.60	33	0.063
Lopburi	6	60	6	60	1	70	16	155.49	102	0.016
Mae Hong Son	4	250	4	250	1	250	0	911.39	14	0.025
Nakhonratchasima	6	60	2	60	2	60	10	257.36	60	0.009
Nakhonsawan	6	150	4	150	0	200	6	282.06	38	0.028
Nongkhai	3	200	4	250	2	300	0	615.91	23	0.031
Prachuap	1	150	1	150	0	150	0	275.86	12	0.045
Ratchaburi	6	60	6	60	5	60	11	107.66	94	0.022
Sakonnakhon	3	200	0	250	3	300	0	642.60	16	0.024
Average transportation cost by public bus										0.029

Note: ¹Number of delivery days from six-day observation²Weighted average cost = $((B_S \times Q_S) + (B_M \times Q_M) + (B_L \times Q_L)) / \text{Days}$ When B_S, B_M, B_L = unit delivery cost by public bus of small, medium and large boxes, respectively, (Baht/box)Q_S, Q_M, Q_L = quantity of blood, boxes; ie., small, medium and large, respectively, (box)³Distance from the NBC to the destination provinces estimated by using Arc Map 9.3 (Appendix B)

4.7.3 Transportation cost by airplane

The estimated cost consists of three steps. The first step, we calculate the daily average weight of blood boxes carried by the two airlines by using the weighted average method. The second step, we use it to estimate blood delivery cost by each airline. The last step, we estimate the current unit transportation cost by airplane based on the first and second results. To estimate the first step, the data on number of blood boxes from Table 4.5 is used. Table 4.16 shows the results of step one; ie., the average weight of blood per day.

Table 4.16 Weighted average of daily blood transported by airplane

Destination airport	Days ¹	Number of blood boxes and weight based on six-day observation						Weighted average weight ² (kg./day)
		B _S	W _S	B _M	W _M	B _L	W _L	
Khonkaen	5	0	3	1	5	6	10	13.00
Chiang Rai	5	9	3	5	5	0	10	10.40
Chiang Mai	6	24	3	8	5	10	10	35.33
Phuket	4	3	3	1	5	0	10	3.50
Had Yai	6	7	3	1	5	7	10	16.00
Suratthani	6	8	3	1	5	0	10	4.83
Udonthani	6	13	3	8	5	6	10	23.17
Nakhonsithammarat	6	4	3	3	5	9	10	19.50
Phitsanulok	6	4	3	2	5	5	10	12.00
Ubonratchathani	5	3	3	0	5	4	10	9.80

Note: ¹Number of delivery days from six-day observation,

²Weighted average weight = $[(B_S \times W_S) + (B_M \times W_M) + (B_L \times W_L)] / \text{Days}$

When B_S, B_M, B_L = Number of small, medium and large blood boxes, respectively

W_S, W_M, W_L = Weight of blood box by size; ie., small, medium and large, respectively,

In the second step, the weighted average in Table 4.17 is used to estimate blood delivery cost. The figure consists of three parts. They are other charge, terminal charge and rate charge. The two airline companies set the charge differently. Thai Airways International Public Company Limited sets other charge for 20 Baht/bill, variable terminal charge by weight at 30, 40 and 50 Bath/bill for 0.10-1.00 kg., 1.01 – 30.00 kg. and 30.01 – 100.00 kg., respectively and rate charge by weight, as shown in Table 4.11. The value also depends on the distances and weight of blood at each destination airport.

$$\begin{aligned} \text{The delivery cost by Thai Airways International Public Company Limited} \\ \text{Delivery cost} &= \text{Other charge} + \text{Terminal charge} + \\ &\quad (\text{Rate charge} \times \text{weighted average}) \end{aligned}$$

For example, from Suvarnabhumi airport to Khonkaen airport

$$\begin{aligned} \text{Delivery cost} &= (20 + 40 + (13 \times 13.00)) \\ &= 229.00 \text{ Baht/day} \end{aligned}$$

Table 4.17 shows all delivery cost from Suvarnabhumi airport to seven regional airports by Thai Airways International Public Company Limited.

Table 4.17 Estimated transportation cost by Thai Airways International Public Company Limited

Destination airport	Weighted average (kg./day)	Other charge (Baht/day)	Terminal charge (Baht/day)	Rate charge (Baht/kg.)	Delivery cost (Baht/day)
Khonkaen	13.00	20	40	13	229.00
Chiang Rai	10.40	20	40	22	288.80
Chiang Mai	35.33	20	50	18	705.94
Phuket	3.50	20	40	22	137.00
Had Yai	16.00	20	40	24	444.00
Suratthani	4.83	20	40	20	156.60
Udonthani	23.17	20	40	16	430.72

For Nok Airlines Company Limited, the charges are set at 20 Baht/bill for other charge, 40 Baht/bill for terminal charge. Meanwhile, the rate charge is calculated from cost data by Nok Airlines Company Limited in Table 4.12 and weighted average value in Table 4.5. Therefore;

$$\begin{aligned}\text{Delivery cost} &= \text{Other charge} + \text{Terminal charge} + \text{Rate charge} \\ &= \text{Other charge} + \text{Terminal charge} + \text{Minimum charge cost} \\ &\quad + ((\text{Weighted average} - \text{Minimum weight}) \times \text{Range weight})\end{aligned}$$

For example, from Don Muang airport to Nakhonsithammarat airport

$$\begin{aligned}\text{Delivery cost} &= 20 + 40 + 150 + ((19.50 - 5.00) \times 20) \\ &= 500.00 \text{ Baht/day}\end{aligned}$$

from Don Muang airport to Phitsanulok airport:

$$\begin{aligned}\text{Delivery cost} &= 20 + 40 + 150 + ((12.00 - 8.00) \times 12) \\ &= 258.00 \text{ Baht/day}\end{aligned}$$

from Don Muang airport to Ubonratchathani airport:

$$\begin{aligned}\text{Delivery cost} &= 20 + 40 + 150 + ((9.80 - 6.00) \times 16) \\ &= 270.80 \text{ Baht/day}\end{aligned}$$

Table 4.18 shows all delivery cost from Don Muang airport to three regional airports by Nok Airlines Company Limited.

Table 4.18 Estimated transportation cost by Nok Airlines Company Limited

Destination airport	Weighted average (kg./day)	Other charge (Baht/day)	Terminal charge (Baht/day)	Rate charge (Baht)	Delivery cost (Baht/day)
Nakhonsithammarat	19.50	20	40	440.00 ¹	500.00
Phitsanulok	12.00	20	40	198.00 ²	258.00
Ubonratchathani	9.80	20	40	210.80 ³	270.80

Note: ¹Minimum charge is 150 Baht (0.01-5.00 kg.) and the range weight is 20 Baht/kg. (6-20 kg.),

²Minimum charge is 150 Baht (0.01-8.00 kg.) and the range weight is 12 Baht/kg. (9-12 kg.),

³Minimum charge is 150 Baht (0.01-6.00 kg.) and the range weight is 16 Baht/kg. (7-14 kg.).

The total transportation cost by the airplane includes two companies, Thai Airways International Public Company Limited and Nok Airlines Company Limited. It can be calculated from delivery cost (Tables 4.17 and 4.18), flight distance (Table 4.4) and blood units (Table 4.7). After summarization, the total cost for each destination airport was shown in Table 4.19. At the bottom of the Table, it says that on average, the transportation cost by the airplane is 0.02 Baht/km./unit.

Table 4.19 Total air transportation cost by the airplane

Destination airport	Delivery cost (Baht/day)	Flight distance (km.)	Blood units (unit/day)	Total air cost ¹ (Baht/km./unit)
Khonkaen	229.00	387	39.20	0.02
Chiang Rai	288.80	678	36.00	0.01
Chiang Mai	705.94	566	124.83	0.01
Phuket	137.00	696	10.00	0.02
Had Yai	444.00	770	73.67	0.01
Suratthani	156.60	552	14.83	0.02
Udonthani	430.72	457	68.33	0.01
Nakhonsithammarat	500.00	607	74.50	0.01
Phitsanulok	258.00	332	35.33	0.02
Ubonratchathani	270.80	483	30.40	0.02
Average total transportation cost by the airplane				0.02

Note: ¹Total air transportation cost = Delivery cost / Flight distance / Blood units

4.7.4 Transportation cost by public carrier

The cost calculation in this research selected nine destination stations (samples) from a total of 46 combined RBCs and destination hospitals based on six-day observation (population) in order to calculate transportation cost by public carrier service. The cost can be estimated from the delivery cost, distance and blood units. The delivery cost is obtained from Table 4.13. The distance is calculated for round trip distances between station/airport and RBCs/hospitals by using Arc Map 9.3. Blood

unit data is obtained from Table 4.7. After summarization, the total cost of each destination airport was shown in Table 4.20. Therefore, on average, the transportation cost by public carrier is 0.09 Baht/km./unit.

Table 4.20 Cost of blood transportation by public carrier

Regional Blood Center/ Hospitals	Delivery cost (Baht/trip)	Distance (km./trip)	Blood units (unit)	Total public carrier cost (Baht/km./unit)
Regional Blood Center 5	40	6.58	60	0.10
Regional Blood Center 6	70	17.52	40	0.10
Regional Blood Center 7	40	6.24	31	0.21
Regional Blood Center 8	100	10.44	38	0.25
Regional Blood Center 9	133	16.50	36	0.22
Regional Blood Center 10	74	12.82	37	0.16
Regional Blood Center 11	600	133.18	75	0.06
Regional Blood Center 12	75	13.97	74	0.07
Udonthani Hospital	48	7.46	69	0.09
Average total cost				0.09

Figure 4.26 shows the components for estimating transportation cost by mode. The summary of transportation cost by the NBC's van mode are 2.94, 0.16, 0.07, 0.05 Baht/km./unit for 22 Karakkadakhom circle, Don Muang airport, Mo Chit bus terminal, Suvarnabhumi airport, respectively. Meanwhile, transportation cost by public bus, airplane and public carrier are 0.03, 0.02 and 0.09 Baht/km./unit, respectively. The results are used to calculate parameters in Chapter 5.

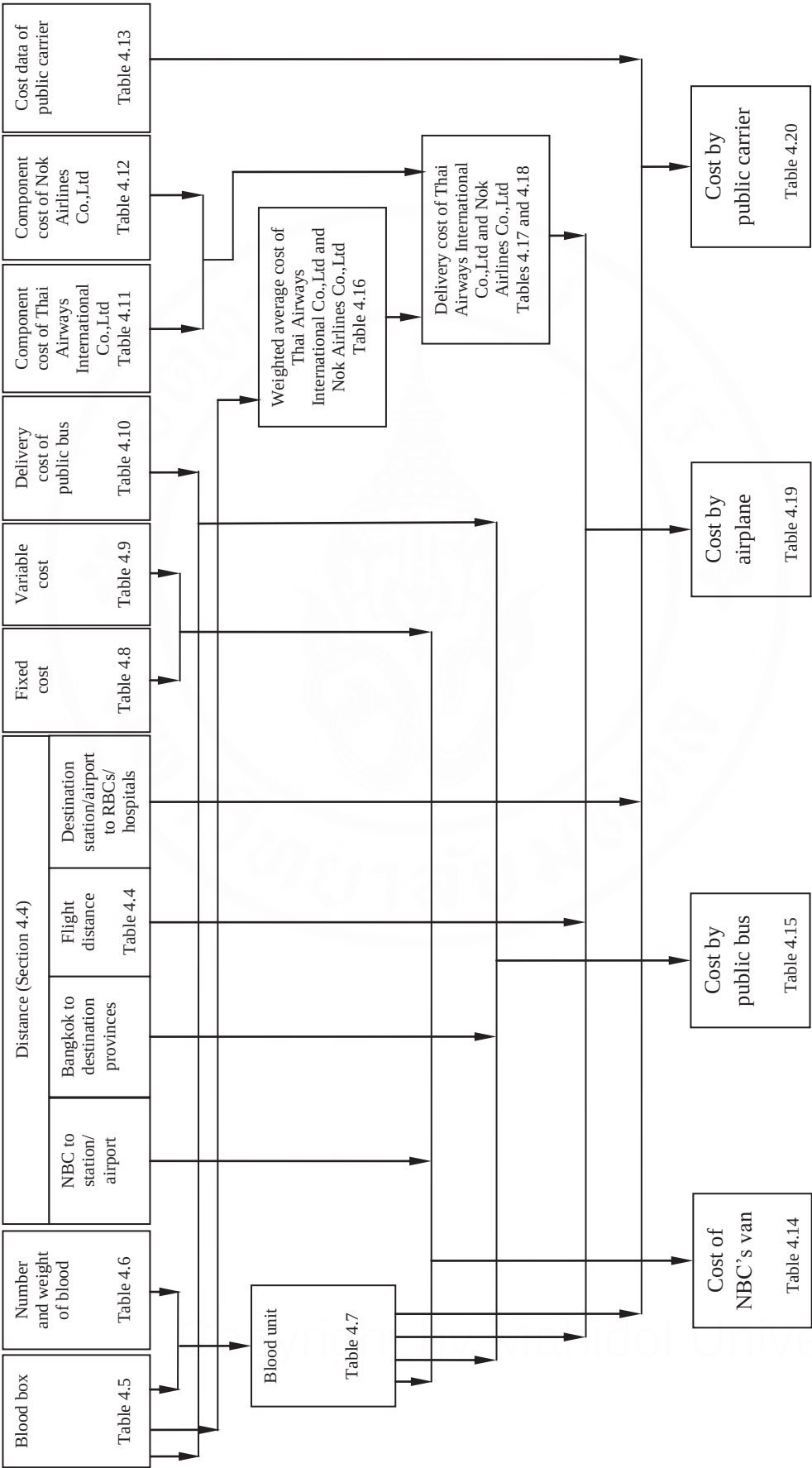


Figure 4.26 Component of transportation cost estimation

4.7.5 The total current blood distribution cost

The blood transportation cost was calculated in previous section. They are the unit in Baht/km./unit. This unit is used as the parameters in mathematical models for cases 1, 2 and 3. The details will be followed in Chapter 5. This section estimated the current blood distribution cost in the unit of Baht/year. This unit is used to consider the total current distribution cost of blood supply chain system in Thailand. The details are explained below.

1) Estimating the current blood distribution cost by NBC's van

Everyday, the NBC's van drops many blood boxes at four stations/airports; namely, 22 Karakkadakhom circle, Don Muang airport, Mo chit bus terminal and Suvarnabhumi airport. The total transportation cost by NBC's van at each station is summarized in Table 4.21. The daily cost is 2,304.57 Baht/day. This cost is estimated the current blood distribution cost by NBC's van.

Table 4.21 Transportation cost by station

Station/Airport	Cost (Baht/day)		Total cost (Baht/day)
	Fixed cost	Variable cost	
22 Karakkadakhom circle (The NBC - 22 Karakkadakhom circle)	654.55	18.57	1,197.80
Don Muang airport (22 Karakkadakhom circle - Don Muang airport)		159.75	
Mo chit bus terminal (Don Muang airport - Mo chit bus terminal - the NBC)		364.93	
Suvarnabhumi airport (The NBC - Suvarnabhumi airport - the NBC)	654.55	452.21	1,106.77
Total cost (Baht/trip/day)	1,309.10	1,234.15	2,304.57

2) Estimating the current blood distribution cost by public bus

The six-day observation data in Tables 4.5 and 4.15 provide the information on the number of blood box by size and unit delivery cost by public bus, respectively. The cost incurred to the NBC is ranging between 1,400 – 2,600 Baht/day. Therefore, the average cost is 1,927 Baht/day. In Table 4.22, the bottom line shows variable costs of 1,910, 1,360, 2,610, 2,130, 2,110 and 1,440 Baht/day.

For example: the cost by public bus on August 10, 2010

$$\begin{aligned}
 &= \sum_{\text{All provinces}} ((\text{Number of small box} \times \text{unit delivery cost of small box}) \\
 &\quad + (\text{Number of medium box} \times \text{unit delivery cost of medium box}) \\
 &\quad + (\text{Number of large box} \times \text{unit delivery cost of large box})) \\
 &= \text{Lopburi } ((1 \times 60) + (0 \times 60) + (1 \times 70)) + \\
 &\quad \text{Chonburi } ((1 \times 120) + (0 \times 140) + (1 \times 160)) + \\
 &\quad \text{Ratchaburi } ((2 \times 60) + (2 \times 60) + (1 \times 60)) + \\
 &\quad \text{Nakhonratchasima } ((0 \times 60) + (1 \times 60) + (1 \times 60)) + \\
 &\quad \text{Nakhonsawan } ((1 \times 150) + (0 \times 150) + (1 \times 200)) + \\
 &\quad \text{Chaiyaphum } ((0 \times 60) + (1 \times 80) + (0 \times 100)) + \\
 &\quad \text{Buriram } ((1 \times 200) + (0 \times 250) + (0 \times 300)) + \\
 &\quad \text{Sakonkakhon } ((0 \times 200) + (0 \times 250) + (0 \times 300)) + \\
 &\quad \text{Nongkhai } ((1 \times 200) + (0 \times 250) + (0 \times 300)) + \\
 &\quad \text{Mae Hong Son } ((0 \times 250) + (1 \times 250) + (0 \times 250)) + \\
 &\quad \text{Prachuapkhiri Khan } ((0 \times 150) + (0 \times 150) + (0 \times 150)) \\
 &= 130 + 280 + 300 + 120 + 350 + 80 + 200 + 0 + 200 + 250 + 0 \\
 &= 1,910 \text{ Baht/day}
 \end{aligned}$$

Table 4.22 Daily blood distribution cost by public bus

Destination Province	Transportation cost by public bus (Baht/day)					
	10/08/10	14/08/10	19/08/10	20/08/10	24/08/10	28/08/10
Lopburi	130	410	270	190	340	200
Chonburi	280	240	260	280	260	280
Ratchaburi	300	120	240	120	240	300
Nakhoratchasima	120	240	180	120	120	60
Nakhonsawan	350	200	200	350	350	350
Chaiyaphum	80	0	60	120	0	0
Buriram	200	0	0	250	300	0
Sakonnakhon	0	0	250	250	250	0
Nongkhai	200	0	650	450	0	0
Mae Hong Son	250	0	500	0	250	250
Prachuap	0	150	0	0	0	0
Total cost	1,910	1,360	2,610	2,130	2,110	1,440

3) Estimating the current blood distribution cost by airplane

Everyday, the NBC delivers many blood boxes to approximately 10 destination airports. Here, we calculate the distribution cost by airplane from two parts. The first is the number of blood box. The second part is the delivery cost by airplane; namely, THAI and NOK. The data is obtained from Tables 4.5 (quantity of blood boxes delivery), 4.11 (component by THAI) and 4.12 (component by NOK), respectively. The results are shown in Table 4.23 for each destination airport. The average air transportation cost is 327.60 Baht/day/airport or 3,276 Baht/day.

For Example: Calculate cost by airplane on August 10, 2010

$$\begin{aligned}
 &= \sum_{\text{All provinces}} (\text{Delivery by THAI} + \text{Delivery by NOK}) \\
 &= \sum_{\text{All provinces}} \text{THAI} (\text{other charge} + \text{terminal charge} + (\text{rate charge} \times \\
 &\quad \times \text{weight box})) + \text{NOK}(\text{other charge} + \text{terminal charge} \\
 &\quad + \text{minimum rate charge} + ((\text{all weight} - \text{minimum rate charge}) \times \\
 &\quad \text{rate charge}))
 \end{aligned}$$

$$\begin{aligned}
&= \text{THAI (Khonkaen (20 + 40 + (13 x 10)) +} \\
&\quad \text{Chiang Mai (20 + 50 + (18 x 43)) + Songkhla (20 + 40 + (24 x 13)) +} \\
&\quad \text{Phuket (20 + 40 + (22 x 3)) + Udonthani (20 + 40 + (16 x 24)) +} \\
&\quad \text{Chiang Rai (20 + 40 + (22 x 11)) + Suratthani (20 + 40 + (20 x 6)) +} \\
&\quad \text{NOK (Ubonratchathani (20 + 40 + 0) +} \\
&\quad \text{Phitsanulok (20 + 40 + 150 + ((16 - 8) x 12)) +} \\
&\quad \text{Nakhonsithammarat (20 + 40 + 150 + ((16 - 5) x 20))} \\
&= 190 + 844 + 372 + 126 + 444 + 302 + 180 + 0 + 306 + 430 \\
&= 3,194 \text{ Baht/day}
\end{aligned}$$

Table 4.23 Calculated blood distribution cost by airplane

Destination Province	Transportation cost by airplane (Baht/day)					
	10/08/10	14/08/10	19/08/10	20/08/10	24/08/10	28/08/10
Khonkaen	190	320	125	0	190	320
Chiang Mai	844	916	682	492	772	510
Songkhla	372	132	252	372	756	780
Phuket	126	126	126	0	170	0
Udonthani	444	476	108	902	316	348
Chiang Rai	302	236	192	0	368	346
Suratthani	180	180	120	120	160	180
Ubonratchathani	0	210	274	322	274	322
Phitsanulok	306	210	534	234	210	210
Nakhonsithammarat	430	570	410	610	670	310
Total cost	3,194	3,376	2,823	3,052	3,886	3,326

4) Estimating the current blood distribution cost by public carrier

In Table 4.20 (column 2), there are nine destinations; ie, 5, 6, 7, 8, 9, 10, 11, 12 and Udonthani hospital that employed the public carrier to pick up blood from the station. The cost per trip is also given in column 1; ie, 40, 70, 40, 100, 133, 74, 600, 75 and 48, respectively. The average cost can be computed by

$$\begin{aligned}\text{The average delivery cost} &= (40 + 70 + 40 + 100 + 133 + 74 + 600 + 75 + 48) / 9) \\ &= 131.11 \text{ Baht/day/place.}\end{aligned}$$

From the six-day observation, it was found that there were 21 destination stations/airports or 25 destination places (RBCs/hospitals) per day. Thus, the transportation cost by public carrier is approximately $131.11 \times 25 = 3,277.75$ Baht/day.

These costs were used to assess the total blood distribution cost from the NBC to the final destinations. Table 4.24 presents costs for two cases; with and without air transportation charge. Currently, the air transportation charges for blood delivery are exempted by two airlines, but can be discontinued in the future, and then the cost will be incurred to the NBC. The costs are categorized into two parts. The first part is the costs incurred to the NBC, which comprise the cost of transportation by NBC's van, bus, and airplane. The second part is the cost incurred to RBCs or the hospital of destination, which refers to the cost of transportation by public carriers.

Table 4.24 Total transportation cost from the NBC to regional destinations.

Unit		Distribution cost incurred to		
		the NBC	RBCs/hospitals	Total
Baht/day	With air transportation cost	7,507	3,278	10,785
	Without air transportation cost	4,231	3,278	7,509
Baht/month	With air transportation cost	225,210	98,340	323,550
	Without air transportation cost	126,930	98,340	225,270
Baht/year	With air transportation cost	2,740,055	1,196,470	3,936,525
	Without air transportation cost	1,544,315	1,196,470	2,740,785

From Table 4.24, the average current cost of blood transportation from the NBC to RBCs or provincial hospitals is 7,507 Baht/day in the case of without air transportation charge. Having considered by year, the figure of transportation cost can be as high as 2,740,785 Baht/year. However, this figure is just the cost when the charges for air transportation are exempted. Without the exemption, the cost incurred to the NBC could be 10,785 or 3,278 Baht/day more. These are the costs that the NBC may have to spend, and the costs are getting higher every year. This is a kind of loss, since the NBC would not have to spend for these costs if only RBCs or hospitals could collect enough blood for their use. This excessive cost is possibly resulted from inappropriate locations or insufficient number of blood centers according to blood demand in the area. Consequently, these RBCs have to request for blood from the NBC everyday. Therefore, it is expected that the analysis and design for proper locations of RBCs may help to resolve the problem. With appropriate locations, the overall blood distribution cost should be reduced. Moreover, the blood quality can be controlled easier, and blood products can be ensured to reach patients safely.

4.8 Summary

For ease of explanation and understanding, this chapter is divided to the seven sections. Section 4.1 explained about data, which consists of two parts. The first part is about collecting primary data. Data of this category has been collected by interviewing operating staff, noting down information, accompanying with the NBC's van that delivers blood to hospitals, and taking photos of interesting events. The second part is about secondary data, which refer to data that have been collected previously. Secondary data for this research were obtained from annual reports of NBC, leaflets distributed during the opening ceremony of each Regional Blood Center, and relevant researches. Section 4.2 explained about the four operational procedures of blood supply chain in Thailand; namely, 1) recruiting blood donors and collecting blood, 2) testing, processing and storing blood, 3) delivering blood components to hospitals and 4) using blood components. Section 4.3 describes about current patterns and procedures of blood services, starting from receiving blood request, packing, and distributing blood. Blood delivery was found to use two forms of transportation; namely, land and air transportation. Modes of blood transportation can be divided into four modes; namely, NBC's van, public bus, airplane, and public carrier. Section 4.4 explained about the calculation of the distance matrix for both land and air transportation. The results were used for estimating blood distribution cost as discussed in Section 4.7, and will also be values of parameters in mathematical models in Chapter 5. Section 4.5 discussed the data regarding blood quantity sent from NBC to all destination provinces (RBCs and hospitals) each day, as obtained from the period of six-day data collection. Blood quantity, collected in terms of blood boxes and blood units, were used for calculating the blood distribution cost. Then Section 4.6 explained about methodology for calculating costs categorized by the four distribution modes. Finally, Section 4.7 is about integrating all the data for assessing costs of blood distribution at present. The resulting costs are presented in two units: Baht/km/unit and Baht/year. Costs in Baht/km/unit will be used as the parameters in the mathematical models for solving the location problems, while costs in Baht/year will be used for examining current costs of blood distribution. Details will be discussed in Chapter 5.

Results obtained from the cost estimation of blood distribution reveal that the current total cost is very high, at about 4,000,000 Baht/year. This great amount of money is considered a big burden to the NBC, and would rather be spent on equipment for blood services such as blood bags, needles, blood group testing agent, etc. As described earlier, the RBC locations in Thailand were not technically designated, but mainly located in the administrative zones designated by the Ministry of Interior. There are always questions whether the current distribution network is right from the perspectives of number, location and service area. It was thought that the inappropriate RBC locations perhaps contribute partly to the current excessive transportation cost. This research takes this question to study, analyze the situation, and re-design the distribution network by employing the quantitative methods. The next chapter will discuss about analyzing and re-designing the locations of regional blood centers.

CHAPTER V

LOCATION ANALYSIS AND DESIGN

In the previous Chapter, several issues regarding blood transportation to the regional destinations (i.e., RBCs and hospitals) were pointed out. Firstly, there is insufficient blood supply at the RBCs. Secondly, the RBCs have very high blood transportation cost, which is approximately three million Baht per year. Thirdly, blood is transported for a long distance, making it difficult for controlling blood quality while delivering. It should be noted that every step of blood movement requires keeping blood at a certain temperature range in order to maintain blood's lively condition, blood quality, and to impede growth of bacteria contaminated in the blood. Finally, time and energy of staff and equipment are wasted with wasteful activities on storing and delivering blood everyday. All problems may be caused by inappropriate RBC locations, regarding both locations and numbers.

Therefore, Chapter 5 will discuss about the analyses for the appropriate numbers and locations of RBCs in Thailand. The discussion is separated into six sections. First, it is the explanation about definitions and objectives of each case that will be analyzed. Second, the mathematical models that will be used for solving the research problems. Two mathematical models are used in this research; namely, transportation model and fixed charge facility location model. Third, preparation of parameter values in the mathematical model is explained. Fourth, the solutions procedures for solving research problems as well as the software tools are described. Fifth, it shows the analysis results obtained in each case in terms of cost and distance for delivering blood; and 6) a summary of various perspectives in each case. The case that is most appropriate to be utilized will also be discussed in this last section.

5.1 Analysis cases

This research analyzes and reports results based on seven cases. They are 1) existing configuration case, 2) new design with unlimited blood supply case, 3) new design with limited blood supply case, 4) existing configuration plus additional new RBCs with unlimited blood supply case, 5) existing configuration plus additional new RBCs with limited blood supply case, 6) locating an additional RBC into the current network with unlimited blood supply case and 7) locating an additional RBC into the current network with limited blood supply case. The details are explained below.

5.1.1 Case 1: existing configuration

Analysis results have revealed that the current configuration of blood distribution is inappropriate. This can be easily seen from the figure of blood distribution cost that the NBC has to support RBCs and regional hospitals, which has already been as high as 8,000 Baht per day. This cost is calculated without the air transportation charge, from which the NBC is exempted. However, the future is uncertain. It is possible that the NBC will have to pay this extra charge in the future. Therefore, Case 1 is proposed in order to present an appropriate configuration of blood transportation for each RBC. The analysis for this case will consider only land transportation because most blood distribution services in the country are conducted by means of land transportation. At present, some RBCs might require long distance of blood distribution since they are responsible for procuring blood to serve some provinces locating far away from the center. An example is Prachinburi province, which has been assigned to be under the responsibility of RBC 3 (Chonburi) according to the current situation. However, geographically, Prachinburi province is located closer to RBC 5 (Nakhonratchasima). Thus the cost for blood transportation is higher than what it was supposed to be, which can be explained with Figure 5.1. Therefore, if we analyze for a proper pattern of blood distribution by using a mathematical model to facilitate the analysis, it would be possible to reduce the transportation cost. The analysis is conducted by assuming that number and locations of RBCs are fixed to be as same as the present configuration. Additionally, it was also assumed that each RBC can procure blood as much as they want (without limitation). The applicable model is the classical transportation model as described in Section 5.2. The results obtained

from Case 1 represent cost of the overall system of blood distribution, blood quantity delivered from RBCs to terminal hospitals on each route, and minimum blood quantity that each RBC should recruit from donors.

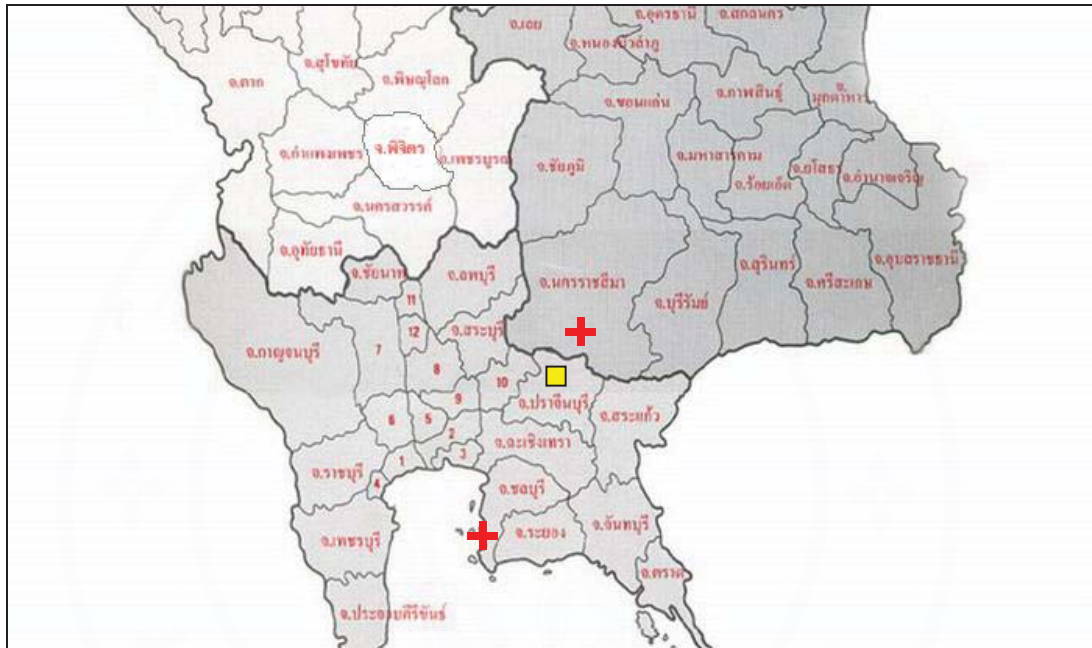


Figure 5.1 Description of Case 1 situation

5.1.2 Case 2: new network design with unlimited blood supply

If the current configuration of blood distribution service at present is inappropriate as discussed in Case 1, then this case will represent the situation when the blood service network is re-designated to become a new system with unlimited blood supply. The analysis will determine whether the system should increase the number of RBCs, or how many RBCs should be available in the system. In addition, it will determine provinces where these RBCs should be located. This is an approach for solving problems at their roots, by using a mathematical model of the Location/allocation type. Case 2 separates the analysis into two parts. The first part is about optimal locations of RBCs that were obtained from assessing establishment costs of those RBCs by considering land price, construction cost, equipment cost, and operation cost. The other part is about analyzing transportation cost and distances for delivering blood from RBCs to their responsible areas to meet blood demand of each province. The applicable model is the Uncapacitated Fixed Charge Facility Location

model, described in Section 5.2.2. The results obtained from Case 2 analysis are the optimal number and locations of RBCs as well as the configuration of blood transportation that incurs minimal total system cost.

5.1.3 Case 3: new network design with limited blood supply

Case 3 has similar objectives to the analysis in Case 2. The only difference is that this case adds a supply constraint, which is to limit the quantity of procured blood, into the mathematical model. This addition is done because, in reality, there is the limitation on blood quantity that the NBC could procure, which do not meet the demand of patients. The NBC has to arrange campaigns to get more blood donors every year. With this addition of the constraint, Case 3 will be more realistic than Case 2. The applicable model is the capacitated fixed charge facility location model, described in Section 5.2.2. The results obtained from Case 3 analysis are the optimal number and locations of RBCs as well as the configuration of blood transportation that incurs minimal total system cost.

5.1.4 Case 4: existing configuration plus additional new RBCs with unlimited blood supply

If the results from re-designing locations of RBCs as obtained from Cases 2 and 3 are not in agreement with locations of existing RBCs, it would be difficult for the NBC to manage the new system. The NBC can decide whether to abolish or to relocate the current RBCs. In order to establish a new RBC, there are many factors to consider, such as construction cost, equipment cost, material cost, employee payment, etc. It would seem like the NBC will have to start from zero again. Therefore, in order to extend from what it has already had, and to correspond to the real situation, the 12 existing RBCs are fixed by adding another constraint, while attempts are made to establish an additional RBC. This case is more likely to happen due to less capital investment than cases 2 and 3. The uncapacitated fixed charge facility location model with a constraint on the fixed locations of the existing 12 RBCs is used to analyze this case. The model is described in Section 5.2.2. The results from Case 4 are presented similarly to those in Case 2. There is only little difference regarding the locations of RBCs resulted from the mathematical model.

5.1.5 Case 5: existing configuration plus additional new RBCs with limited blood supply

Case 5 is similar to Case 4, with an addition of a constraint on the procured blood quantity. This is to determine whether the procured blood quantity has any impact on the design of a new blood service system. It is likely that the design would change, since blood is actually procured at some limited quantity and it is delicate for using. The capacitated fixed charge facility location model with a constraint on the fixed locations of the 12 existing RBCs is used to analyze this case. The model is described in Section 5.2.2. The results obtained from Case 5 analysis are the optimal number and locations of RBCs as well as the configuration of blood transportation that incurs minimal total system cost. All the existing NBC and the 12 RBCs are remained at the same current locations in this new design.

5.1.6 Case 6: locating an additional RBC to the current network with unlimited blood supply

In most real-world cases, it is very unlikely to demolish the established infrastructure such as RBCs. Therefore, this case keeps the current configuration of 12 RBCs intact and thinks about where the next RBC should be located as the NBC has a plan to establish RBC 1 at Ayutthaya province. RBC one has not been set up yet (the circle as shown in Figure 5.2). So, in case 6, we analyze the optimal location of RBC one given that the current NBC and 12 RBCs are fixed as they are. The uncapacitated fixed charge facility location model with additional constraints on the fixed location of the existing NBC and 12 RBCs and the total 14 locations is used to analyze this case. The model is described in Section 5.2.2. The analysis can provide the answer whether Ayutthaya province is still the best location choice in order to minimize the total system cost.

5.1.7 Case 7: locating an additional RBC to the current network with limited blood supply

Case 7 has similar objectives to the analysis in Case 6. The difference is that this case adds a constraint on the procured blood quantity. This is because blood can be procured at some limited quantity. It is expected that this limitation can have the impact on patterns of the blood service system. The applicable model is similar to case 6 plus the constraint on blood supply. The model is described in Section 5.2.2.

The results obtained from Case 5 analysis are the optimal number and locations of RBCs as well as the configuration of blood transportation that incurs minimal total system cost. For this case, the NBC and all the existing 12 RBCs are remained at the current locations. With an additional RBC, this case will contain 13 RBCs altogether, which was actually planned originally by the NBC.



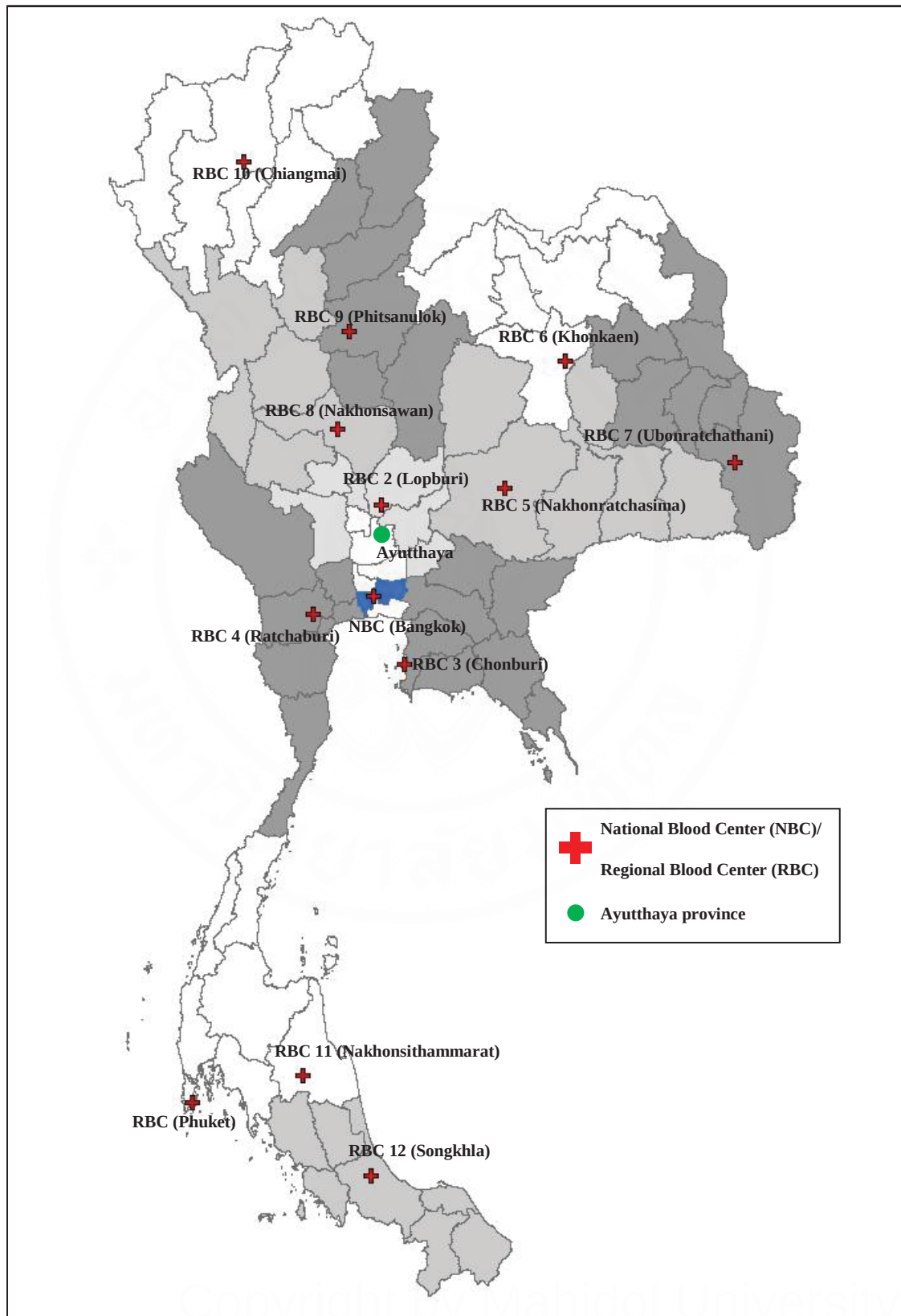


Figure 5.2 The NBC's planned location of RBC one at Ayutthaya province (in circle)

5.2 Mathematical model

For our network design problem, the question is where should RBCs be located and what should be their respective service provinces; hence, the location-allocation model is the applicable. In this research, there are two main types of applicable mathematical models. The first type is the classical transportation model. The second type is Fixed Charge Facility Location problems (Daskin, 1995). The mathematical formulation of these models can be explained below.

5.2.1 Transportation model

Transportation model is used to formulate the problem in Case 1. The mathematical expression is explained below.

Parameters

S_i = Blood supply at RBC i (units/year)

D_j = Blood demand at demand point j (units/year)

C_{ij} = The unit transportation cost of blood from RBC i to demand point j which measured by distance (kilometer)

Decision Variables

X_{ij} = The amount of transported blood from RBC i to demand point j (units)

Mathematical Formulation

$$\text{Objective function} \quad \text{Minimize} \quad \sum_i \sum_j C_{ij} X_{ij} \quad (1)$$

$$\text{Subject to} \quad \sum_j X_{ij} \leq S_i \quad ; \quad \forall_i \quad (2)$$

$$\sum_i X_{ij} \geq D_j \quad ; \quad \forall_j \quad (3)$$

$$X_{ij} \geq 0 \quad ; \quad \forall_{i,j} \quad (4)$$

The objective function (1) minimizes the total transportation cost. Constraint (2) stipulates that the total amount of blood transported from any RBC i must be less than or equal to its total supply. Constraint (3) ensures that each demand point j receives at least as much as it requires. Finally, constraint (4) is the nonnegativity condition. This research has added a dummy location in the set of demand points for balancing demand-supply because the total blood supply from all RBCs (S_i) are more than the total blood demand (D_j). By doing so, the model can always find the optimal solution to the problem.

5.2.2 Fixed Charge Facility Location model

The fixed Charge Facility Location model is used for solving problems in Cases 2 – 7, although the modification is necessary in some cases. This model is divided into 2 sub-models namely: 1) Uncapacitated Fixed Charge Facility Location model, which is for determining candidate provinces that are capable to establish an RBC and can procure blood with unlimited quantity; and 2) Capacitated Fixed Charge Facility Location model. This latter sub-model is for the case when the candidate province, where the new RBC will be located, has limited blood quantity. The sub-models can be explained in details below.

1) Uncapacitated Fixed Charge Facility Location model

This model is used for unlimited of blood in cases 2, 4 and 6. Its mathematical formulation is described as follows:

Parameters

f_j = fixed cost of locating an RBC at candidate site j (Baht)

h_i = blood demand at point i (units/year)

d_{ij} = transportation distance from demand point i to the RBC j (km.)

α = transportation cost per unit distance per unit blood demand (Baht/km./unit)

Decision variables

$X_j = 1$ if an RBC is located at candidate site j or 0 if not

Y_{ij} = fraction of blood demand at demand point i that is served by an RBC at site j

Mathematical formulation

$$\text{Objective function} \quad \text{Minimize} \quad \sum_j f_j X_j + \alpha \sum_i \sum_j h_i d_{ij} Y_{ij} \quad (1)$$

Subject to

$$\sum_j Y_{ij} = 1 \quad \forall i \quad (2)$$

$$Y_{ij} \leq X_j \quad \forall i, j \quad (3)$$

$$X_j = 0, 1 \quad \forall j \quad (4)$$

$$Y_{ij} \geq 0 \quad \forall i, j \quad (5)$$

The objective function (1) minimizes the total cost which is the sum of the fixed RBC costs and the total demand point-weighted distance multiplied by the cost per unit distance per unit blood demand. It is subject to the constraints (2) – (5).

Constraint (2) stipulates that each demand point i be served. Constraint (3) says that demands at demand point i cannot be assigned to the RBC at candidate site j unless we locate an RBC at node j . Constraints (4) are the integrality constraint. Nonnegativity is specified in constraint (5).

2) Capacitated Fixed Charge Facility Location model

This model is used for limited of blood in cases 3, 5 and 7. The different details from the uncapacitated model in 1) are as follows;

Additional parameter

k_j = capacity of an RBC at candidate site j if located there (units/year)

Additional constraint (6)

For limited capacity of blood

$$\sum_i h_i Y_{ij} \leq k_j X_j \quad \forall j \quad (6)$$

Constraints (6) ensures that the amount of blood supplied from any point j is limited to the its capacity of k_j

In cases 4 (existing configuration plus additional new RBCs with unlimited blood supply), and 5 (existing configuration plus additional new RBCs with limited blood supply) the existing locations of the NBC and 12 RBCs are fixed. Therefore, another constraint in (7) is included.

Additional constraint (7)

For fixing the current configuration

$$X_1, X_6, X_9, X_{14}, X_{21}, X_{22}, X_{23}, X_{37}, X_{41}, X_{50}, X_{51}, X_{57}, X_{76} = 1 \quad (7)$$

Where subscripts 1, 6, 9, 14, 21, 22, 23, 37, 41, 50, 51, 57 and 76 are the NBC, RBC 6, RBC 3, RBC 10, RBC 5, RBC 11, RBC 8, RBC 9, RBC Phuket, RBC 4, RBC 2, RBC 12 and RBC 7, respectively.

In cases 6 (locating an additional RBC to the current network with unlimited blood supply) and 7 (locating an additional RBC to the current network with limited blood supply), the additional constraint in (8) on the total number of 14 RBCs is imposed. This means only one new RBC is located by the model in order to compare with the planned RBC one at Ayutthaya province.

Adding constraint (8)

For total number of RBCs is 14;

$$\sum_j X_j = 14 \quad \forall_j \quad (8)$$

Table 5.1 summarizes the mathematical models for all cases. In summary, this research has to prepare five parameters; ie., blood supply (S_i in the transportation model, k_j in the Fixed Charge Facility Location model), blood demand (D_j in the transportation model, h_i in the Fixed Charge Facility Location model), fixed cost (f_j), variable cost (α), distance (d_{ij}). The next section will describe about these parameters.

Table 5.1 Summary of mathematical model by case

Mathematical model	Cases						
	1	2	3	4	5	6	7
Transportation model	✓						
Uncapacitated Fixed Charge Facility Location model		✓		✓		✓	
Capacitated Fixed Charge Facility Location model (Adding constraint 6)			✓		✓		✓
Adding constraint (7)				✓	✓	✓	✓
Adding constraint (8)						✓	✓

5.3 Parameters in the mathematical model

There are several parameters required in the above mathematical models. The parameters are obtained by close observation of all processes during the actual blood distribution and secondary data from the NBC. The details are explained below.

5.3.1 Blood supply (units/year)

Blood quantity is obtained from the Annual Report of 2006 (NBC, 2007). The provinces acquire blood mainly from the four main sources; namely, blood stock or blood quantity from the previous fiscal year, blood collection managed by hospitals, Red Cross Chapters, and relatives of patients (substitution). As shown in Table 5.2, the total blood quantity obtained from 76 provinces is 1,807,816 units/year.

Table 5.2 Blood supply by province, 2006

Node	Province	Blood supply (units)				
		Stock	Collected by			Total
			hospital	Chapter	substitution	
01	Bangkok	486,243	78,659	18,900	15,903	599,705
02	Krabi	134	1045	3536	723	5,438
03	Kanchanaburi	206	4,026	7,627	137	11,996
04	Kalasin	63	1,479	7,857	1,152	10,551
05	Kamphaengphet	120	2,078	4,278	744	7,220
06	Khonkaen	1,529	13,031	45,509	7,220	67,289
07	Chanthaburi	498	8,518	10,911	5,901	25,828
08	Chachoengsao	209	3,096	10,357	496	14,158
09	Chonburi	1,238	23,540	29,705	5,034	59,517
10	Chai Nat	355	1,816	4,029	633	6,833
11	Chaiyaphum	926	1,053	8,388	1,828	12,195
12	Chumphon	506	3,428	8,082	5,029	17,045
13	Chiang Rai	385	7,080	14,758	5,824	28,047
14	Chiang Mai	1,258	18,287	35,179	2,509	57,233
15	Trang	331	1,973	4,408	0	6,712
16	Trat	46	1,077	2,116	498	3,737
17	Tak	169	3,291	3,719	106	7,285
18	Nakhonnayok	222	1,139	4,616	6	5,983
19	Nakhonpathom	173	3,437	8,764	842	13,216
20	Nakhonphanom	84	848	5,918	89	6,939
21	Nakhonratchasima	1,391	4,517	58,252	1,679	65,839
22	Nakhonsit	371	7,558	17,312	1,178	26,419
23	Nakhonsawan	536	5,061	15,563	4,122	25,282
24	Nonthaburi	236	6,308	8,742	325	15,611
25	Narathiwat	537	1,188	4,486	0	6,211
26	Nan	184	3,561	6,133	235	10,113

Table 5.2 Blood supply by province, 2006 (cont.)

Node	Provinces	Blood supply (units)				
		Stock	Collected by			Total
			hospital	Chapter	substitution	
27	Buriram	706	8,584	8,869	706	18,865
28	Pathumthani	2,777	6,674	16,213	1,044	26,708
29	Phachuap	427	2,881	5,409	341	9,058
30	Prachiburi	353	1,246	10,555	0	12,154
31	Pattani	88	1,710	2,491	0	4,289
32	Ayutthaya	379	4,330	14,966	219	19,894
33	Phayao	158	3,762	5,076	2,362	11,358
34	Phangnga	155	2,001	1,369	0	3,525
35	Phatthalung	170	2,713	4,856	426	8,165
36	Phichit	313	2,369	7,045	70	9,797
37	Phitsanulok	404	4,234	17,985	3,254	25,877
38	Phetchaburi	21	1,855	5,689	0	7,565
39	Phetchabun	421	4,274	10,625	4,955	20,275
40	Phare	202	5,152	5,378	788	11,520
41	Phuket	546	7,700	4,086	0	12,332
42	Maharakham	87	2,528	9,434	0	12,049
43	Mukdahan	23	2,058	4,426	2	6,509
44	Mae Hong Son	96	1,582	1,564	335	3,577
45	Yasothon	191	1,122	6,167	131	7,611
46	Yala	132	2,710	2,093	2,973	7,908
47	Roi Et	536	2,036	15,822	57	18,451
48	Ranong	83	2,252	1,291	294	3,920
49	Rayong	686	6,568	8,491	50	15,795
50	Ratchaburi	491	6,529	17,221	1,707	25,948
51	Lopburi	435	5,116	21,638	335	27,524
52	Lampang	855	7,888	9,238	3,738	21,719

Table 5.2 Blood supply by province, 2006 (cont.)

Node	Provinces	Blood supply (units)				
		Stock	Collected by			Total
			hospital	Chapter	substitution	
53	Lamphun	167	2,361	7,819	1,028	11,375
54	Loei	330	2,978	6,221	1,409	10,938
55	Sisaket	430	2,720	14,795	607	18,552
56	Sakonnakhon	249	2,234	9,661	863	13,007
57	Songkhla	1,438	10,809	21,754	2,995	36,996
58	Satun	78	921	803	69	1,871
59	Samutprakan	501	2,726	10,599	0	13,826
60	Samutsongkhram	146	1,764	2,058	10	3,978
61	Samutsakhon	721	3,392	7,822	49	11,984
62	Sakaeo	254	659	5,160	868	6,941
63	Saraburi	522	6,244	14,430	1,905	23,101
64	Singburi	150	2,752	3,407	0	6,309
65	Sukhothai	204	3,803	5,721	207	9,935
66	Suphanburi	127	1,569	6,207	987	8,890
67	Suratthani	317	8,418	11,612	93	20,440
68	Surin	166	6,771	13,115	0	19,992
69	Nongkhai	854	2,983	7,624	0	11,461
70	Nongbualamphu	78	659	5,282	232	6,251
71	Angthong	143	1,814	2,055	169	4,181
72	Amnatcharoen	35	720	3,611	1	4,367
73	Udonthani	1,084	4,025	25,835	471	31,415
74	Uttaradit	259	1,756	7,264	4,927	14,206
75	Uthaithani	329	2,185	4,546	0	7,060
76	Ubonratchathani	536	6,899	34,510	0	41,945
Total		517,803	388,130	799,053	102,890	1,807,816

5.3.2 Blood demand (units/year)

The demand of blood in each province is based on the annual report of the fiscal year of 2006 (NBC, 2007). The quantity of blood to be considered include blood given to patients in hospitals and blood disposed away due to expiration or contaminated diseases. The diseases that may contaminate blood and lead to blood disposal include Syphilis, HIV-Ab, HIV-Ag, Anti-HCV, and HBsAg. In particular, it consists of blood used with the patients and blood distributed in all 76 provinces. The total blood demand is 1,503,746 units/year. The data are summarized in Table 5.3

Table 5.3 Blood demand by province, 2006

Node	Provinces	Blood demand (units)		
		Patients use	Disposed blood	Total
01	Bangkok	346,631	23,963	370,594
02	Krabi	5,055	340	5,395
03	Kanchanaburi	12,300	1,137	13,437
04	Kalasin	10,637	1,103	11,740
05	Kamphaengphet	8,478	500	8,978
06	Khonkaen	54,547	4,661	59,208
07	Chanthaburi	24,074	1,915	25,989
08	Chachoengsao	13,748	908	14,656
09	Chonburi	50,949	2,974	53,923
10	Chai Nat	5,747	396	6,143
11	Chaiyaphum	13,023	1,323	14,346
12	Chumphon	16,179	1,396	17,575
13	Chiang Rai	28,690	2,523	31,213
14	Chiang Mai	60,675	3,956	64,631
15	Trang	7,460	433	7,893
16	Trat	3,412	256	3,668
17	Tak	6,861	740	7,601
18	Nakhonnayok	3,996	354	4,350

Table 5.3 Blood demand by province, 2006 (cont.)

Node	Provinces	Blood demand (units)		
		Patients use	Disposed blood	Total
19	Nakhonpathom	16,998	760	17,758
20	Nakhonphanom	5,694	984	6,678
21	Nakhonratchasima	50,415	6,889	57,304
22	Nakhonsithammarat	18,842	1,410	20,252
23	Nakhonsawan	21,338	1,815	23,153
24	Nonthaburi	11,907	185	12,092
25	Narathiwat	6,831	430	7,261
26	Nan	8,305	1,314	9,619
27	Buriram	19,376	1,026	20,402
28	Pathumthani	20,179	1,018	21,197
29	Phachuap	7,257	1,830	9,087
30	Prachiburi	9,479	1,599	11,078
31	Pattani	5,282	228	5,510
32	Ayutthaya	18,455	1,139	19,594
33	Phayao	10,443	1,045	11,488
34	Phangnga	3,571	589	4,160
35	Phatthalung	6,975	603	7,578
36	Phichit	7,515	585	8,100
37	Phitsanulok	21,423	1,409	22,832
38	Phetchaburi	7,123	469	7,592
39	Phetchabun	16,354	2,069	18,423
40	Phare	10,657	834	11,491
41	Phuket	10,965	425	11,390
42	Mahasarakham	9,527	1,359	10,886
43	Mukdahan	5,269	574	5,843
44	Mae Hong Son	2,959	640	3,599
45	Yasothon	6,288	761	7,049

Table 5.3 Blood demand by province, 2006 (cont.)

Node	Provinces	Blood demand (units)		
		Patients use	Disposed blood	Total
46	Yala	8,619	525	9,144
47	Roi Et	16,846	1,184	18,030
48	Ranong	3,384	363	3,747
49	Rayong	15,018	1,381	16,399
50	Ratchaburi	22,104	1,489	23,593
51	Lopburi	21,368	2,000	23,368
52	Lampang	19,731	1,852	21,583
53	Lamphun	11,394	728	12,122
54	Loei	8,490	1,221	9,711
55	Sisaket	13,918	1,357	15,275
56	Sakonnakhon	11,504	1,309	12,813
57	Songkhla	24,598	1,103	25,701
58	Satun	2,109	193	2,302
59	Samutprakan	16,673	961	17,634
60	Samutsongkhram	3,955	420	4,375
61	Samutsakhon	9,015	1,058	10,073
62	Sakaeo	5,409	1,219	6,628
63	Saraburi	18,575	2,173	20,748
64	Singburi	5,870	705	6,575
65	Sukhothai	8,622	597	9,219
66	Suphanburi	7,597	644	8,241
67	Suratthani	17,208	770	17,978
68	Surin	15,005	1,103	16,108
69	Nongkhai	6,164	3,676	9,840
70	Nongbualamphu	3,535	616	4,151
71	Angthong	4,497	340	4,837
72	Amnatcharoen	2,813	499	3,312

Table 5.3 Blood demand by province, 2006 (cont.)

Node	Provinces	Blood demand (units)		
		Patients use	Disposed blood	Total
73	Udonthani	24,431	2,788	27,219
74	Uttaradit	12,486	1,004	13,490
75	Uthaithani	5,527	455	5,982
76	Ubonratchathani	28,682	2,110	30,792
Total		1,387,036	116,710	1,503,746

5.3.3 Fixed cost of the NBC/RBCs (Baht)

Fixed cost consists of four parts. They are land cost, construction cost, equipment cost and operation cost.

1) Land cost

Estimation on land cost requires two main inputs. The first input is the land price where the building will be constructed. The second input is the land size for construction. According to the Annual Report of 2006 (NBC, 2006), it is found that high blood demand occurs at the center hospital of each province. This is because these hospitals have sufficient equipments for treatment, and they also have a great number of patients. These center hospitals are situated in Muang districts. Therefore, land cost estimation for building an RBC in each province is based on the land price in Muang district in the province (The treasury department, 2010). Regarding land size for construction, it is obtained by averaging the data appeared in the brochures propagated during the opening ceremonies of the NBC, the RBC 3 in Chonburi (NBC, 1999), RBC 7 in Ubonratchathani (NBC, 2004), RBC 8 in Nakhonsawan (NBC, 2006), and RBC 9 in Phitsanulok (NBC, 2011). These RBCs had land area of approximately 1,000, 394, 263, 239 and 512 square wa respectively. Note that one square wa is equivalent to four square meters. The average land area is equal to $(394+263+239+512)/3 = 352$ square wa.

2) Construction cost

The estimation of construction cost of the candidate RBC in each province is conducted based on buildings characteristics, material costs and floor areas of current RBCs. The following historical data are utilized in the estimation.

- RBC 3 (Chonburi) – The building was constructed in 1999. It is a two-storey building, with the total floor area of 1,037 square meters. The RBC 3 office is located in the first floor, with a total floor area of 202.5 square meters. The construction cost was 1,541,728 Baht (NBC, 1999). Therefore, the unit construction cost is $1,541,728/202.5 = 7,613 \text{ Baht/m}^2$

- RBC 4 (Ratchaburi) – The building was constructed in 1999. It is a two-storey building, with the area of 400 square meters. This building is used to be the Ratchaburi Civil Servant Club and building of the Provincial Town Planning Office of Ratchaburi, which were located in the first and the second floor respectively (NBC, 2002).

- RBC 7 (Ubonratchathani) – The building was constructed in 2004. It is a two-storey building, with the total floor area of 522.5 square meters. The construction cost was 4,400,000 Baht (NBC, 2004). Therefore, the unit construction cost is $4,400,000/522.5 = 8,421 \text{ Baht/m}^2$

- RBC 8 (Nakhonsawan) – The building was constructed in 2006. It is a two-storey building, with the total floor area of 478 square meters. The first floor has total floor area of 234 square meters, whereas the second floor has 244 square meters. The construction cost was 4,335,000 Baht (NBC, 2006). Therefore, the unit construction cost is $4,335,000/478 = 9,069 \text{ Baht/m}^2$

- RBC 9 (Phitsanulok) – Construction of the buildings was completed in 2011. There are two buildings; namely, the main building and the technical building. The total floor area of these buildings is 2,250 square meters, with 2,100 square meters belongs to the main building and the remaining 150 square meters belongs to the technical building (NBC, 2011).

- Special RBC (Phuket) – The construction was completed in 2009. There are two buildings, with a total floor area of 1,306 square meters. The main building is a two-storey building, with a floor area of 1,137 square meters. The auxiliary building is also a two-storey building, with a floor area of 169 square meters. The construction cost was 48,477,233 Baht (NBC, 2010). Therefore, the unit construction cost is $48,477,233 / 1,306 = 37,119 \text{ Baht/m}^2$

For other RBCs with unknown cost data, the unit construction cost is assumed to be the average value from RBCs 3, 7 and 8; i.e., $(7,613 + 8,421 + 9,069)/3 = 8,368 \text{ Baht/m}^2$. The construction area is assumed to be the average value from RBCs 9, 23, 50 and 76; i.e., $(202.5+478+400+522.5)/4 = 400.75 \text{ m}^2/\text{RBC}$. The NBC has the construction cost of 300,000,000 Baht.

3) Equipment cost

The Special RBC in Phuket had an equipment cost of 44,721,574 baht (NBC, 2009). Their equipment comprised blood quality testing devices, computer systems, and a vehicle for blood donation. The equipment costs of RBC 7, Ubonratchathani (NBC, 2004) and RBC 8, Nakhonsawan (NBC, 2006) are incurred from blood quality testing devices, which were 18,092,770 Baht and 16,248,258 Baht respectively. Equipment costs of other RBCs are calculated based on the average equipment cost of RBC 7 and RBC 8 which is $(18,092,770+16,213,258)/2 = 17,153,014 \text{ Baht}$. The equipment cost of The NBC is calculated based on the cost of the special RBC in Phuket because both of them similarly provide full function services.

4) Operation cost

The operation cost is estimated by considering number of floors of the buildings in each RBC. The buildings of the special RBC (Phuket) have two floors. The operation cost was 226,005 Baht/year, whereas the training cost was 174,950 Baht/year (NBC, 2009). Operation cost of the NBC is estimated to be approximately four times higher than the cost of the special RBC (Phuket). The operation cost of RBC Phuket is $226,005 + 174,950 = 400,955 \text{ Baht/year}$. The building of NBC is an eight-storey building, thus there are more equipments and more officers. The operation cost of NBC is $400,955 \times (8/2) = 1,603,820 \text{ Baht/year}$. And the operation cost of other RBCs is calculated based on the NBC. According to a previous research, it was found

that the NBC can acquire blood for five times higher than regular RBCs. This finding can be used to estimate costs regarding officers and equipments required for operation of other RBCs (Nuchpayoon, 2010). The operation cost of other RBCs is assumed to be one-fifth of the NBC's, that is $1,603,820/5 = 320,764$ Baht/year.

Therefore the total fixed cost is equal to (Land area x unit land cost) + (Area x unit construction cost) + Equipment cost + Operation cost. Table 5.4 shows the estimated fixed cost of NBC by provinces.

Table 5.4 Estimated fixed cost of the NBC/RBCs

Node	Provinces	Components of fixed cost						Total Annual cost (Baht)
		Land area (Wa ²)	Land cost (Baht/ Wa ²)	Area (m ²)	Construction (Baht/m ²)	Equipment (Baht)	Operation (Baht)	
01	Bangkok	1,000	300,000	300,000	0 Baht	178,886,296	1,603,820	780,490,116
02	Krabi	352	22,750	401	8,368	17,153,014	320,764	28,835,189
03	Kanchanaburi	352	12,500	401	8,368	17,153,014	320,764	25,752,189
04	Kalasin	352	11,000	401	8,368	17,153,014	320,764	24,699,189
05	Kamphaengphet	352	15,750	401	8,368	17,153,014	320,764	26,371,189
06	Khonkaen	352	12,250	401	8,368	17,153,014	320,764	25,139,189
07	Chanthaburi	352	21,000	401	8,368	17,153,014	320,764	28,219,189
08	Chachoengsao	352	16,000	401	8,368	17,153,014	320,764	26,459,189
09	Chonburi	394	25,000	203	7,613	17,153,014	320,764	27,815,506
10	Chai Nat	352	12,000	401	8,368	17,153,014	320,764	25,051,189
11	Chaiyaphum	352	13,750	401	8,368	17,153,014	320,764	25,667,189
12	Chumphon	352	13,750	401	8,368	17,153,014	320,764	25,667,189
13	Chiang Rai	352	29,000	401	8,368	17,153,014	320,764	31,035,189
14	Chiang Mai	352	37,500	401	8,368	17,153,014	320,764	34,027,189
15	Trang	352	22,500	401	8,368	17,153,014	320,764	28,747,189
16	Trat	352	10,000	401	8,368	17,153,014	320,764	24,347,189

Table 5.4 Estimated fixed cost of the NBC/RBCs (Cont.)

Node	Provinces	Components of fixed cost						Total Annual cost (Baht)
		Land area (Wa ²)	Land cost (Baht/ Wa ²)	Area (m ²)	Construction (Baht/m ²)	Equipment (Baht)	Operation (Baht)	
17	Tak	352	26,875	401	8,368	17,153,014	320,764	30,287,189
18	Nakhonnayok	352	10,250	401	8,368	17,153,014	320,764	24,435,189
19	Nakhonpathom	352	32,500	401	8,368	17,153,014	320,764	32,267,189
20	Nakhonphanom	352	11,500	401	8,368	17,153,014	320,764	24,875,189
21	Nakhonratchasima	352	23,000	401	8,368	17,153,014	320,764	28,923,189
22	Nakhonsithammarat	352	24,500	401	8,368	17,153,014	320,764	29,451,189
23	Nakhonsawan	239	30,725	478	9,069	16,213,258	320,764	28,212,297
24	Nonthaburi	352	41,000	401	8,368	17,153,014	320,764	35,259,189
25	Narathiwat	352	11,900	401	8,368	17,153,014	320,764	25,015,989
26	Nan	352	11,250	401	8,368	17,153,014	320,764	24,787,189
27	Buriram	352	13,000	401	8,368	17,153,014	320,764	25,403,189
28	Pathumthani	352	27,500	401	8,368	17,153,014	320,764	30,507,189
29	Phachuap Khirikhan	352	10,500	401	8,368	17,153,014	320,764	24,523,189
30	Prachiburi	352	27,500	401	8,368	17,153,014	320,764	30,507,189
31	Pattani	352	22,500	401	8,368	17,153,014	320,764	28,747,189
32	Ayuthaya	352	10,000	401	8,368	17,153,014	320,764	24,347,189

Table 5.4 Estimated fixed cost of the NBC/RBCs (Cont.)

Node	Provinces	Components of fixed cost						Total Annual cost (Baht)
		Land area (Wa ²)	Land cost (Baht/ Wa ²)	Area (m ²)	Construction (Baht/m ²)	Equipment (Baht)	Operation (Baht)	
33	Phayao	352	20,000	401	8,368	17,153,014	320,764	27,867,189
34	Phangnga	352	27,750	401	8,368	17,153,014	320,764	30,595,189
35	Phatthalung	352	25,000	401	8,368	17,153,014	320,764	29,627,189
36	Phichit	352	18,500	401	8,368	17,153,014	320,764	27,339,189
37	Phitsanulok	512	10,000	2,250	8,368	17,153,014	320,764	41,421,410
38	Phetchaburi	352	10,000	401	8,368	17,153,014	320,764	24,347,189
39	Phetchabun	352	2,500	401	8,368	17,153,014	320,764	21,707,188
40	Phare	352	23,750	401	8,368	17,153,014	320,764	29,187,189
41	Phuket	352	16,500	1,306	37,119	44,721,574	400,955	99,407,762
42	Maharakham	352	16,500	401	8,368	17,153,014	320,764	26,635,189
43	Mukdahan	352	10,500	401	8,368	17,153,014	320,764	24,523,189
44	Mae Hong Son	352	25,000	401	8,368	17,153,014	320,764	29,627,189
45	Yasothon	352	20,000	401	8,368	17,153,014	320,764	27,867,189
46	Yala	352	11,000	401	8,368	17,153,014	320,764	24,699,189
47	Roi Et	352	21,000	401	8,368	17,153,014	320,764	28,219,189
48	Ranong	352	27,500	401	8,368	17,153,014	320,764	30,507,189

Table 5.4 Estimated fixed cost of the NBC/RBCs (Cont.)

Node	Provinces	Components of fixed cost						Total fixed cost (Baht)
		Land area (Wa ²)	Land cost (Baht/ Wa ²)	Area (m ²)	Construction (Baht/m ²)	Equipment (Baht)	Operation (Baht)	
49	Rayong	352	17,500	401	8,368	17,153,014	320,764	26,987,189
50	Ratchaburi	352	30,000	400	8,368	17,153,014	320,764	31,380,913
51	Lopburi	352	32,500	401	8,368	17,153,014	320,764	32,267,189
52	Lampang	352	19,000	401	8,368	17,153,014	320,764	27,515,189
53	Lamphun	352	22,500	401	8,368	17,153,014	320,764	28,747,189
54	Loei	352	16,000	401	8,368	17,153,014	320,764	26,459,189
55	Sisaket	352	12,500	401	8,368	17,153,014	320,764	25,227,189
56	Sakonkakhon	352	16,000	401	8,368	17,153,014	320,764	26,459,189
57	Songkhla	352	35,000	401	8,368	17,153,014	320,764	33,147,189
58	Satun	352	11,000	401	8,368	17,153,014	320,764	24,699,189
59	Samutprakan	352	31,900	401	8,368	17,153,014	320,764	32,055,989
60	Samutsongkhram	352	20,000	401	8,368	17,153,014	320,764	27,867,189
61	Samutsakhon	352	12,500	401	8,368	17,153,014	320,764	25,227,189
62	Sakao	352	13,125	401	8,368	17,153,014	320,764	25,447,189
63	Saraburi	352	14,200	401	8,368	17,153,014	320,764	25,825,589
64	Singburi	352	21,000	401	8,368	17,153,014	320,764	28,219,189

5.3.4 Cost per unit distance per unit demand (Baht/km./unit)

This parameter could be obtained from previous calculation in Chapter 4. The parameter is used for calculation together with distance. Since there are several modes for current blood distribution, such as by the NBC's van, public bus, airplane and public carrier, the resulting values of α are different according to the transportation mode. The parameter α can be summarized in Table 5.5.

Table 5.5 Summary of alpha (α) value by modes

Modes		Alpha (α = Baht/km./unit)
NBC' van	22 Karakkadakhom circle	2.94
	Don Muang airport	0.16
	Mo Chit bus terminal	0.07
	Suvarnabhumi airport	0.05
Public bus		0.03
Airplane		0.02
Public carrier		0.09

5.3.5 Distance (km.)

In order to study comprehensively about blood transportation, this research used five transportation distances forms. The first form is the distances from the NBC to 22 Karakkadakhom Circle, to Mo Chit bus terminal, to Don Muang airport, and to Suvarnabhumi airport. The second form is the distances from the origin provinces to the destination provinces. The third form is the distances from the origin airports to the destination airports. The forth form is the distances from all destination bus termini to all RBCs. Last, the fifth form is the distances from the destination airport to the RBC in the province. These distances are used to calculate for blood distribution cost by considering transportation modes that are applied ($C_{ij} \times \alpha$). Different transportation modes incur different costs.

For example, in case of blood transportation from the NBC to RBC 9, cost calculation can be divided into three parts as follows.

Part 1: The blood transportation cost from the NBC to Don Muang airport

Part 2: The blood transportation cost from Don Muang airport to Phitsanulok airport

Part 3: The blood transportation cost from Phitsanulok airport to RBC 9

The cost calculation for this example of blood transportation is shown in Figure 5.3.

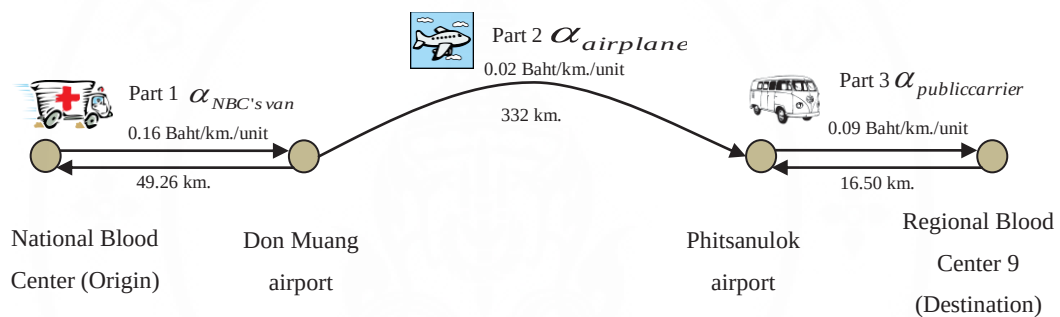


Figure 5.3 Illustration of the blood delivery from NBC to RBC 9

$$\begin{aligned}
 \text{Transportation cost} &= (\text{distance from NBC to Don Muang airport} \times \alpha_{NBC's\ van}) + \\
 &\quad (\text{distance from Don Muang airport to Phitsanulok airport} \times \\
 &\quad \alpha_{airplane}) + (\text{distance from Phitsanulok airport to RBC 9} \times \\
 &\quad \alpha_{publiccarrier}) \\
 &= (49.26 \times 0.16) + (332 \times 0.02) + (16.50 \times 0.09) \\
 &= 16.01 \text{ Baht/unit}
 \end{aligned}$$

This research considers blood transportation cost from all origin provinces to all destination provinces. These costs have to be estimated by considering current blood distribution. We have made the following assumptions in order to estimate blood transportation costs.

1) It is assumed that all provinces are eligible to be the RBC. Then cost calculation for blood transportation is conducted by considering a transportation mode that incurs the minimum cost. Sometimes there can be emergency blood requests from hospitals, and they will have to send an ambulance to receive blood at the NBC, which will incur higher cost than usual. However, this research will consider only the regular blood request.

2) The current blood transportation modes are used. The transportation types are known from data collection. The first type is land transportation, which employed to Buriram, Chaiyaphum, Chonburi, Lopburi, Prachuapkhirikhan, Maehongson, Nakhonratchasima, Nakhonsawan, Nongkhai, Ratchaburi, and Sakonnakhon provinces. The second type is air transportation, which employed to Khonkaen, Chiangrai, Phayao, Chiangmai, Phuket, Phang-nga, Songkhla, Suratthani, Nakhonsithammarat, Udonthani, Nongbualamphu, Phitsanulok, and Ubonratchathani provinces.

3) For provinces with an airport or near the airport the transportation is made by an airplane. This group of provinces includes Krabi, Trang, and Nakhonphanom. Air transportation is assumed because the shorter transportation directly affects blood quality. This research considers air transportation service from only two airlines; namely, Thai Airways International and Nok Air airlines.

4) Blood transportation within a region is considered as the short-distance transportation. The vehicle type to be used is either bus or van. Some examples of this short-distance transportation are from Nakhonratchasima to Surin, from Songkhla to Yala, and from Chonburi to Trat, in the Northeast, South and East, respectively.

5) For long-distance blood transportation across the regions, flights may be available. There are two categories. The first category is the flight from Phuket International Airport to Chiang Mai International Airport. The second category is the flight from Udon Thani International Airport to Chiang Mai International Airport. From the existing available flights at present, plans for blood transportation can be made as follows:

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- The plan of transporting blood from and to provinces locating near Chiang Mai International Airport, such as Maehongson, Chiangrai, Lampang, Lamphun, Phrae, Nan, and Phayao to southern provinces locating near Phuket International Airport, such as Phang-nga, Krabi, Suratthani, Nakhonsithammarat, Trang, Satun, Phatthalung, Songkhla, Pattani, Narathiwat, and Yala.

- The plan of transporting blood from and to provinces locating near Chiang Mai International Airport to provinces locating near Udon Thani International Airport, such as Nongkhai, Nongbualamphu, Sakonnakhon, and Khonkaen.

6) For long-distance blood transportation across regions, air and bus and may be combined. The point of changing vehicle types occurs in Bangkok (Don Muang airport or Suvarnabhumi airport). Consideration on time and cost of blood transportation for this category is based on the province of origin, and can be divided as follows;

- Transportation that starts from Bangkok. This characteristic is appropriate for provinces locating near Bangkok. For example, in order to deliver blood from RBC Kanchanaburi to RBC Suratthani, a public carrier is used for transporting blood from Kanchanaburi to Bangkok (at Suvarnabhumi airport), then take a flight to Suratthani airport, and Suratthani RBC will finally send a vehicle to pick up the blood from the airport, Figure 5.4 shows the supply chain.

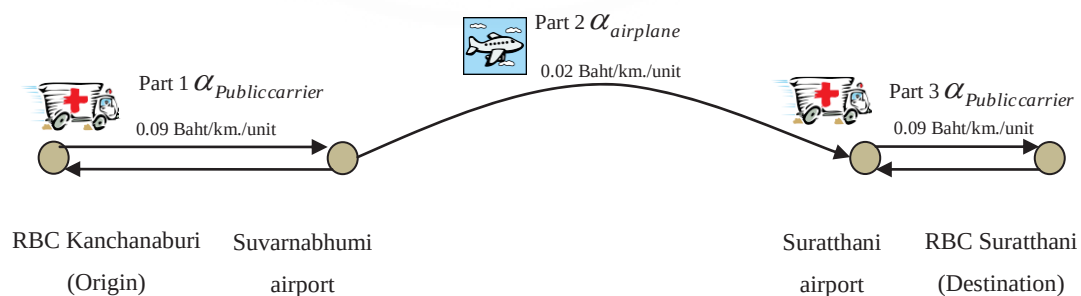


Figure 5.4 Illustration of blood delivery from RBC Kanchanaburi to RBC Suratthani

- Transportation that starts from the province of origin. This characteristic is appropriate for provinces locating far away from Bangkok. For example, in order to deliver blood from RBC Loei to RBC Ratchaburi, RBC Loei will transport the blood to Loei bus station, then a public carrier will take the blood to Mo Chit bus terminal, and RBC Ratchaburi will finally send its vehicle to pick up the blood from Mo Chit bus terminal to its place, as shown in Figure 5.5

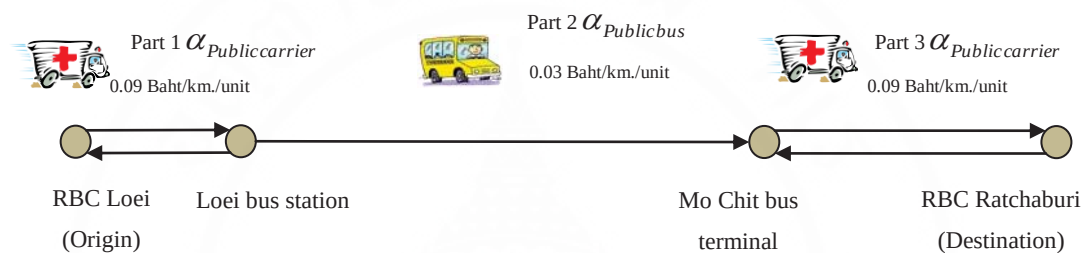


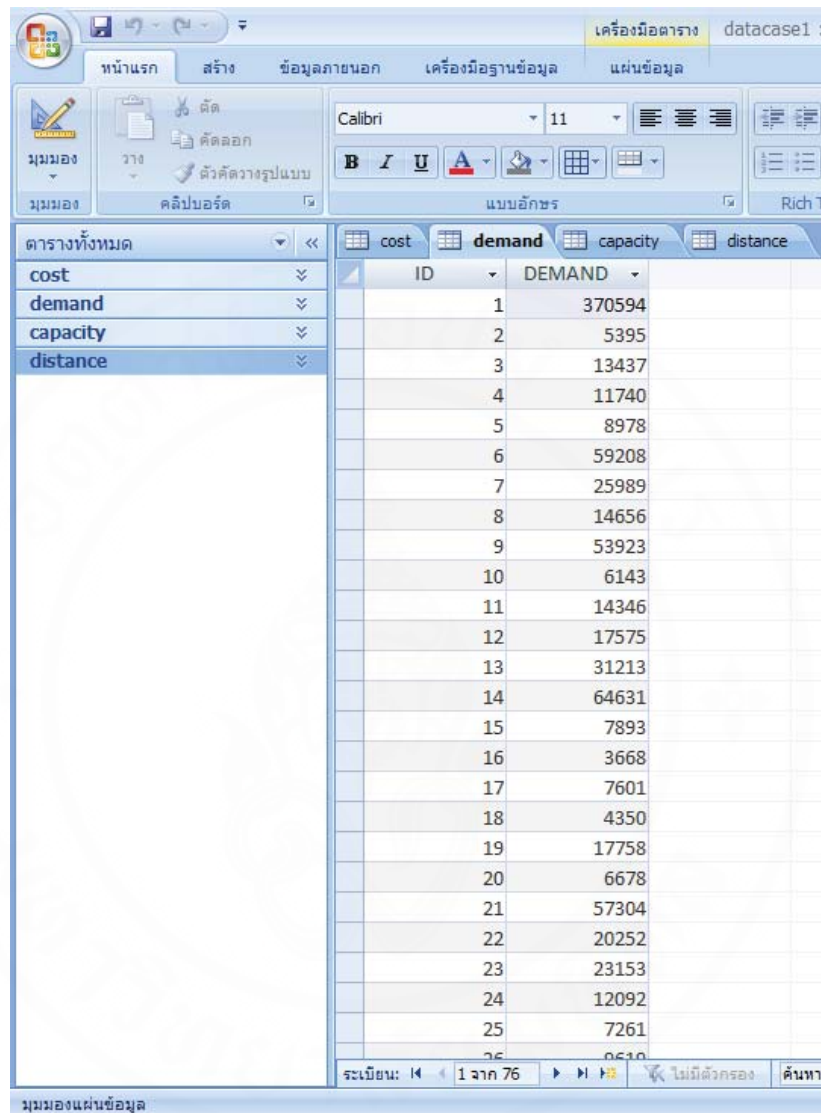
Figure 5.5 Illustration of blood delivery from Loei to Ratchaburi

7) All types of transportation, from 1) to 6) may be considered and used in combination according to appropriateness. The blood transportation cost is calculated for all 76 provinces to all 76 provinces then forms a cost matrix. These costs are used as the parameters in the mathematical models. The solution approach is explained in the next section.

5.4 Solution approach

This research uses two main application software for solving the optimization problem; namely, 1) LINDO Release 6.1, for the transportation model (Case 1) and 2) IBM ILOG OPL IDE 6.3, for the Fixed-Charge Facility Location problem model (Cases 2 - 7). In addition, supplementary software are also necessary including;

1) Microsoft Access 2007 is used for storing necessary information data in the database. The parameters required for transportation and Fixed Charge Facility Location model are also stored in the database. Figure 5.6 shows the captured screen of blood demand data.



The screenshot shows the Microsoft Access 2007 interface. The 'demand' table is selected in the 'Table View' tab. The table contains 25 rows of data. The 'ID' column ranges from 1 to 25, and the 'DEMAND' column contains numerical values. The status bar at the bottom indicates '1 จาก 76' (1 of 76) records.

ID	DEMAND
1	370594
2	5395
3	13437
4	11740
5	8978
6	59208
7	25989
8	14656
9	53923
10	6143
11	14346
12	17575
13	31213
14	64631
15	7893
16	3668
17	7601
18	4350
19	17758
20	6678
21	57304
22	20252
23	23153
24	12092
25	7261

Figure 5.6 Database storage by Microsoft Access 2007

2) Visual Basic 2005 is used to read the required parameters from Access database and write the mathematical expression. Figure 5.7 shows a part of VB code. Meanwhile, Figure 5.8 displays the mathematical expression of the transportation model developed by Visual Basic 2005. Figure 5.9 displays a part of five parameters of Fixed Charge Facility Location problem model.

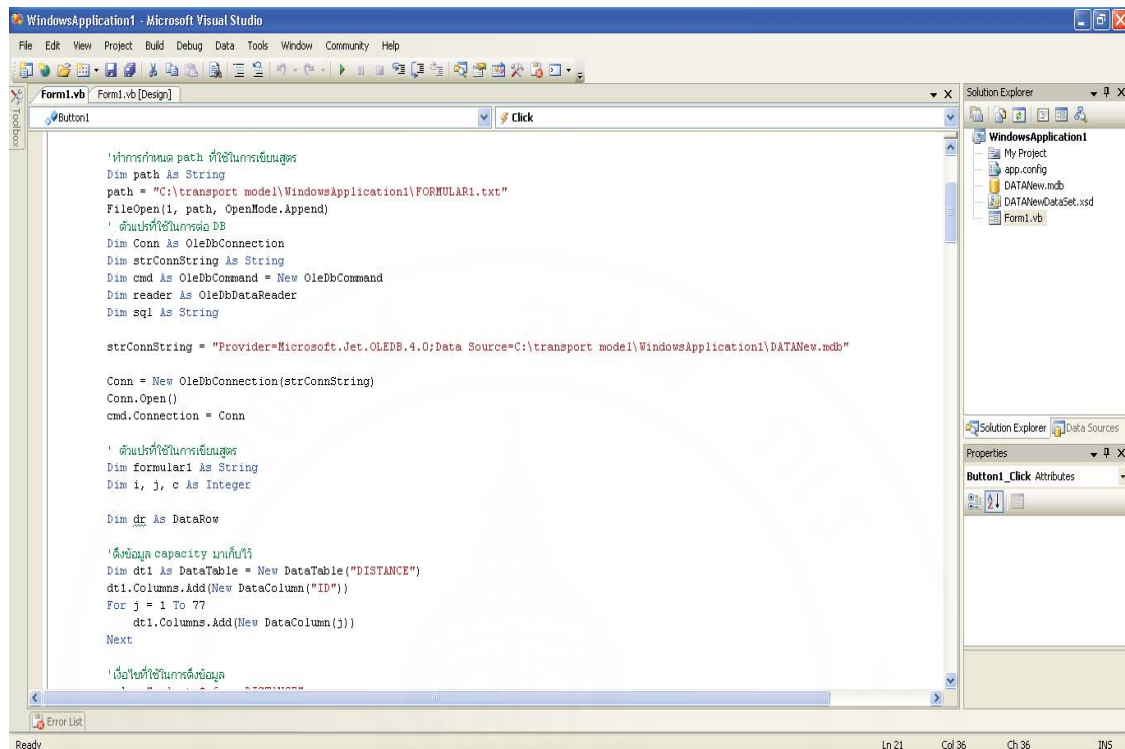


Figure 5.7 A captured screen of Visual Basic 2005 codes for generation transportation mathematical model

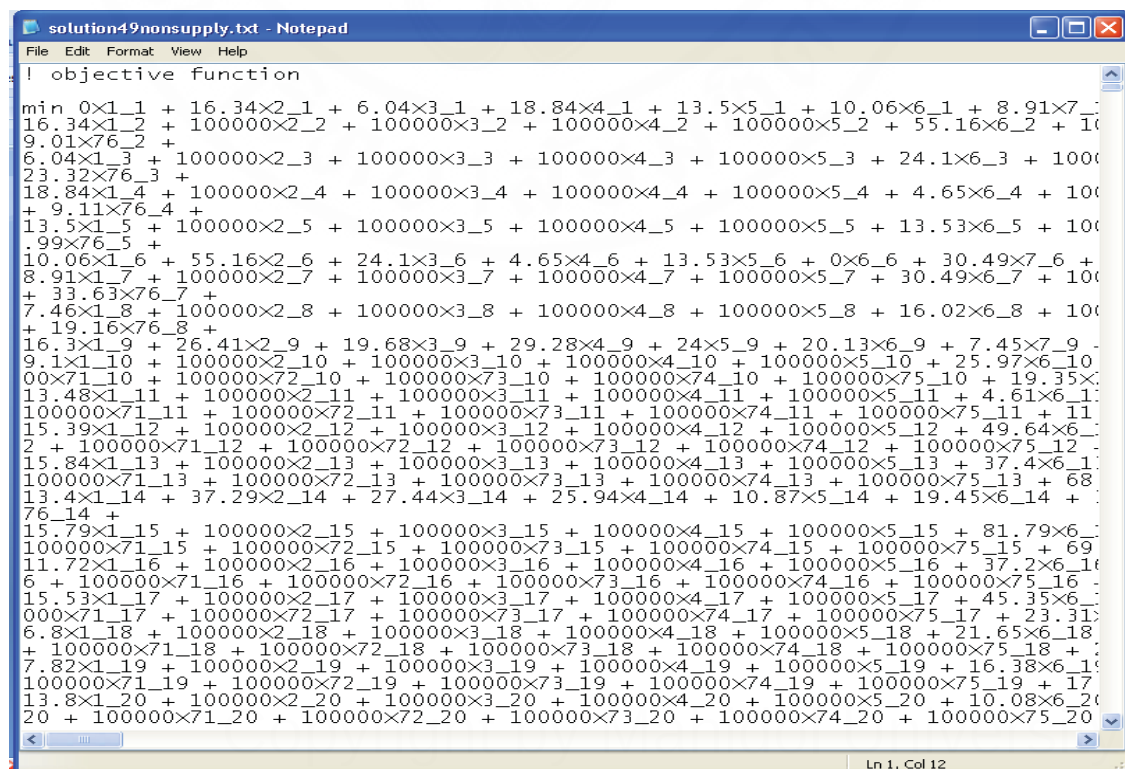


Figure 5.8 Mathematical expression of the Transportation model developed by Visual Basic 2005

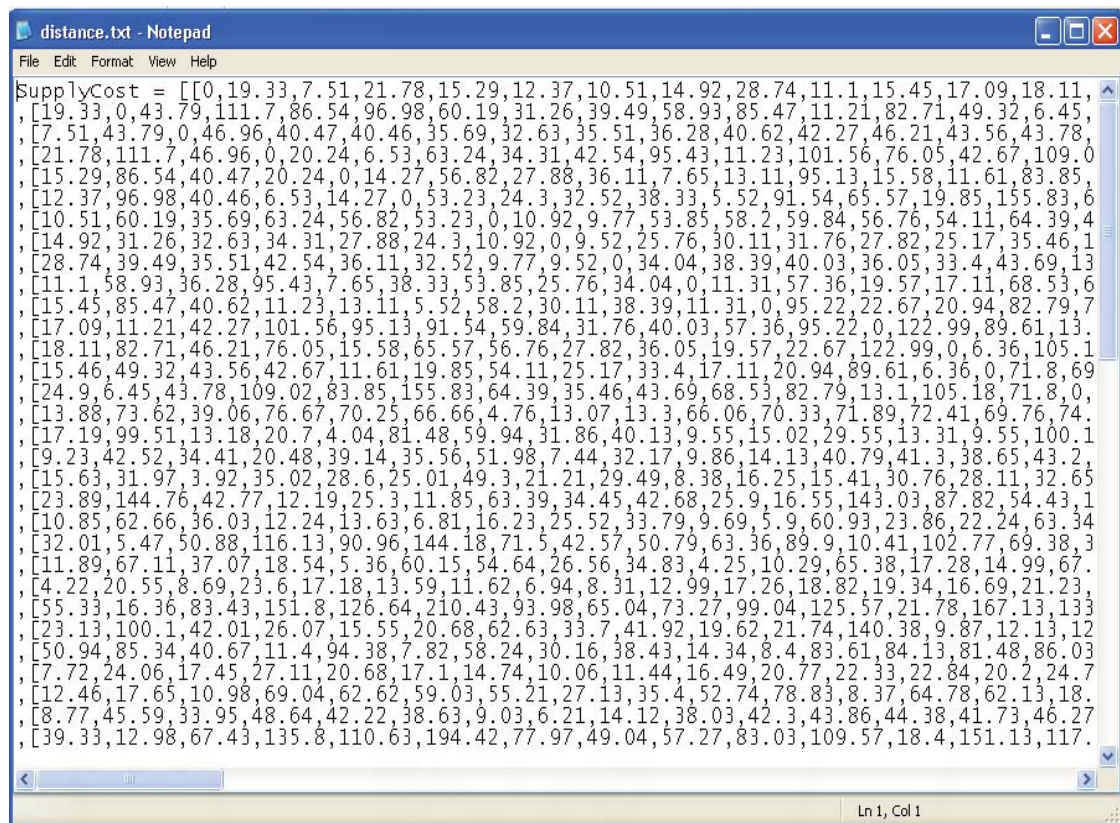


Figure 5.9 Distance in the Fixed-Charge Facility Location problem model developed by Visual Basic 2005

The Mathematical expression of the Transportation model in Figure 5.8 is then solved by using LINDO 6.1. The solver is capable to accommodate 200,000 variables, 64,000 constraints, 20,000 integer variables and 2,000,000 nonzero. It begins with the access to LINDO 6.1 (Figure 5.10), then paste the mathematical expression onto LINDO 6.1 window. On the menu bar, click Solve to find the optimal solution (Figure 5.11)

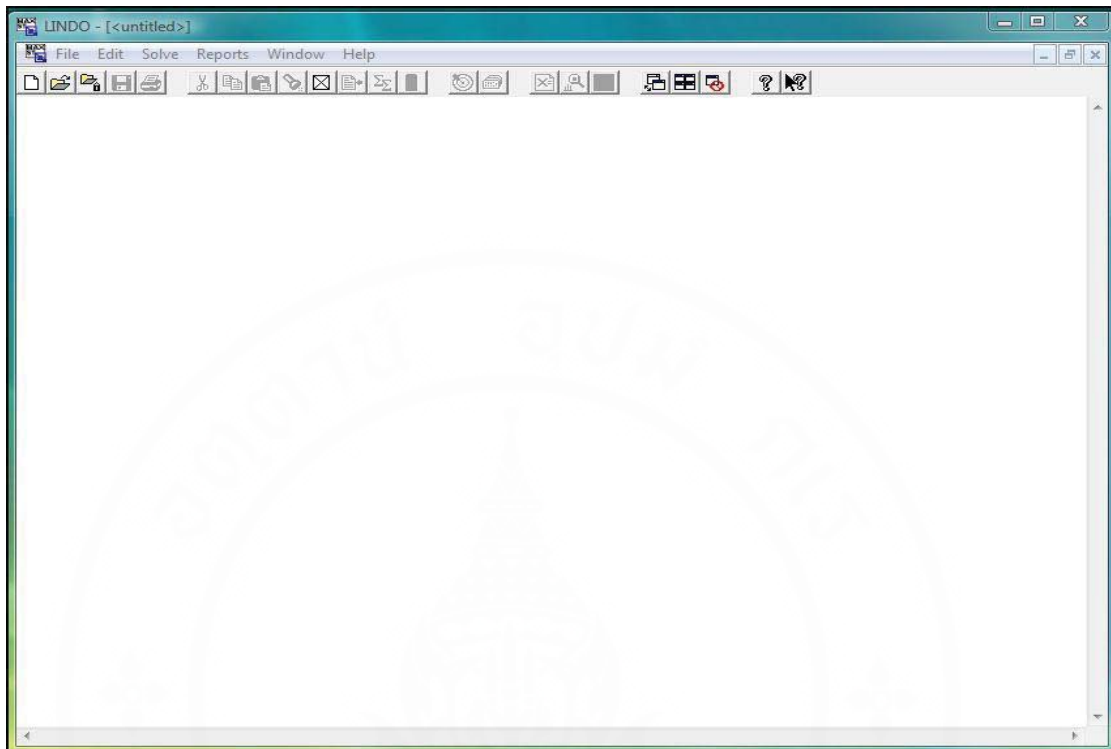


Figure 5.10 Window of program LINDO 6.1

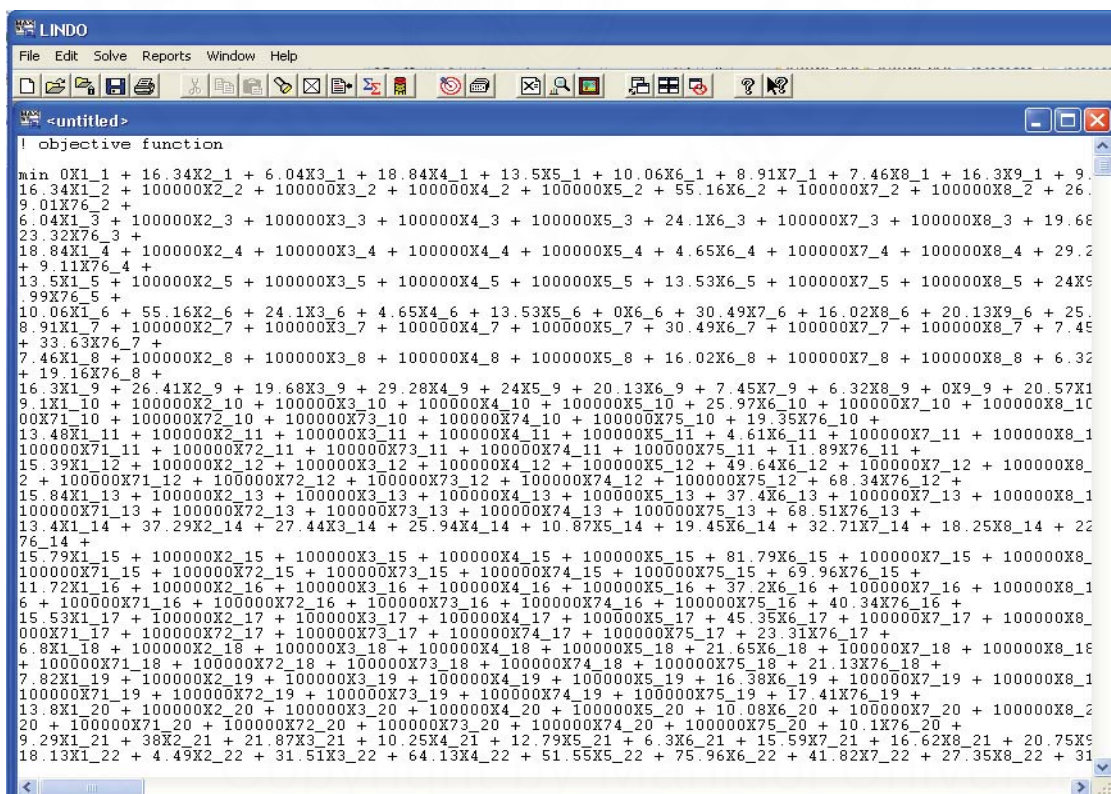


Figure 5.11 Mathematical expression of the transshipment model in LINDO window

For more advanced mathematical model like Fixed-Charge Facility Location problem model in this research, LINDO is not capable to solve it to the optimality. Therefore, the written parameters (supply, demand, fixed cost and variable cost (distance $\times \alpha$)) and mathematical expression by visual basic 2005 are inputted to be solved by the more powerful solver - IBM ILOG OPL IDE 6.3 (Figure 5.12) in stead. Click Run and Default Run Configuration to find the optimal solution (Figure 5.13).

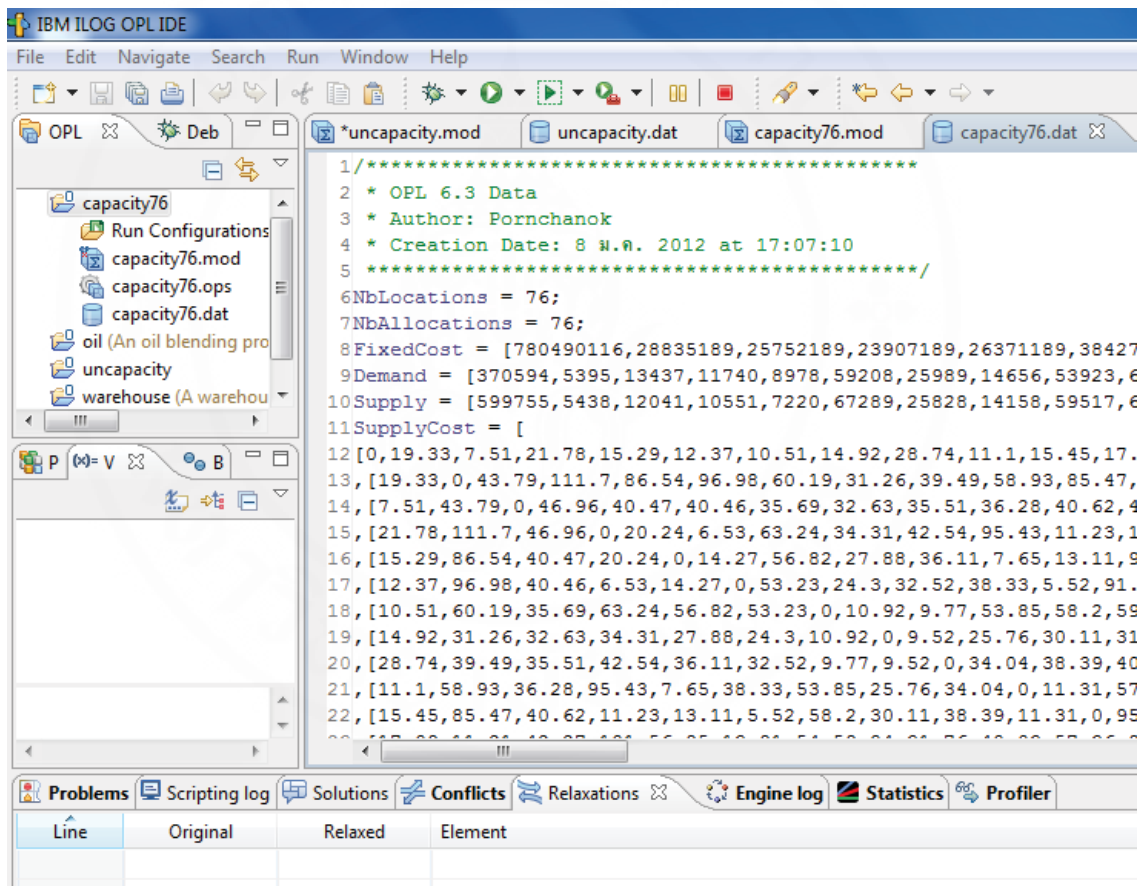


Figure 5.12 Parameters of Fixed-Charge Facility Location problem model

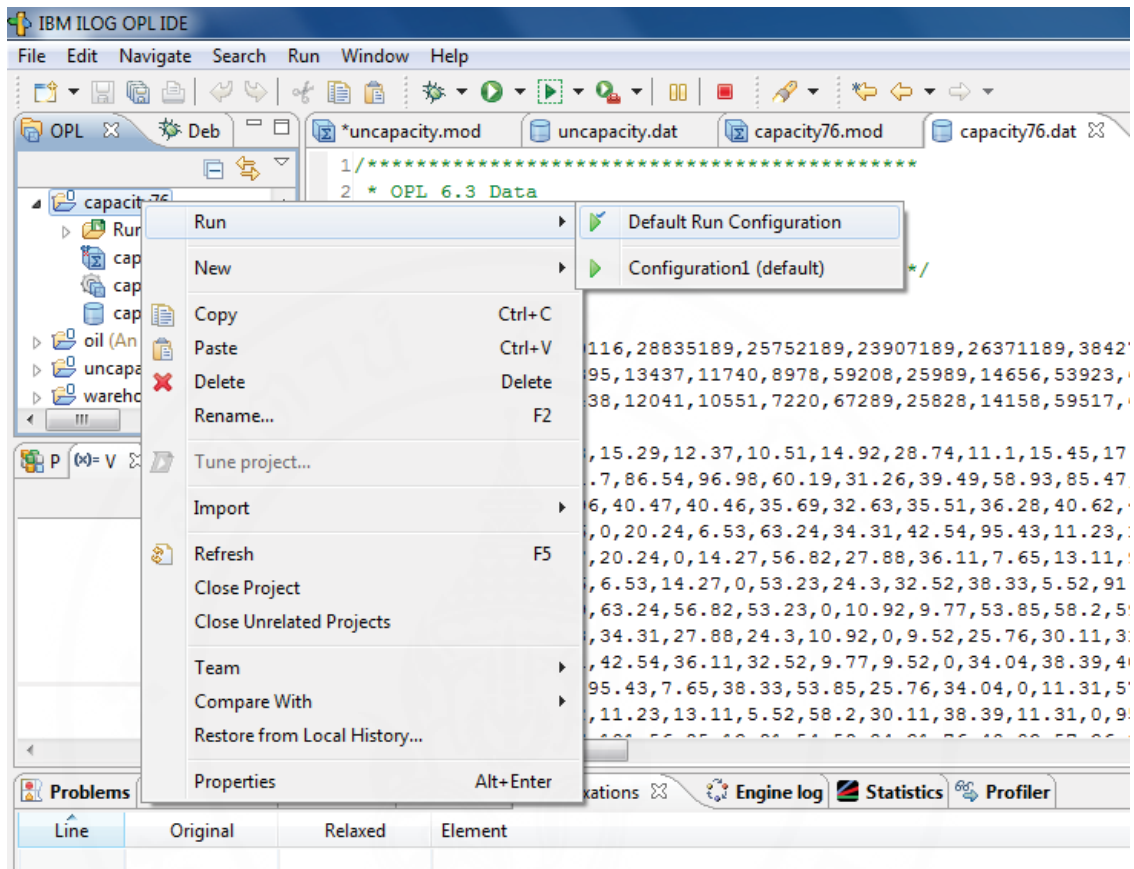


Figure 5.13 Captured screen of IBM ILOG OPL IDE 6.3

In the next section, we will explain and discuss about input parameters and results for individual cases.

5.5 Case 1: existing configuration

Case 1 is the analysis of the optimal blood distribution given the current locations of the NBC and 12 RBCs. Besides, there are several by-product results including the total transportation distance and the ideal capacity of any RBC. The demand point is at the province level. There are totally 76 points. Meanwhile, the supply points are the NBC and 12 RBCs, or 13 totally. The applicable model is the classical transportation problem as explained clearly in Section 5.2.1. The results are the optimal transportation pattern from all RBCs to all hospitals which minimizes the total transportation cost. The difference between the current and optimal cost may be interpreted as the waste or opportunity loss from not being able to manage the blood distribution very efficiently.

5.5.1 Parameters for case 1: transportation model

With respect to the analysis of case 1, the source of sample data for blood distribution analysis is based on Section 5.3. In case, there are three input parameters; i.e., supply (S_i), demand (D_j), and distance (C_{ij}). According to the assumption that all RBCs are capable to supply blood sufficiently without any limitation, the amount of blood the RCB can supply is set to 1,000,000 units per year in the model. The quantity of blood demand is obtained from Table 5.3. A dummy location is added to create the balance between total demand and supply of blood. The dummy demand value is 11,496,254 units/year (blood supply – blood demand = 13,000,000 – 1,503,746). As a result, the transportation problem is always feasible. The distance matrix uses data in Section 5.3.5.

5.5.2 Optimal distribution pattern for case 1

Figure 5.14 shows the optimal blood distribution pattern based on the transportation model. There are 13 locations. The NBC is in Bangkok. Meanwhile, RBCs are located in twelve provinces; ie., Lopburi, Chonburi, Ratchaburi, Nakhonratchasima, Khonkaen, Ubonratchathani, Nakhonsawan, Phitsanulok, Chiang Mai, Nakhonsithammarat, Songkhla and Phuket. The service provinces of each RBC are slightly changed. Table 5.6 summarizes the resulting service provinces, transported blood volume, transportation distance and cost for individual supply points. At present, Lopburi (RBC 2) is responsible for six provinces; i.e., Chai Nat, Nakhonnayok, Lopburi, Saraburi, Singburi and Suphanburi. However, according to the optimal results

in Table 5.6, the responsible area of Lopburi (RBC 2) should cover seven provinces; namely, Ayutthaya, Lopburi, Nakhonnayok, Singburi, Suphanburi, Saraburi, and Angthong. These seven provinces are close to one another; therefore, they are the optimal solution as compared to the present service provinces. The weighted average transportation cost is 6.32 Baht/unit. The highest average transportation cost is 12.10 Baht/unit for Phuket. In this particular research, the location of RBCs is determined in Muang district of respective provinces. However, the RBC 11 (Nakhonsithammarat) and RBC 12 (Songkhla) were not located in Muang district. Their minimum distances of about 30 km were more than other RBCs. Generally, most of RBCs are located in Muang district due to the proximity to the populous area where large hospitals (center hospitals or Maharaj hospitals) can be found. These hospitals are capable to accommodate a huge number of patients, so the blood demand is very high. This may be a reason why RBCs are located in the populous area because such locations may shorten the distance of blood distribution to surrounding hospitals as well as facilitate blood supply procurement and public relations. The transportation cost in each province may not be much different. From case 1, it is found that the network of RBCs slightly changed. Regarding to the responsible area of blood procurement and minimum blood supply, it renders to the change of servicing area of each RBC. The blood volume in Table 5.6 may be used as a guideline in determining the ideal capacity or blood supply that each RBC should procure for the hospitals in its respective servicing provinces. This is to achieve the optimal or minimum cost of blood distribution country-wide. For example, Chiang Mai (RBC 10) should have at least 154,255 units of blood. However, the current situation is somehow far from the ideal as observed by a lot of blood request placed at the NBC are from remote provinces.

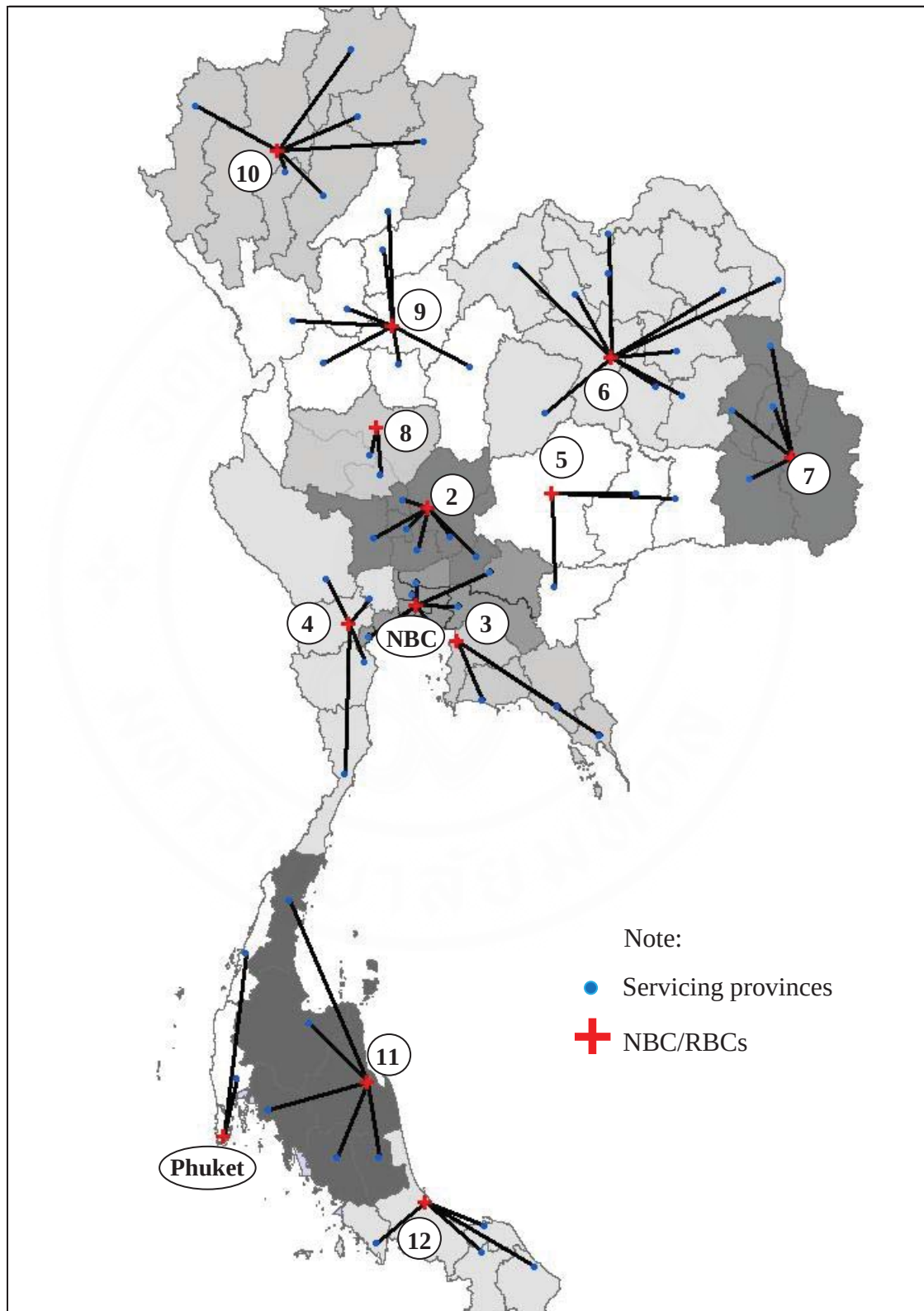


Figure 5.14 The optimal blood distribution pattern: Case 1

Table 5.6 Optimal results for case 1

No	Provinces	Servicing area (provinces)		Optimal transported blood volume (units)	Transportation distance (km.)			Transportation cost (Baht/unit)		
		Optimal	Current		Min	Mean	Max	Min	Mean	Max
1.	Bangkok	8	9	461,699	0.90	51.54	162.52	0.16	10.04	14.92
2.	Lopburi	7	6	87,713	3.20	111.77	165.93	0.27	5.74	15.69
3.	Chonburi	4	7	99,979	2.34	162.76	250.95	0.18	9.71	13.30
4.	Ratchaburi	5	8	71,467	11.12	100.66	215.77	1.00	2.73	8.26
5.	Nakhonratchasima	4	6	100,442	6.58	151.70	175.48	0.59	6.69	7.87
6.	Khonkaen	11	6	184,622	10.00	136.82	276.86	0.90	7.00	11.85
7.	Ubonratchathani	5	7	62,271	6.24	107.60	171.89	0.56	5.73	8.02
8.	Nakhonsawan	3	5	35,278	10.44	36.11	61.00	0.94	3.29	4.25
9.	Phitsanulok	8	6	100,134	3.45	96.82	179.93	0.27	6.34	8.11
10.	Chiang Mai	7	6	154,255	5.62	173.90	286.41	0.45	7.49	12.13
11.	Nakhonsithammarat	6	7	76,671	30.00	104.53	298.68	2.70	4.97	10.41
12.	Songkhla	5	7	49,918	33.84	110.66	197.49	2.70	4.75	7.25
13.	Phuket	3	6	19,297	4.63	192.75	292.61	0.36	12.10	13.02
				Average total transportation						
					7.25	124.12	190.00	0.47	6.32	13.05

4.5.3 Cost comparison for case 1

Recall that the estimated current blood distribution cost from the origin (Bangkok) to the destination (RBCs/hospitals demanding blood supply) is 4,130,304 Baht/year (Table 4.24). The model however yielded the optimal cost for comparison. Table 5.7 showed the optimal distribution pattern solved by LINDO 6.1. The first column indicated the distribution pair between the source of blood supply and the demand point. The second column reports the inputted unit transportation cost between the pair. The third column is the amount of blood that should be transported between the pair. Meanwhile the last column is the product of the amount of transportation blood and unit transportation cost. The summation at the bottom lines of 5,121,403 Baht for transportation from all provinces to all provinces and 857,297 Baht for only Bangkok to all provinces. The optimal transportation cost decreases by $(4,130,304 - 857,297) = 3,273,007$ Baht from the present.

Table 5.7 Optimal results from solving the transportation model in Case 1

Pairs (1)	C_{i_j} (Baht/unit) (2)	X_{i_j} (units) (3)	$C_{i_j} X_{i_j}$ (Baht) (4)
Bangkok_Bangkok	0.16	370,594	60,036
Bangkok_Chachoensao	14.92	14,656	218,668
Bangkok_Nonthaburi	4.22	12,092	51,028
Bangkok_Pathumthani	7.72	21,197	163,641
Bangkok_Phachiburi	8.77	11,078	97,154
Bangkok_Samutprakan	7.18	17,634	126,612
Bangkok_Samutsongkhram	13.64	4,375	59,675
Bangkok_Samutsakhon	7.99	10,073	80,483
Sum Bangkok to other provinces	64.60	461,699	857,297
Chonburi _Chanthaburi	9.77	25,989	253,913
Chonburi _Chonburi	0.18	53,923	9,706
Chonburi _Trat	13.30	3,668	48,784

Table 5.7 Optimal results from solving the transportation model in Case 1 (cont.)

Pairs (1)	C_{i_j} (Baht/unit) (2)	X_{i_j} (units) (3)	$C_{i_j} X_{i_j}$ (Baht) (4)
Chonburi _Rayong	6.06	16,399	99,378
Khonkaen_Kalasin	6.53	11,740	76,662
Khonkaen_ Khonkaen	0.90	59,208	53,287
Khonkaen_Chaiyaphum	5.52	14,346	79,190
Khonkaen_Nakhonpanom	11.85	6,678	79,134
Khonkaen_Maharakham	4.15	10,886	45,177
Khonkaen_Rot Et	4.85	18,030	87,446
Khonkaen_Loei	7.07	9,711	68,657
Khonkaen_Sakonkakhon	8.29	12,813	106,220
Khonkaen_Nongkhai	7.73	9,840	76,063
Khonkaen_Nongbualamphu	5.00	4,151	20,755
Khonkaen_Udonthani	4.63	27,219	126,024
Chiang Mai_Chiang Rai	6.36	31,213	198,515
Chiang Mai_ Chiang Mai	0.45	64,631	29,084
Chiang Mai_ Nan	12.13	9,619	116,678
Chiang Mai_ Phayao	5.12	11,488	58,819
Chiang Mai_ Mae Hong Son	9.13	3,599	32,859
Chiang Mai_Lampang	4.72	21,583	101,872
Chiang Mai_Lamphun	2.53	12,122	30,669
Nakhonratchasima_ Nakhonratchasima	0.59	57,304	33,935
Nakhonratchasima_Buriram	5.72	20,402	116,699
Nakhonratchasima_Sakaeo	7.87	6,628	52,162
Nakhonratchasima_Surin	6.49	16,108	104,541
Nakhonsithammarat_ Krabi	5.47	5,395	29,511
Nakhonsithammarat_Chumphon	10.41	17,575	182,956
Nakhonsithammarat_Trang	3.13	7,893	24,705.09

Table 5.7 Optimal results from solving the transportation model in Case 1 (cont.)

Pairs (1)	C_{i_j} (Baht/unit) (2)	X_{i_j} (units) (3)	$C_{i_j} X_{i_j}$ (Baht) (4)
Nakhonsithammarat_ Nakhonsithammarat	2.70	20,252	54,680
Nakhonsithammarat_Phthalung	5.77	7,578	43,725
Nakhonsithammarat_Suratthani	5.66	17,978	101,755
Nakhonsawan_Chai Nat	4.25	6,143	26,108
Nakhonsawan_ Nakhonsawan	0.94	23,153	21,755
Nakhonsawan_Uthathani	2.32	5,982	13,878
Phitsanulok_Kamphaengphet	4.66	8,978	41,837
Phitsanulok_Tak	5.38	7,601	40,893
Phitsanulok_Phichit	3.51	8,100	28,431
Phitsanulok_ Phitsanulok	0.27	22,832	6,165
Phitsanulok_Phetchabun	6.56	18,423	120,855
Phitsanulok_Phare	8.11	11,491	93,192
Phitsanulok_Sukhothai	3.45	9,219	31,806
Phitsanulok_Uttaradit	6.74	13,490	90,923
Phuket_Phangnga	13.02	4,160	54,163
Phuket_ Phuket	0.36	11,390	4,100
Phuket_Ranong	11.18	3,747	41,891
Ratchaburi_Kanchanaburi	3.08	13,437	41,386
Ratchaburi_Nakhonpathom	2.87	17,758	50,965
Ratchaburi_Phachuap Khirikhan	8.26	9,087	75,059
Ratchaburi_Phetchaburi	2.25	7,592	17,082
Ratchaburi_ Ratchaburi	1.00	23,593	23,612
Lopburi_Nakhonnayok	8.83	4,350	38,411
Lopburi_Ayutthaya	3.43	19,594	67,207
Lopburi_ Lopburi	0.27	23,368	6,309
Lopburi_Saraburi	15.69	20,748	325,536

Table 5.7 Optimal results from solving the transportation model in Case 1 (cont.)

Pairs (1)	C_{i_j} (Baht/unit) (2)	X_{i_j} (units) (3)	$C_{i_j} X_{i_j}$ (Baht) (4)
Lopburi_Singburi	1.82	6,575	11,967
Lopburi_Suphanburi	4.96	8,241	40,875
Lopburi_Angthong	2.40	4,837	11,609
Songkhla_Narathiwat	7.25	7,261	52,642
Songkhla_Pattani	3.93	5,510	21,654
Songkhla_Yala	5.22	9,144	47,732
Songkhla_Songkhla	2.70	25,701	69,393
Songkhla_Satun	4.64	2,302	10,681
Ubonratchathani_Mukdahan	8.02	5,843	46,861
Ubonratchathani_Yasonthon	5.58	7,049	39,333
Ubonratchathani_Sisaket	4.86	15,275	74,236
Ubonratchathani_Amnatcharoen	4.44	3,312	14,705
Ubonratchathani_Ubonratchathani	0.56	30,792	17,293
Total	427.49	1,503,746	5,121,403

This annual excessive cost is a considerably high amount of money. As being the independent agency that pursues charity and non-profit works, the annual budget of the NBC should be used for the maximum benefit. One can say that this budget should be used for developing quality inspection/control because it is the technicality that the NBC is specialized. Million of Baht should not be wasted in the long-distance blood distribution because regional hospitals are already within the responsible area of RBCs. However, there are many reasons attributable to insufficient blood supply such as limited of number blood donors, the expertise of responsible officers or the readiness of necessary tools. All these contributed to many daily blood requests to the NBC from regional hospitals and RBCs. Perhaps, there are potential benefits to think about improving the blood distribution in Thailand.

5.6 Case 2: new network design with unlimited blood supply

This case represents the situation when the blood service network is re-designated to become a new system with unlimited blood supply. The analysis will determine whether the system should increase the number of RBCs, or how many RBCs should be available in the system. In addition, it will determine provinces where these RBCs should be located. The results will be presented in two parts. The first part considers the overview of the optimal distribution pattern obtained from each case. The second part involves the total system cost and appropriateness of arrangement of the candidate RBCs whose locations were located. The new network design of blood service in Case 2 specified that all candidate RBCs in 76 provinces can procure blood at unlimited supply. This case used the Uncapacitated Fixed Charge Facility Location model. Details of this model were explained in Section 5.2.1.

This research used the IBM ILOG OPL IDE 6.3 software as the tool to solve the problem. According to the resulting optimal location and blood distribution pattern as shown in Figure 5.15, this case suggests to locate only one NBC in Bangkok (X_1). That means, in corresponding to the unlimited blood quantity of this case's assumption, this lone NBC is capable in providing blood to all provincial hospitals sufficiently. Historically, this blood distribution network pattern of Case 2 is similar to the network in the past. There was only one blood center, which was the National Blood Center (NBC, 2007). There was no policy to establish RBCs in big provinces for helping the NBC. But the NBC was unable to meet the demand. Much of the blood had to be disposed due to expiration and degradation as a result of long distance delivery. The blood quality control was also under standard. Therefore, much of the blood was lost uselessly.

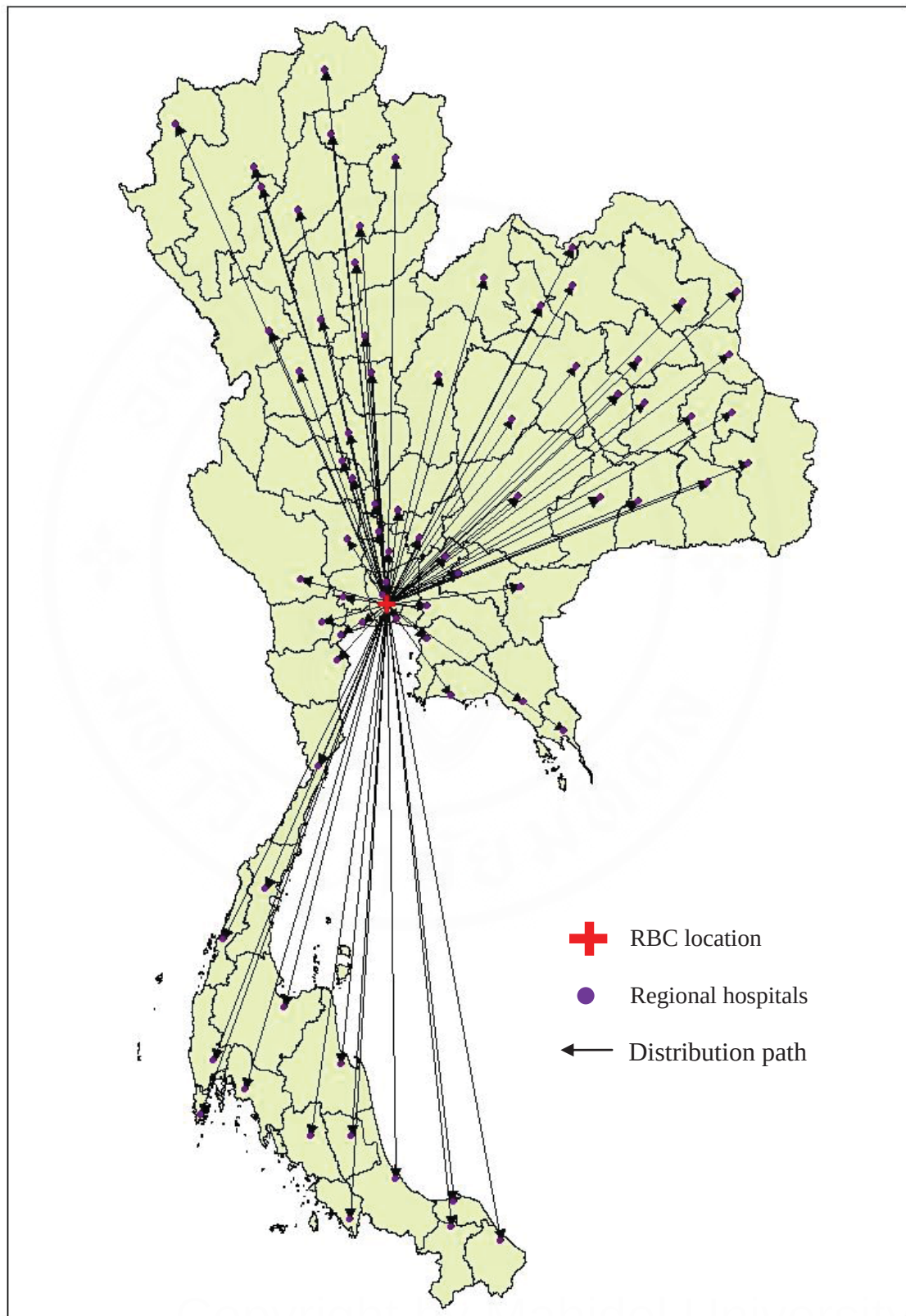


Figure 5.15 Optimal locations and distribution patterns of Case 2

The total system cost of Case 2 was found 800,417,932 Baht (details are shown in Table G.1 of Appendix G). This cost divided into two parts. The first part is the fixed cost for establishing the RBC for 780,490,116 Baht. This cost was estimated from the combination of land price, the construction, technical equipment required for the RBC, and operational cost. The second part was the transportation cost, which was 19,927,816 Baht. The line graph in Figure 5.16 shows transportation costs for all provinces. The province with the highest cost was Narathiwat, which is about 55.33 Baht/unit (Appendix G, Table G.1, column 3: Delivery cost). The distance from the NBC to this province is about 1,185 km. At present, blood is delivered to this province via several delivery modes. Firstly, blood is delivered by the NBC's van to Suvarnabhumi Airport. Then it is taken by an airplane to Hat Yai Airport. The Songkhla RBC sends a van to take the blood from the airport. In the following day, the blood will be delivered from the Songkhla RBC to Narathiwat hospital by a public carrier. In total, the lead time (from the NBC to Narathiwat hospital) takes approximately 30 hours, which is so long that blood quality may be affected. In this situation, temperature inside the blood box can be fluctuated due to using several transportation modes. More importantly, the temperature may be hard to control.

According to the results obtained from the Case 2 analysis, only the NBC would have to take a great working regarding blood recruitment. In addition, it will also face problems regarding quality control and high transportation cost everyday. This blood service is the pattern that the NBC used in the past. The major problem happened to the NBC. It could not recruit sufficient blood for all the hospitals. The analysis results of Case 2 revealed that the NBC will need to prepare blood for all 76 provincial hospitals equal for 1,503,746 units/year (Details are shown in Table G.1 of Appendix G). However, at present, the NBC can obtain blood only 588,748 units/year. That means the NBC cannot procure sufficient blood for all hospitals in Thailand. Therefore, this was a reason that the Thai Red Cross Society had a policy to establish RBCs in big provinces in order to recruit sufficient blood procurement and to reduce blood delivery time. The blood service system development starts from the central and disperses to regional areas. In case of Thailand, the central refers to Bangkok because of the convenience of blood transportation and efficient blood recruitment.

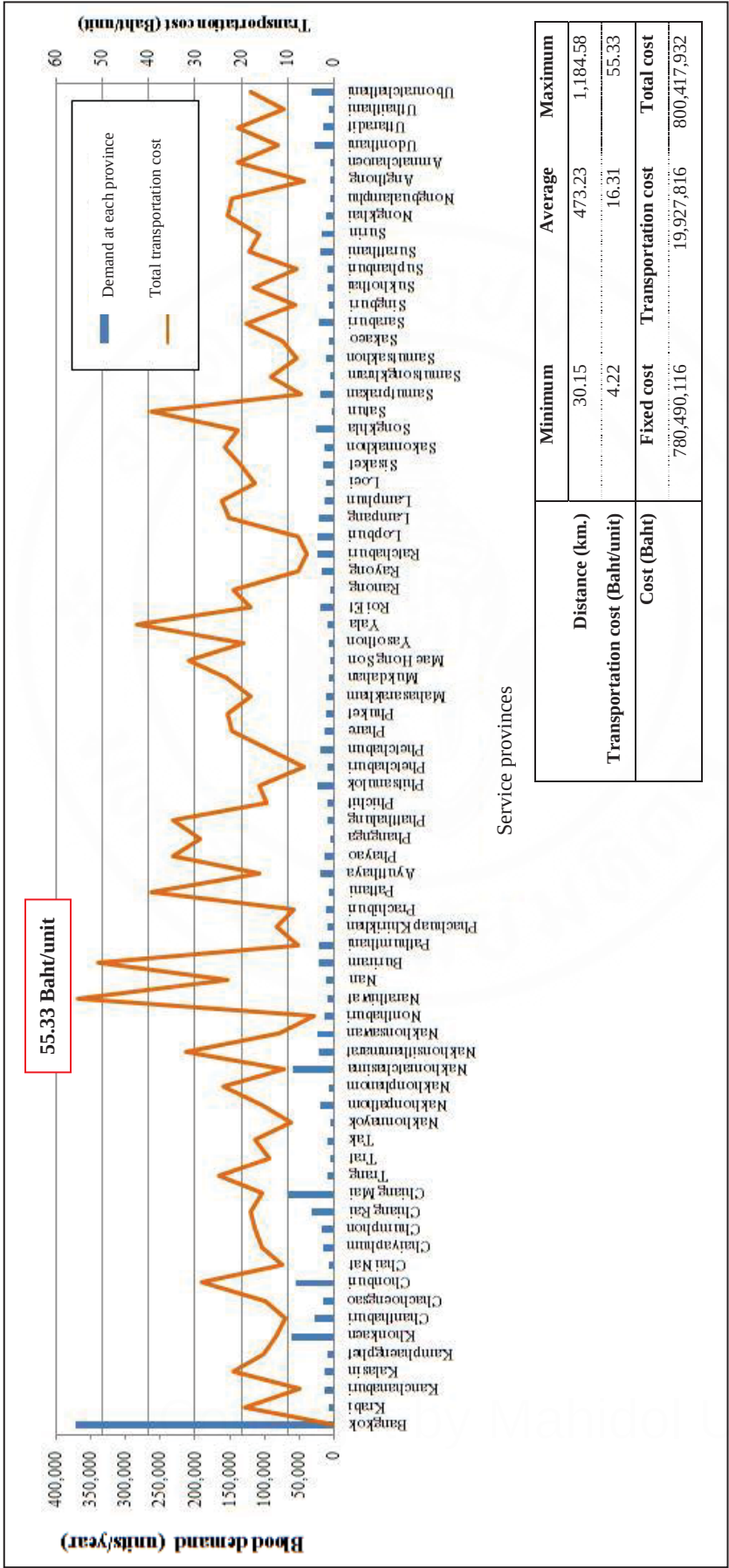


Figure 5.16 Demand and transportation cost by province

5.7 Case 3: new network design with limited blood supply

When considering previous data of blood demand and blood supply, an increasing trend of procured blood units was found over the years, as shown in Figure 5.17 (see more details in Figure E.1 of Appendix E). Although, the NBC could procure more blood over time; blood demand also keeps increasing even more. In addition, the difficulties also relate to characteristics of blood products that had various limitations, such as temperature. Blood also has a short expiration period of only 21 days (the processes of recruitment, collection, and distribution). Another important limitation is that blood cannot be donated so frequently. In order to allow new red blood cells to be generated, a donor would have to wait for three months before being able to donate again. Therefore, the donor can donate as often as four units per year, which is insufficient for daily blood consumption of the increasing number of patients. Accordingly, procured blood quantity was added as a constraint in the model of Case 3 so that the assumption more closely to the real situation.

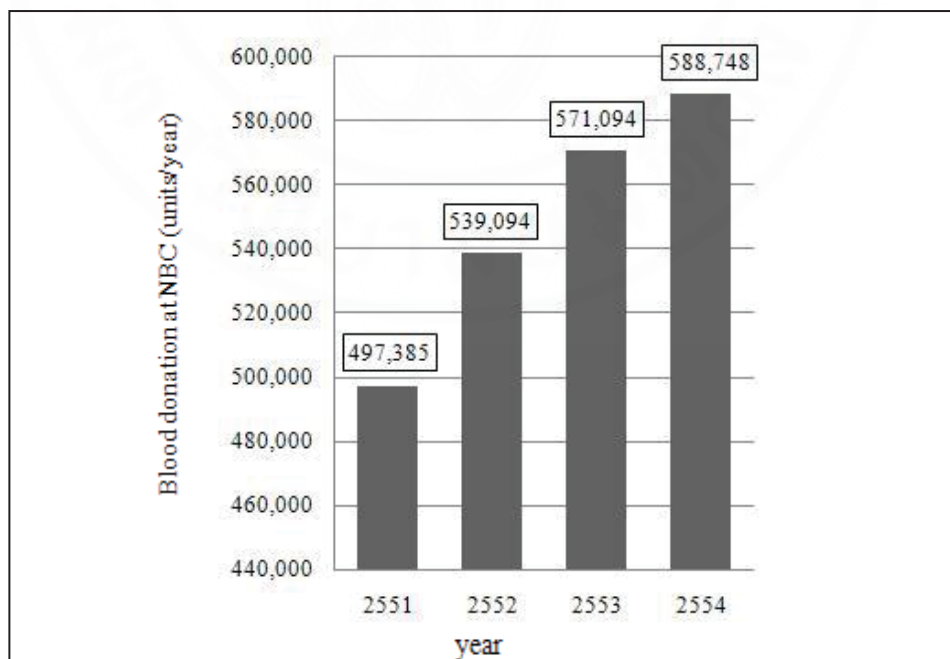


Figure 5.17 Blood donation at NBC

The analysis results of Case 3 are shown that 36 RBCs should be established, which include 11 RBCs in the Central region (including the NBC in Bangkok), four RBCs in the Northern region, 11 RBCs in the Northeastern region, four RBCs in the Southern region, four RBCs in the Eastern region, and two RBCs in the Western region (details are shown in Table H.1 of Appendix H). Figure 5.18 displays comparative locations of the RBCs. According to the population consensus in 2010, these are provinces with relatively dense population. It is therefore assumed that optimal provinces for establishing RBCs are provinces with higher population or with higher economic activities than other provinces in the region. At present, the 12 RBCs are located in Lopburi, Chonburi, Ratchaburi, Nakhonratchasima, Khonkaen, Ubonratchathani, Nakhonsawan, Phitsanulok, Chiang Mai, Nakhonsithammarat, Songkhla, and Phuket, all of which are also ranked in the top 20 provinces in Thailand in terms of population density. This is considered reasonable because, with more population, it is likely that there will be more blood donors. Regarding patients, most of them would prefer to have treatment in hospitals with higher efficiency on medical services. Such these hospitals are known as center hospitals, which also include provincial hospitals. In addition, since these hospitals are within the area of Muang district of each province, it is therefore more convenient and faster to deliver blood from the RBCs to patients due to shorter distances.

Comparing the structure of blood service networks in Thailand and Japan, both countries divide their administration boundaries into provinces, and both of them employ similar decentralized blood services model. The analysis of Case 3 also resulted in an arrangement of RBCs similar to the existing system of blood service network in Japan. According to Figure 5.19 that shows population density in provinces of Japan, provinces with high population density were generally chosen for establishing Principal Blood Centers. They have duties to provide blood services to hospitals in nearby provinces. Each of these seven Principle Blood Centers in Japan functions similarly to the National Blood Center of Thailand, which is located in Bangkok. In conclusion, it is much likely that RBCs are appropriate to be located in the important and crowded provinces for the convenience of blood recruitment and blood delivery.

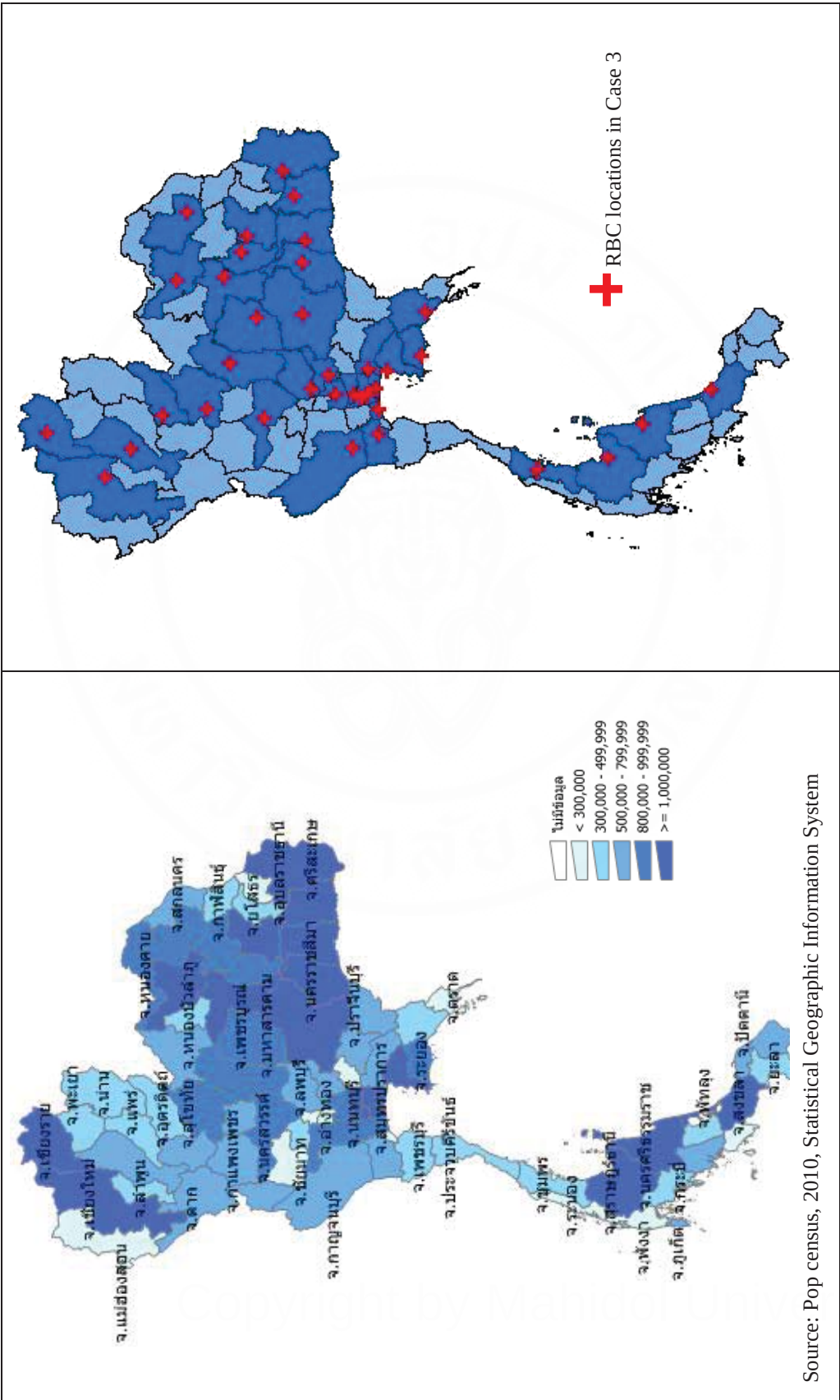


Figure 5.18 The relationship between the number of population and the optimal RBC locations in Case 3

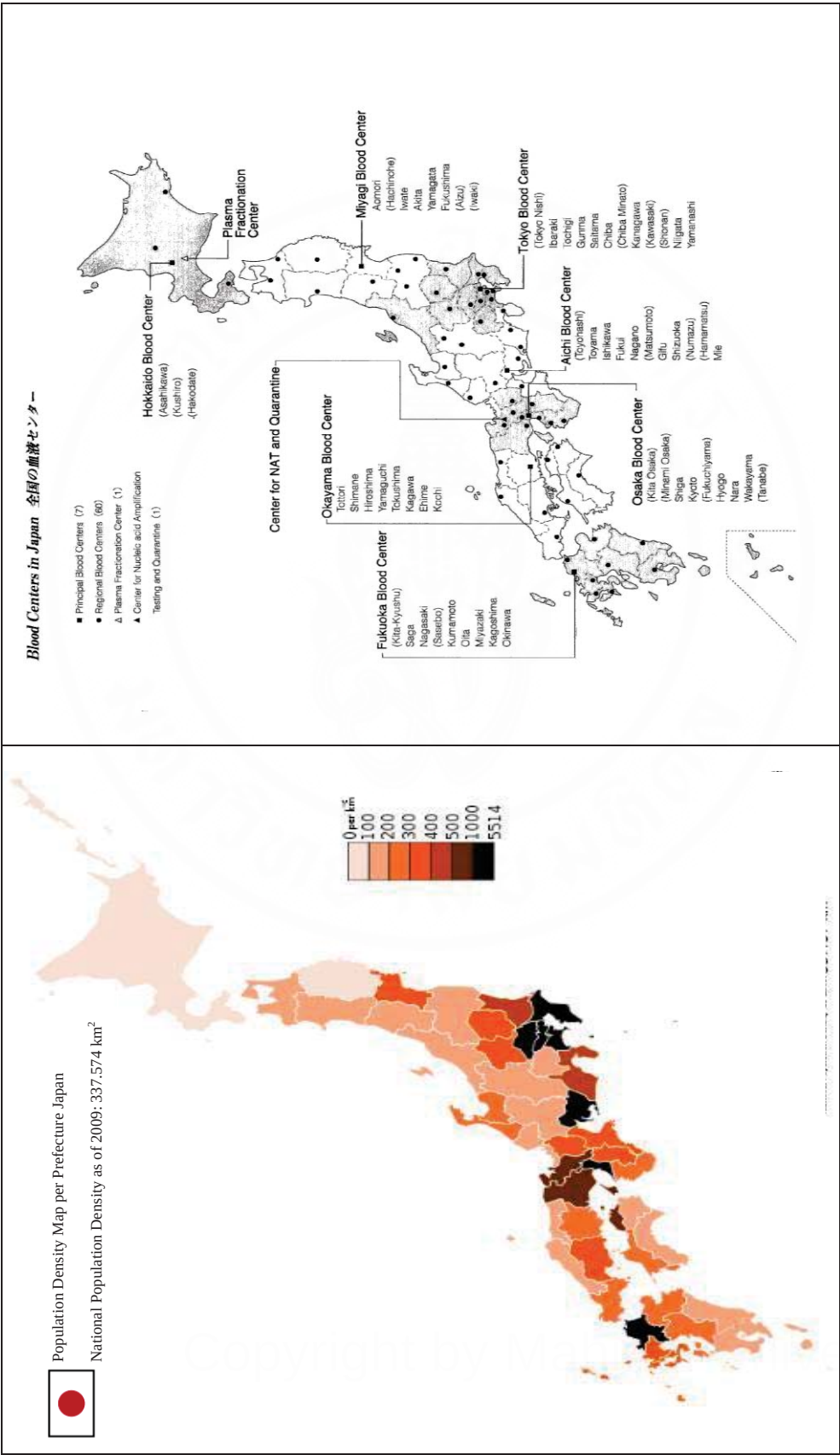


Figure 5.19 The relationship between population density and blood center locations in Japan (Japanese Red Cross, 2007)

The analysis results in Case 3 (detailed in Table H.1 of Appendix H), it was found that the total fixed cost for establishing all 36 RBCs was 1,778,840,146 Baht. The establishment cost for the NBC in Bangkok was the highest one, which was 780,490,116 Baht. These 36 RBCs include all the currently existing 12 RBCs, except only the Phuket RBC. The optimal RBCs location and blood distribution pattern were shown in Figure 5.20. Some RBCs serve only one province such as Chanthaburi RBC, Chachoengsao RBC, Chaiyaphum RBC, Chumporn RBC, Chiangrai RBC, Buriram RBC, Rayong RBC and Samutprakarn RBC. Some RBCs serve nearby provinces. Some RBCs serve not only hospitals in several nearby provinces but also require some support from the NBC in Bangkok in order to meet the demand. For example, Songkhla RBC has duty to serve six provinces; namely, Narathiwat, Pattani, Phatthalung, Yala, Songkhla, and Satun. Meanwhile, the Songkhla RBC also receives blood from the Bangkok RBC too.

Regarding the locations of all the RBCs, the model located more RBCs in the Central Region than other regions. This is because the blood demand of this region was accounted for as high as 57% of the overall demand of the country. For this pattern of blood distribution, the average distance of all routes in the network is about 197 km. The transportation cost decrease about 4.5 (transportation cost of Case 2/Case 3 = 19,927,816/4,413,858). The details are shown in Table G.1 of Appendix G and Table H.2 of Appendix H. The most of the transportation routes are short routes between provinces around the RBC. Figure 5.21 displays relationship between Blood supply (Bar graph) and Transportation cost (Line graph) of all the 36 RBCs, as required for serving their corresponding service provinces. According to the figure, the NBC (Bangkok) should prepare blood at the highest quantity among all RBCs, which is about 600,000 units/year, so that it can meet the demand of its service provinces. Regarding responsible areas of the RBCs in Case 3 as shown in the figure, each RBC is responsible for approximately two service provinces.

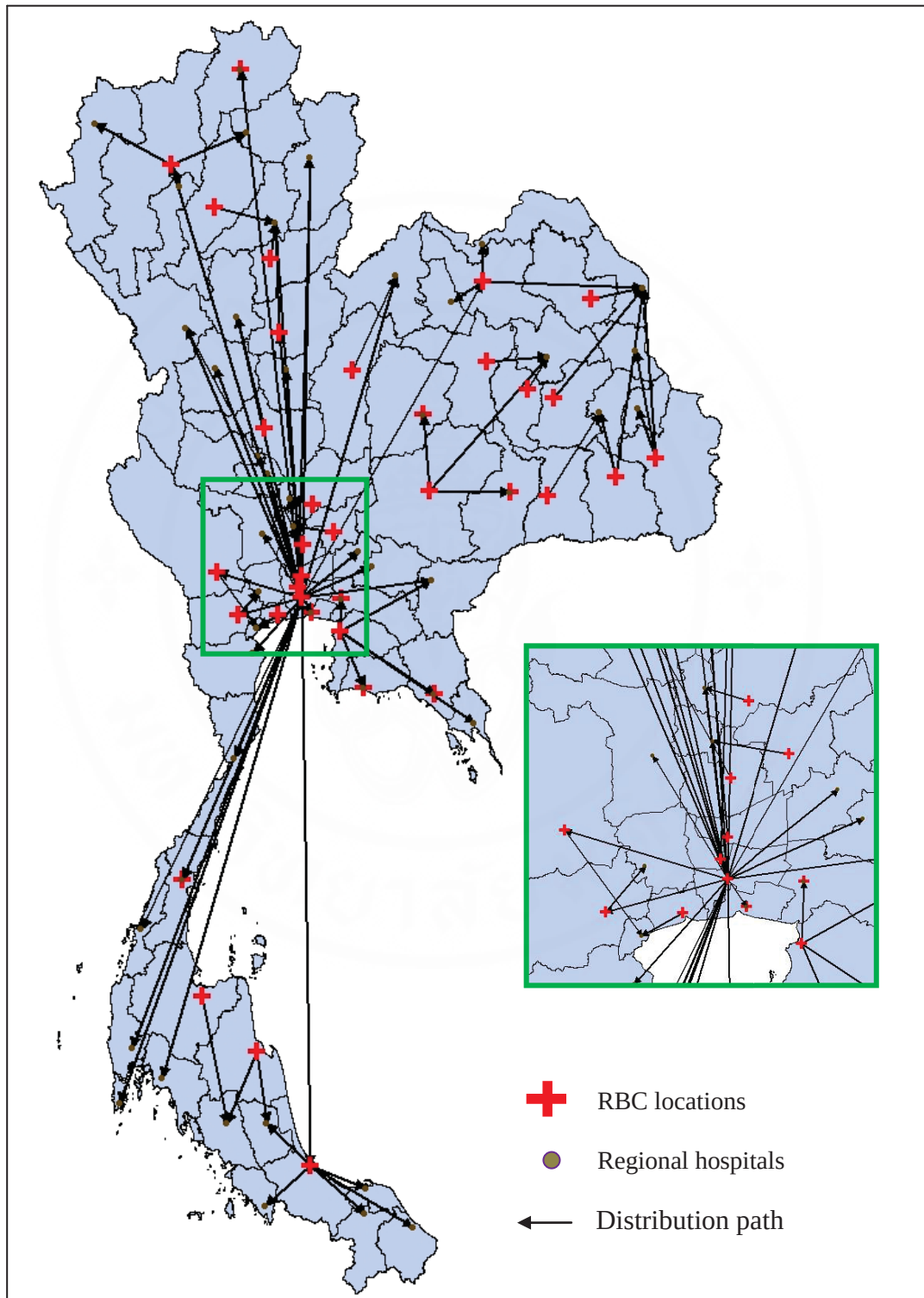


Figure 5.20 Optimal locations and distribution pattern of Case 3

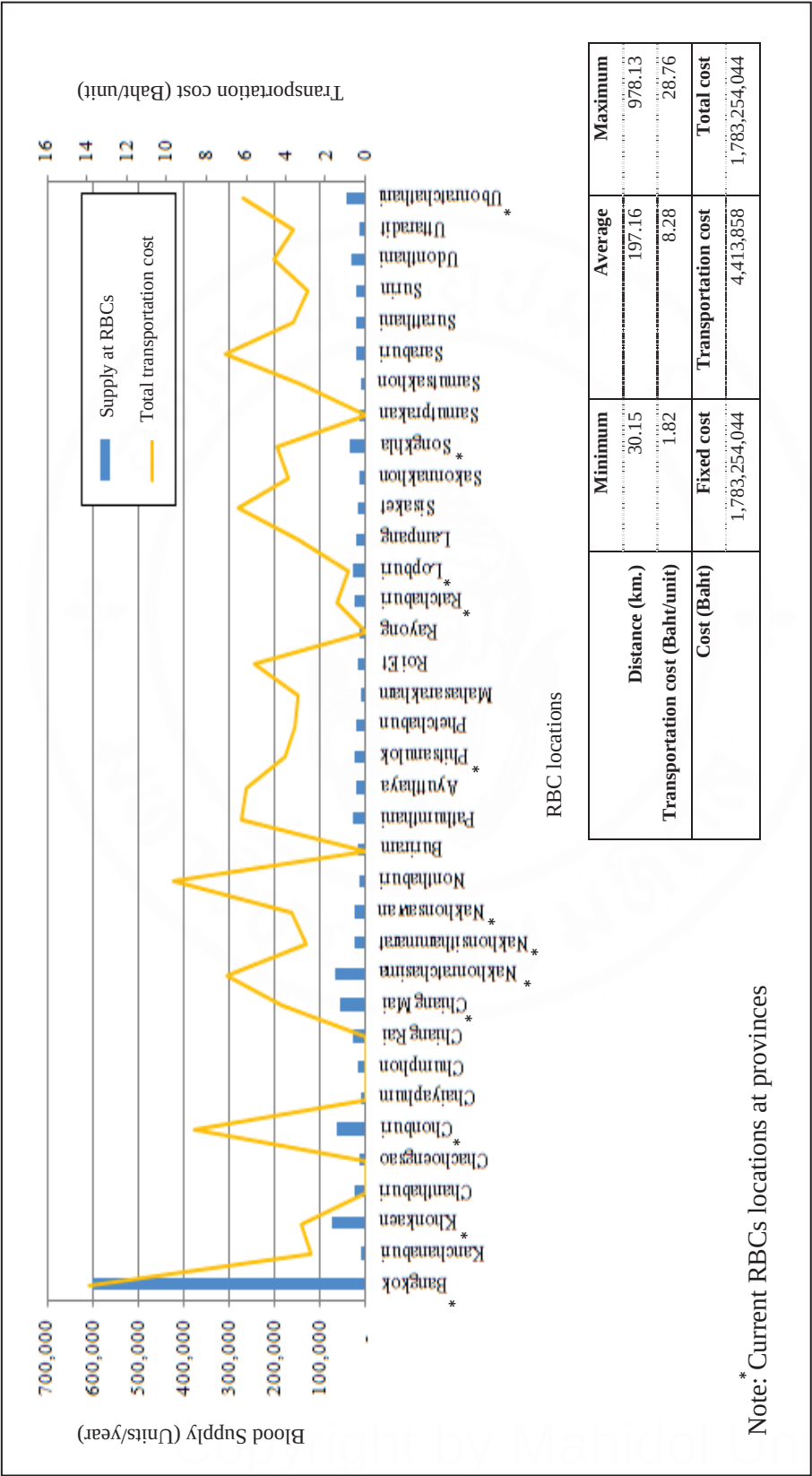


Figure 5.21 Supply and transportation cost at each RBC in Case 3

Despite the advantage of lower transportation cost, there is also a disadvantage due to many more number of RBCs, which increases the establishment cost. Establishment of an RBC requires a high total cost of equipments, machines, technical experts, etc. This cost varies adversely with the transportation cost. With the higher number of RBCs, blood distribution would require shorter transportation distance, and that means less transportation cost. The results of Case 3 analysis shows that, when considering one year of operation that involves both fixed cost and transportation cost, the fixed cost is accounted for 99% of the total cost. It seems like this model pays too much attention to transportation cost without considering real limitations, such as the possibility of acquiring enough budget for establishing all these 36 RBCs. Therefore, we will continue with Case 4, which proposes a solution to determine the optimal blood distribution network pattern by maintaining all 13 existing RBCs. It is hopeful that the case assumption will yield a better option for designing the blood distribution service network.

5.8 Case 4: existing configuration plus additional new RBCs with unlimited blood supply

The National Blood Center is a non-profit organization. Most of its budget comes from the government and donation. The limited budget is therefore a very important issue when making decisions of establishing its branches as RBCs. Establishment of each RBC requires capital for many millions Baht, and various details are needed to be considered. Therefore, Case 4 analyzes for the optimal network design pattern that is closest to the current pattern. For this case, all RBCs are reserved like the present. More locations for RBCs can also be added so that blood distribution service covers all areas in Thailand. In this case, we assume that all RBCs can procure blood sufficiently for their patients. In other words, these RBCs have unlimited blood supply. The Uncapacitated Fixed Charged Facility Location model, as explained in Section 5.2.2 was used.

The results derived from Case 4 and corresponding details are displayed in Table I.1 of Appendix I. Figure 5.22 shows a comparison between the designated blood distribution pattern that the NBC has determined and the optimal distribution pattern of Case 4. According to the figure, all 13 locations (one NBC and 12 RBCs) remain unchanged. Based on the assumption, this case will not establish new RBCs in any provinces if the existing 13 RBCs can procure sufficient blood. Therefore, the total number of locations is still at 13. The 13 locations are in Bangkok, Lopburi, Chonburi, Ratchaburi, Nakhonratchasima, Khonkaen, Ubonratchathani, Nakhonsawan, Phitsanulok, Chiangmai, Nakhonsrithammarat, Songkhla, and Phuket. However, there is a difference between the two patterns, which is the transportation routes for sending blood to provinces under responsibility of each RBC.

For example, Sakaew will change its route from taking blood at Chonburi RCB to taking blood at the Nakhonratchasima RBC instead. In case of Sisaket in the Northeastern region, previously, the NBC assigns Sisiaket to take blood from Nakhonratchasima RBC. However, results in Case 4 suggest that blood services for Sisaket province should be taken care by Ubonratchathani RBC, supposed that it has sufficient blood supply. This is because the distance from Sisaket to Ubonratchathani (60 km.) is much shorter than the distance to Nakhonratchasima (270 km.). If Sisaket hospital receives bloods from Ubonratchathani, the transportation distance will be reduced by 78%. That means the transportation cost will be reduced and blood quality will be enhanced. Details regarding blood transportation to Sisaket province are shown in Figure 5.23. As mentioned above, it can be seen that the route arrangement for blood transportation based on administrative zones specified by the Department of Provincial Administration's Inspectors, the Ministry of Interior might be inappropriate. The National Blood Center might need to consider new routes for blood distribution since the objectives of operation between the blood service sector and the Ministry of Interior are different.

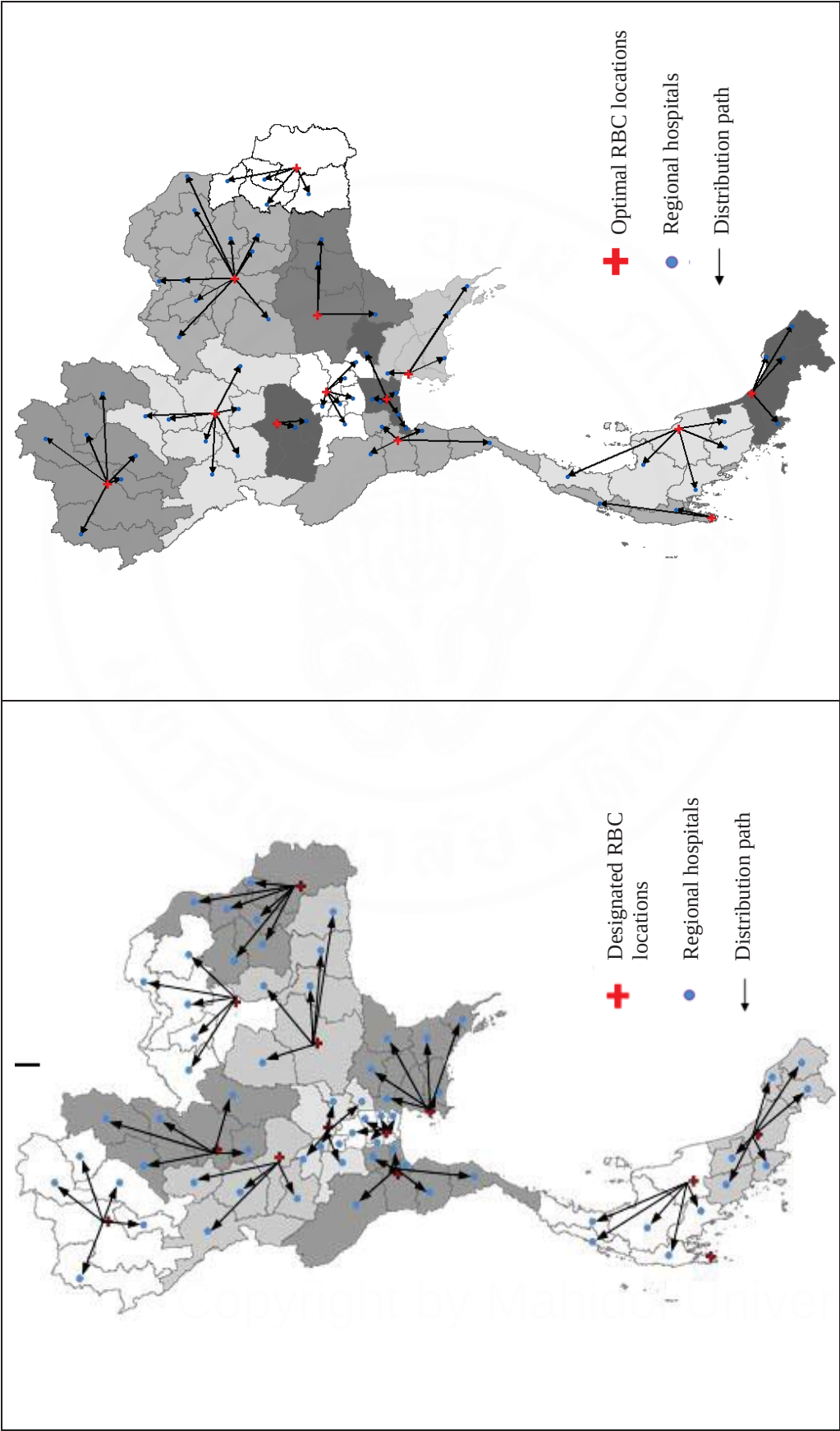


Figure 5.22 The comparison between designated RBC locations and the optimal result in Case 4

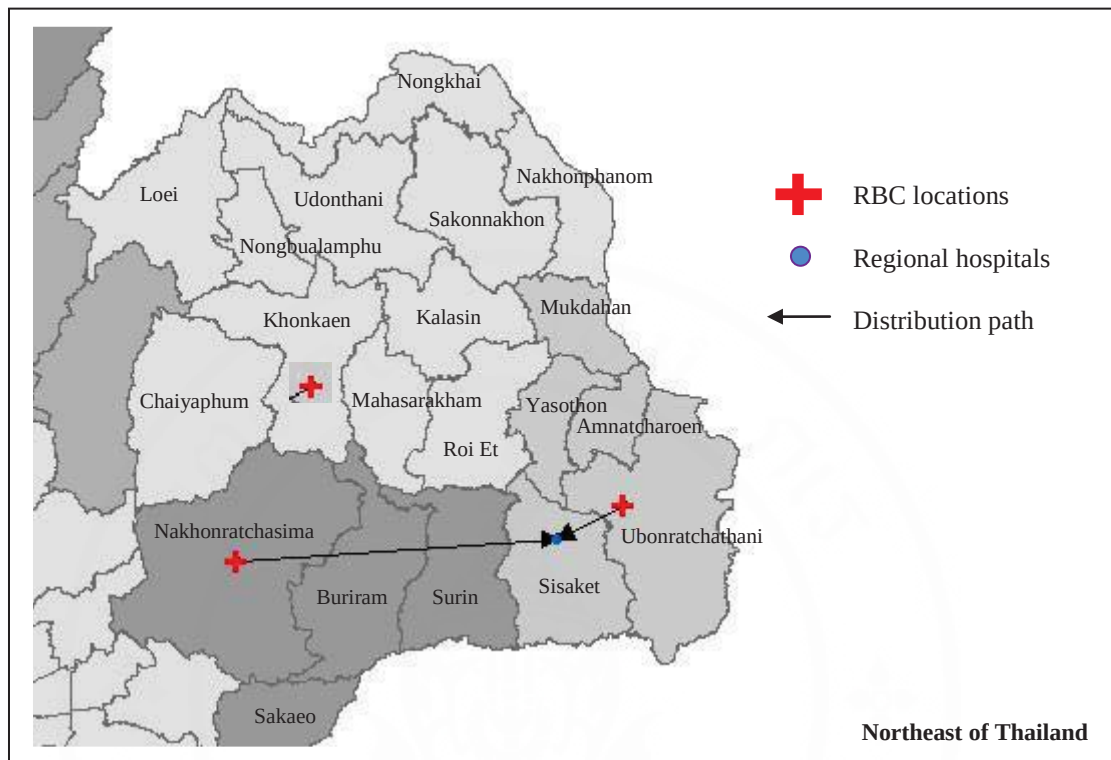


Figure 5.23 The distance between RBC Nakhonratchasima and Ubonratchathani to Sisaket

Table 5.8 reports results from solving the Uncapacitated Fixed Charged Facility Location model in case 4 (see more details in Table I.2 of Appendix I). Column 1 shows optimal locations of all 13 RBCs, Columns 2 and 3 show the number of provinces that each RBC takes responsibility. Accordingly, most RBCs have fewer provinces, except only Khonkaen, Phitsanulok, and Chiang Mai RBCs that have more responsible provinces. In particular, Khonkaen RBC has five more provinces under responsibility. Although the Northeastern region has the largest area among all regions, accounted for about one third of the whole country, there are only three RBCs in this region; namely, Nakhonratchasima, Khonkaen, and Ubonratchathani RBCs. Blood supply quantities of these RBCs according to the current blood distribution pattern are 65,839, 31,415 and 41,945 units/year, respectively. Khonkaen RBC appears to be the one that has the smallest blood quantity. However, in order to comply with the optimal result of Case 4, Khonkaen RBC will need to recruit blood for as much as 184,622 units/year. This high amount of blood is certainly too high for

Khonkaen RBC to be able to obtain by itself alone due to various problems concerning blood donors, equipment, locations, infrastructure, and insufficient officers in the RBC.

The designated RBCs pattern was specified by the Ministry of Interior. We calculated the transportation distance of designated RBC locations by using the Uncapacitated Fixed Charged Facilities Location model. The Table 5.8 shows the current transportation distance, (150.47 km. on average) at the bottom line. This is relatively longer than the optimal re-design's (131 km. on average). The longest transportation distance of the current case is even much greater than that of the Case 4 situation; i.e., 927.80 km versus 348.63 km (Table 5.8). Furthermore, from the total transportation cost perspective, the current network incurred about 6.3 million Baht annually or about 1.7 million Baht over the optimal total transportation cost in Case 4. Locating RBCs without proper analysis and design seems to cost the NBC a bit more every year, not to mention the quality of blood that can be affected from longer transportation distance.

Column 6 highlights the importance of donor recruitment. The table shows the amount of blood that each ideal RBC must have in order to fulfill the demand. Meanwhile, the fourth column shows the actual amount of blood supply. It is obvious that the NBC is the only blood center that can serve the demand of its respective service provinces. This conforms to the actual current situation that RBCs cannot supply sufficient blood to patients. The NBC, therefore, needs to reinforce and empower them. All designated RBCs will have to do a lot of work for recruiting sufficient number of donors, otherwise the estimated cost saving will never come true. This is the major challenge for the NBC and perhaps for other NBCs globally too.

Table 5.8 Optimal result for Case 4

Optimal RBCs in Case 4 (1)	Servicing provinces		Supply (Units/year)			Supply graph (Units/year) (7)
	Current (2)	Case 4 (3)	Current (4)	Optimal (5)	Differ (6)	
Bangkok	9	7	599,705	447,043	152,662	
Lopburi	6	7	27,524	87,713	-60,189	
Chonburi	7	5	59,517	114,635	-55,118	
Ratchaburi	8	5	25,948	71,467	-45,519	
Nakhonratchasima	6	4	65,839	100,442	-34,603	
Khonkaen	6	11	67,289	184,622	-117,333	
Ubonratchathani	7	5	41,945	62,271	-20,326	
Nakhonsawan	5	3	25,282	35,278	-9,996	
Phitsanulok	6	8	25,877	100,134	-74,257	
Chiangmai	6	7	57,233	154,255	-97,022	
Nakhonsrithammarat	7	6	26,419	76,671	-50,252	
Songkhla	7	5	36,996	49,918	-12,922	
Phuket	6	3	10,407	19,297	-8,890	
Distance (km.)						
Current RBCs		Minimum	Average	Maximum		
		30.15	150.47	927.80		
Optimal RBCs Case 4		30.15	131.00	348.63		
Transportation cost (Baht/unit)						
Current RBCs		Minimum	Average	Maximum		
		1.82	6.57	24.11		
Optimal RBCs Case 4		1.82	5.00	15.69		
Cost (Baht)						
Fixed cost		Transportation cost		Total cost		
Current RBCs		1,223,307,173	6,309,685	1,229,616,858		
Optimal RBCs Case 4		1,223,307,173	4,652,906	1,227,960,079		

5.9 Case 5: existing configuration plus additional new RBCs with limited blood supply

Since blood from the NBC is supplied to serve the demand of blood disease patients and surgical patients in hospitals (Table E.2 of Appendix E), there should be some relationship between supplied blood quantity and number of hospitals. Figure 5.24 displays relationship between demanded blood quantity (the line graph) and number of hospitals (the bar graph). These two factors tend to correspond positively to each other, with an exception of Bangkok, whose value is outstanding from other provinces. The average quantity of blood demand for each hospital is 1,664 units/hospital/year, but it is as high as 3,600 units/hospital/year for the demand in Bangkok. That means blood demand in Bangkok is over two times higher than other provinces in general. Quantity of blood is an important issue that the RBCs should prepare to ensure its sufficiency for all the demand. Therefore, Case 5 has set an assumption that there is a limitation of blood quantity that the RBCs can procure.

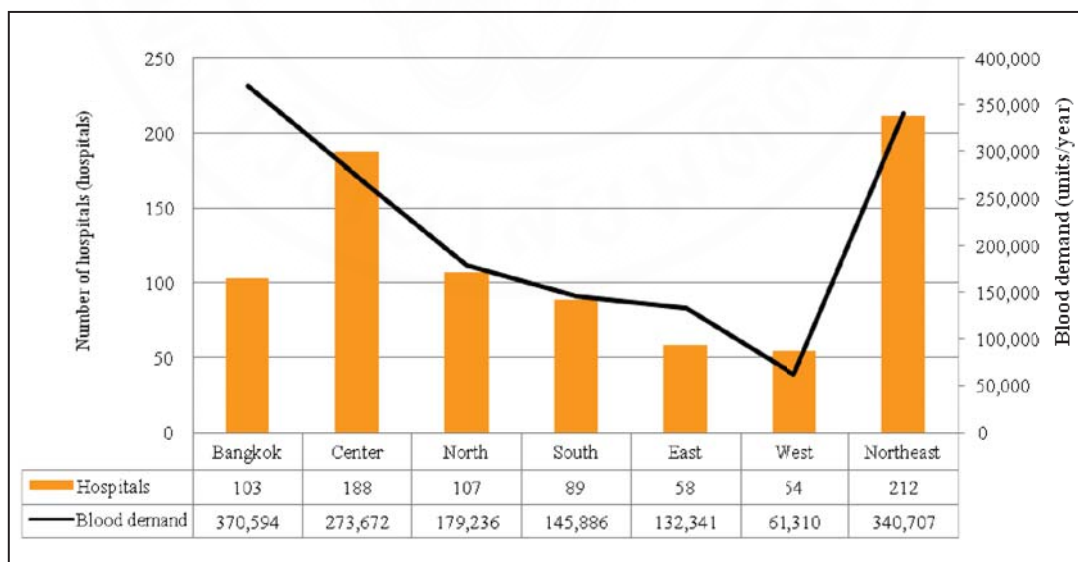


Figure 5.24 Blood demand and the number of hospitals

Figure 5.25 shows analysis results according to Case 5. The results suggest that 36 RBCs should be established. Among them, 11, 4, 5, 4, 2, and 10 RBCs will be in the Central, the Northern, the Southern, the Eastern, the Western, and the Northeastern regions respectively (Details are shown in Table J.1 of Appendix J). Regarding the distribution pattern, some RBCs distribute blood only to hospitals in the province. Some RBCs also distribute blood to nearby provinces. Meanwhile some RBCs need support from the NBC in Bangkok because they have insufficient blood. These patterns of blood distribution are similar to Case 3. Locations of all RBCs in Case 5 and Case 3 are also the same, with an exception of only one RBC. Case 5 locates one RBC in Phuket province whereas Case 3 locates one RBC in Mahasarakarm province instead, as shown in Figure 5.25.

It is also found that the NBC should prepare sufficient blood quantity for two groups of its clients. The first group refers to hospitals in Bangkok, and the second group comprises RBCs and provincial hospitals. Blood quantities required for these two groups are 370,594 and 229,111 units/year, respectively. That means the NBC will need to support blood for regional areas for about one third of its procured blood quantity, which is similar to the current situation.

At the bottom line of Table 5.9, the optimal total system cost is found to be 1,855,935,936 Baht (Fixed cost + Transportation cost). The average distance for blood transportation is about 181.06 km. (Transportation cost varies positively with the distance). There is another blood delivery route from other RBCs that only needs to supply blood to hospitals within the province, such as Chiangmai RBC. When Chiangmai RBC sends blood to Maharaj Nakorn Chiangmai Hospital, it needs only one mode for blood delivery, which is the public carrier mode. Thus the cost for blood transportation of such this RBC is much lower than the cost of the NBC. Figure 5.26 displays similarity of locations and arrangement of RBCs in Case 3 and Case 5.

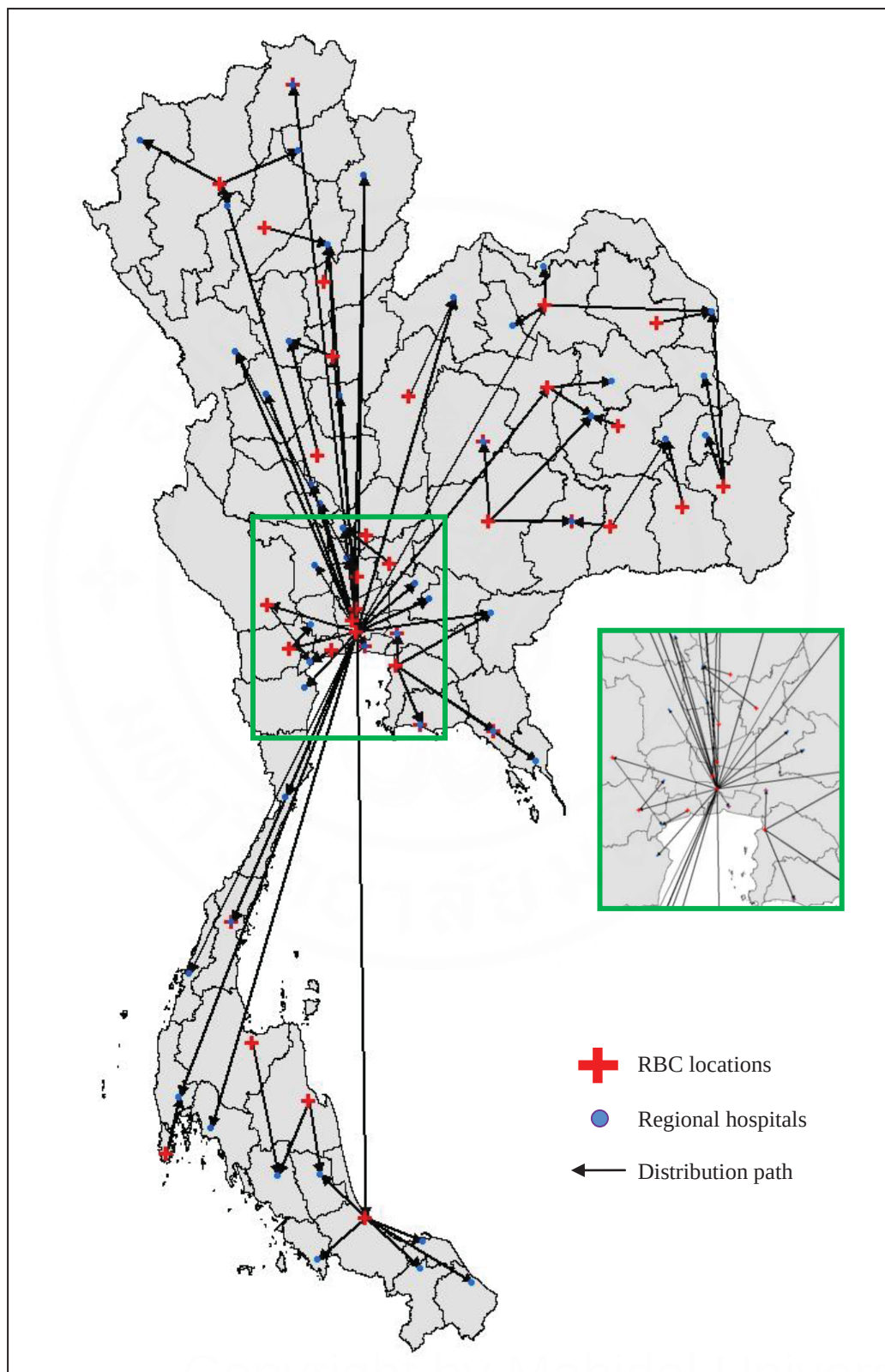


Figure 5.25 Optimal locations and distribution pattern of Case 5

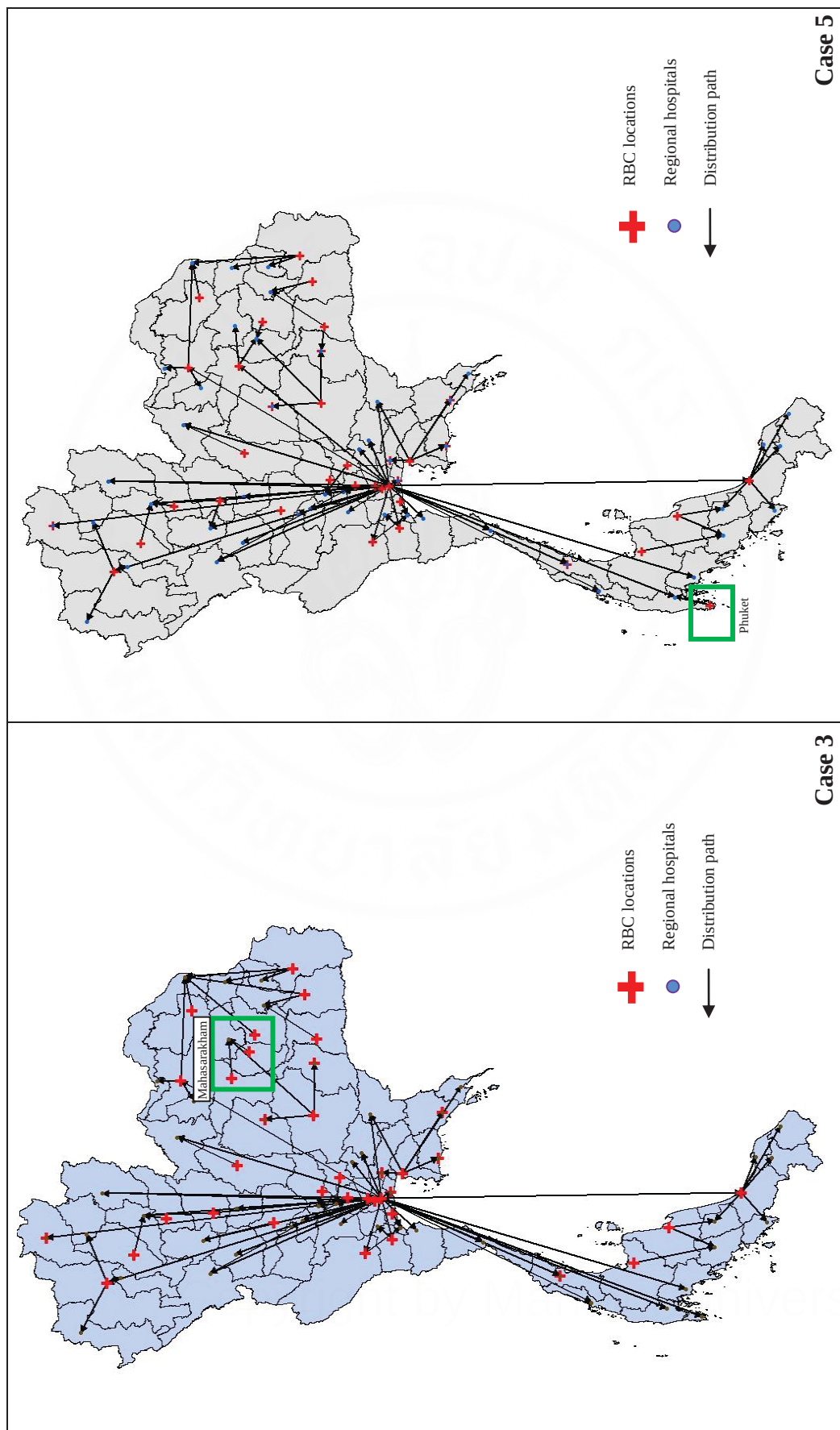


Figure 5.26 The comparison of the optimal locations and distribution pattern between Case 3 and Case 5

Table 5.9 shows a comparison between Case 3 and Case 5 regarding number of RBCs and blood quantity of each RBC. According to Column 1 and Column 2 of the Table, we can see that there is only one different RBC between these two cases; i.e., Phuket RBC in Case 5 and Mahasarakam RBC in Case 3. According to Column 7, we can see that the supplied blood quantities of the RBCs do not differ much. However, considering the total cost of the system, the cost of Case 5 is quite much higher than that of Case 3. The margin is about 72.7 million Baht. It should be noted that 99% of the total cost is fixed cost. According to the real situation, 13 RBCs of Case 5 have actually been established, while only 12 RBCs of Case 3 that have been established. Thus Case 5 needs fixed cost for only 23 RBCs, while Case 3 needs the fixed cost for 24 RBCs, with the additional Mahasarakam RBC.

According to the results, it can be concluded that the optimum number of RBCs is 36 RBCs. This is considered under the constraint of limited blood quantity that each RBC can procure. This number of RBCs can be reduced if each RBC can procure more blood. For example, with an assumption of unlimited blood quantity, the number of RBCs in Case 2 and Case 4 are 1 and 13 RBCs, respectively. However, blood is a product that, unlike others, its production cannot be enhanced. This is because blood has many limitations in terms of the origin (blood donors), life cycle of only 21 days, blood transmitted diseases, appropriate temperature for storing each type of blood products, etc. These are challenging issues waiting to be solved by the NBC.

Table 5.9 Optimal results for Case 5 in comparison with Case 3

Optimal RBCs (provinces)			Servicing provinces			Supply (Units/year)			Supply graph (Units/year) (8)						
Case 3 (1)	Case 5 (2)		Case 3 (3)	Case 5 (4)	Case 5 (5)	Case 5 (6)	Differ (7)		0	100,000	200,000	300,000	400,000	500,000	600,000
Bangkok	Bangkok		30	29	599,711	599,705	6								
Lopburi	Lopburi		2	2	27,524	27,524	0								
Chonburi	Chonburi		6	6	65,171	59,517	5,654								
Ratchaburi	Ratchaburi		2	2	25,947	25,948	-1								
Nakhonratchasima	Nakhonratchasima		5	4	65,838	65,839	-1								
Khonkaen	Khonkaen		2	3	74,551	67,289	7,262								
Ubonratchathani	Ubonratchathani		4	4	41,945	41,945	0								
Nakhonsawan	Nakhonsawan		2	2	25,282	25,282	0								
Phitsanulok	Phitsanulok		2	3	25,877	25,877	0								
Chiangmai	Chiang Mai		4	4	57,230	57,233	-3								
Nakhonsrihammarat	Nakhonsrihammarat		3	3	26,419	26,419	0								
Songkhla	Songkhla		6	6	36,996	36,996	0								
Pathumthani	Pathumthani		2	2	26,709	26,708	1								
Ayutthaya	Ayutthaya		2	2	19,894	19,894	0								
Nonthaburi	Nonthaburi		2	2	15,611	15,611	0								
Samutprakan	Samutprakan		1	1	13,827	13,826	1								
Samutsakhon	Samutsakhon		2	2	11,984	11,984	0								
Saraburi	Saraburi		2	2	22,114	21,831	283								
Chiang Rai	Chiang Rai		1	1	28,048	28,047	1								
Phetchabun	Phetchabun		2	2	20,275	20,275	0								
Lampang	Lampang		2	2	21,719	21,719	0								
Uttaradit	Uttaradit		2	2	14,206	14,206	0								

Table 5.9 Optimal results for Case 5 in comparison with Case 3 (cont.)

Optimal RBCs (provinces)		Servicing provinces			Supply (Units/year)		Supply graph (Units/year)					
Case 3 (1)	Case 5 (2)	Case 3 (3)	Case 5 (4)	Case 3 (5)	Case 5 (6)	Differ (7)	(8)					
Chumphon	Chumphon	1	1	17,044	17,045	-1						
Suratthani	Suratthani	2	2	20,440	20,440	0						
Chanthaburi	Chanthaburi	1	1	25,668	25,828	-160						
Chachoengsao	Chachoengsao	1	1	13,677	14,158	-481						
Rayong	Rayong	1	1	15,796	15,795	1						
Kanchanaburi	Kanchanaburi	2	2	11,996	11,996	0						
Chaiyaphum	Chaiyaphum	1	1	10,367	12,195	-1,828						
Buriram	Buriram	1	1	18,866	18,865	1						
Roi Et	Roi Et	2	2	18,451	18,451	0						
Sisaket	Sisaket	3	2	18,552	18,552	0						
Sakonkakhon	Sakonkakhon	2	2	13,007	13,007	0						
Surin	Surin	2	3	19,992	19,992	0						
Udonthani	Udonthani	4	4	31,414	31,415	-1						
Maharakham	Phuket	2	2	12,049	12,332	-283						
Distance (km.)		Minimum		Average		Maximum						
Optimal RBCs Case 3		30.15		197.16		978.13						
Optimal RBCs Case 5		30.15		181.06		978.13						
Delivery cost (Baht/unit)		Minimum		Average		Maximum						
Optimal RBCs Case 3		1.82		8.28		28.76						
Optimal RBCs Case 5		1.82		6.59		28.76						
Cost (Baht)		Fixed cost		Transportation cost		Total cost						
Optimal RBCs Case 3		1,778,840,146		4,413,858		1,783,254,044						
Optimal RBCs Case 5		1,851,612,720		4,323,216		1,855,935,936						

Supply of Case 3

Supply of Case 5

5.10 Case 6: locating an additional RBC into the current network with unlimited blood supply

For all 13 designated RBCs that the NBC has planned to establish, only Ayutthaya RBC has not been established yet. Therefore, Case 6 is intended to find whether there is any other location that may be more appropriate than Ayutthaya province. For this purpose, the locations of the existing 12 RBCs and the NBC are fixed. This case is of the Uncapacitated Fixed Charge Facilities location problem with two additional constraints on fixing the 13 existing locations (constraint 7) and imposing only one new RBC (constraint 8). In order to find the optimal location without limitation of blood supply, procurable blood quantity is not used as constraint 6 in this case.

Figure 5.27 shows the optimal locations and distribution patterns of RBCs in Case 6. The optimal location of the additional RBC is suggested in Trat province instead of Ayutthaya. Trat RBC is responsible for supplying blood to just two provinces, Trat and Chanthaburi (shown with the green box in the Figure 5.27). Considering geographical characteristics of Trat, its Northern part is connected with the Kingdom of Cambodia and Chanthaburi. On East, south, and west, Trat are connected to Cambodia, the Gulf of Thailand, and Chanthaburi, respectively. That means Trat is in a position that has no common boundary with any other provinces of Thailand except Chanthaburi. This characteristic makes Trat the only province in Thailand that has only one exit, which is via Chanthaburi, to other provinces. The RBC that is closest to Trat is Chonburi RBC, with a distance of 234 km, or equivalent to about six hours for a round trip. That means the time needed for taking blood from Chonburi is about 75% of the regular working hours (eight hours). Therefore, setting up an RBC in Trat would help saving blood delivery time for hospitals in Trat and also in Chanthaburi province.

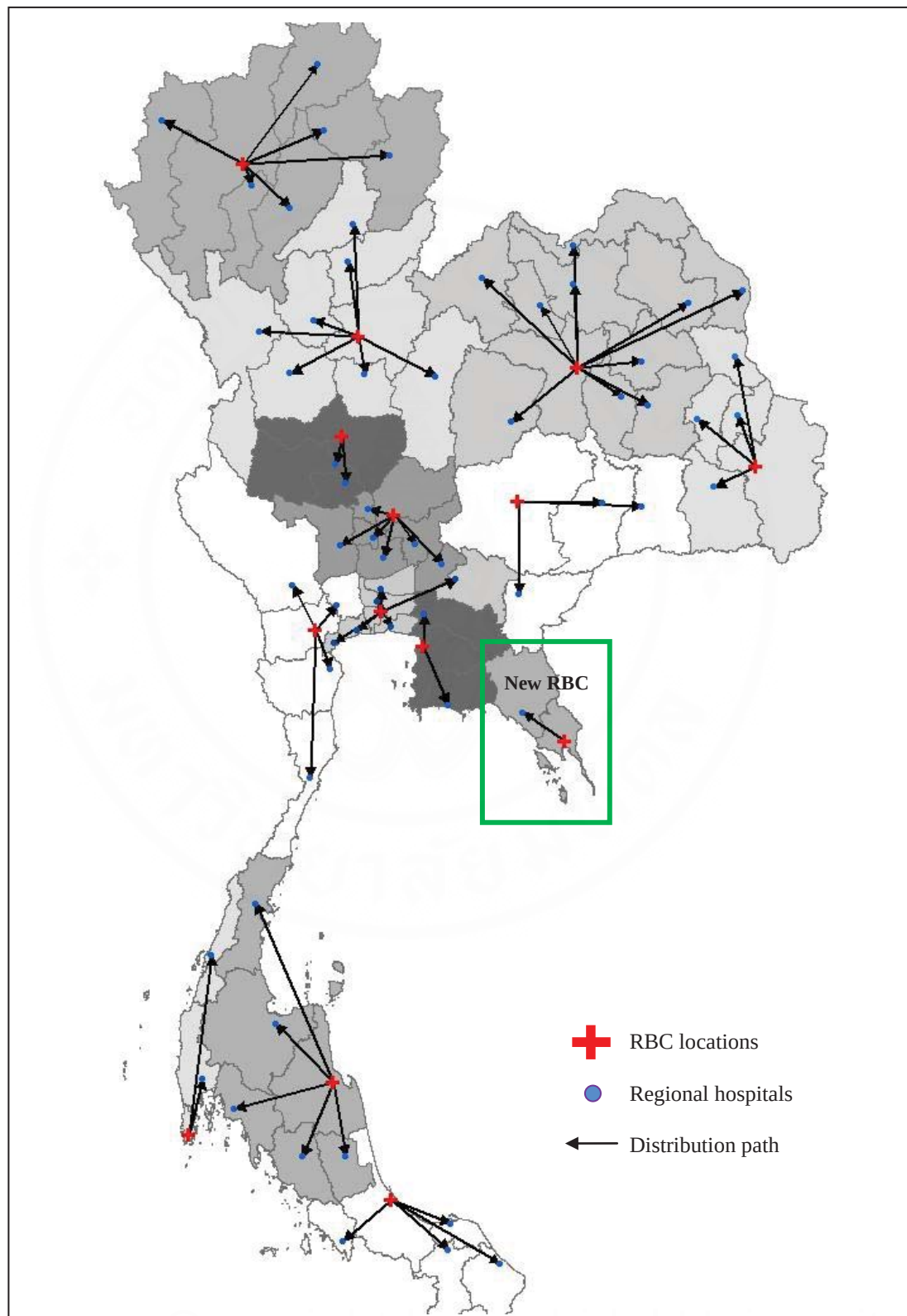


Figure 5.27 Optimal locations and distribution pattern of Case 6

Table 5.10 presents details regarding blood supply quantities of RBCs as obtained from Case 6 (which includes Trat RBC), comparing to the existing RBCs of the current pattern. Columns 1 and 2 of the table show lists of the designated RBCs and the RBCs of Case 6. Columns 3 and 4 show the number of provinces to be served by each RBC. Columns 5, 6 and 7 present a comparison of blood supply quantity. It can be seen that Bangkok NBC is the only blood center that can procure blood with a higher quantity than what required for the optimal result in Case 6, with a margin of about 152 thousand units. All other RBCs can procure less than what is required for the optimal result. That means all the 13 RBCs cannot procure sufficient blood for the demand of their responsible hospitals. The NBC needs to support them to fulfill the blood demand. The total system cost of Case 6 is found to be 1,252,128,279 Baht, which comprise the fixed cost of 1,247,654,362 Baht (as detailed in Table K.1 of Appendix K) and the transportation cost of 4,473,917 Baht (as detailed in Table K.2 of Appendix K). The total cost of Case 6 is lower than the current RBC pattern (the designated pattern) for about 1.4 million Baht. The difference is due only to transportation cost, since the fixed cost of establishing Ayutthaya RBC is assumed to be equal to that of Trat RBC. By locating the new RBC in Trat, the average distance can be saved for about 18 km. from the designated pattern (the average distance of designated RBCs – the average distance of optimal RBC in Case 6 = $144.73 - 126.63 = 18.10$ km.). The saved distance implies an advantage of Case 6 in being able to reduce transportation cost, which occurs in each blood transportation trip from RBCs to hospitals.

From a long experience, the NBC realizes that blood quantity is a very important factor when a decision has to be made regarding the RBC establishment. An RBC without blood is like a hospital without any physicians. Therefore, if the blood distribution pattern in Case 6 is to be followed, the ability on blood procurement of Trat RBC is a very important issue. According to the general information about Trat, its population is about 200,000 persons, which makes it rank number four of the lowest population provinces in Thailand following Ranong, Samutsongkram, and Singburi, respectively. This low population enables Trat to have only one member of parliament for the whole province. According to the analysis in Cases 3 and 5, most RBCs were found to be appropriately located in areas with dense population and in big

cities. From the perspective of blood usage quantity (blood demand), there are only four member hospitals under Trat RBC, which are Trat hospital, Bo Rai hospital, Khao Saming hospital, and Klong Yai hospital (NBC, 2007). Moreover, even though Trat hospital is a provincial hospital, its status is just a general hospital, not a central hospital, due to its small size. Therefore, blood demand for Trat RBC will not be so high. In sum, Trat may not be the best choice for establishing the next RBC, due to its low population and low blood demand. Thus, by adding blood quantity as another constraint into the mathematical model, Case 7 is proposed instead to analyze for the optimal location of an additional RBC and the optimal distribution pattern of the blood service system.

Table 5.10 Optimal results for Case 6 in comparison with designated RBCs

Designated RBCs (14 provinces) (1)	Optimal RBCs of Case 6 (14 provinces) (2)	Servicing provinces		Supply (Units/year)			Supply graph (Units/year) (8)
		Designated (3)	Case 6 (4)	Designated (5)	Optimal (6)	Differ (7)	
Bangkok	Bangkok	1	7	599,705	447,043	152,662	
Lopburi	Lopburi	6	7	27,524	87,713	-60,189	
Chonburi	Chonburi	7	3	59,517	84,978	-25,461	
Ratchaburi	Ratchaburi	7	5	25,948	71,467	-45,519	
Nakhonratchasima	Nakhonratchasima	6	4	65,839	100,442	-34,603	
Khonkaen	Khonkaen	6	11	67,289	184,622	-117,333	
Ubonratchathani	Ubonratchathani	7	5	41,945	62,271	-20,326	
Nakhonsawan	Nakhonsawan	5	3	25,282	35,278	-9,996	
Phitsanulok	Phitsanulok	6	8	25,877	100,134	-74,257	
Chiangmai	Chiangmai	6	7	57,233	154,255	-97,022	
Nakhonsrithammarat	Nakhonsrithammarat	7	6	26,419	76,671	-50,252	
Songkhla	Songkhla	7	5	36,996	49,918	-12,922	
Phuket	Phuket	6	3	10,407	19,297	-8,890	
Ayuthaya	Trat	5	2	19,894	29,657	-9,763	
Distance (km.)		Minimum		Maximum			
Designated RBCs		45.70		144.73		382.17	
Optimal RBCs Case 6		30.15		126.63		348.63	
Transportation cost (Baht/unit)		Minimum		Maximum			
Designated RBCs		1.82		6.97		36.32	
Optimal RBCs Case 6		1.82		5.17		15.69	
Cost (Baht)		Fixed cost		Transportation cost		Total cost	
Designated RBCs		1,247,654,362		5,892,619		1,253,546,981	
Optimal RBCs Case 6		1,247,654,362		4,473,917		1,252,128,279	

5.11 Case 7: locating an additional RBC into the current network with limited blood supply

Case 7 has an objective to present a new pattern of blood distribution by adding the constraint on the limitation of blood supply into the mathematical model. That means, in this case, it is assumed that each RBC can procure blood at a limited quantity. In addition, this case also assumes that there are only 14 RBCs in total in the system (constraint 8), and 13 of them are the existing RBCs whose locations are fixed as the present. The problem is formulated by the Capacitated Fixed Charged Facility Location model plus the constraints 7 and 8. The model is solved by using IBM ILOG OPL IDE 6.3 software. However, the result supports the infeasible solution (Figure L.1 of Appendix L). This is because the establishment of these mere 14 RBCs is insufficient for procuring blood to meet the total blood demand. According to Figure 5.28, blood supply of the 13 existing RBCs altogether is 1,071,906 units/year, while the overall countrywide blood demand is 1,503,746 units/year. That means the additional 14th RBC must have a blood supply quantity at least 431,840 units/year (Blood demand – Blood supply = 1,503,746 - 1,071,906 = 431,840) to make the problem have a feasible solution. This quantity is considered extremely high since an existing RBC, on average, can procure blood for only about 40,000 units/year/RBC. Therefore, the assumptions of Case 7 result in an infeasible or impractical solution because no single RBC can procure blood for as much as 400,000 units per year by itself. Moreover, according to the results obtained in Case 3 and Case 5, the optimum number of RBCs, as corresponding to the current situation, was found to be 36 RBCs, so that they all together can supply sufficient blood quantity for the whole country's demand.

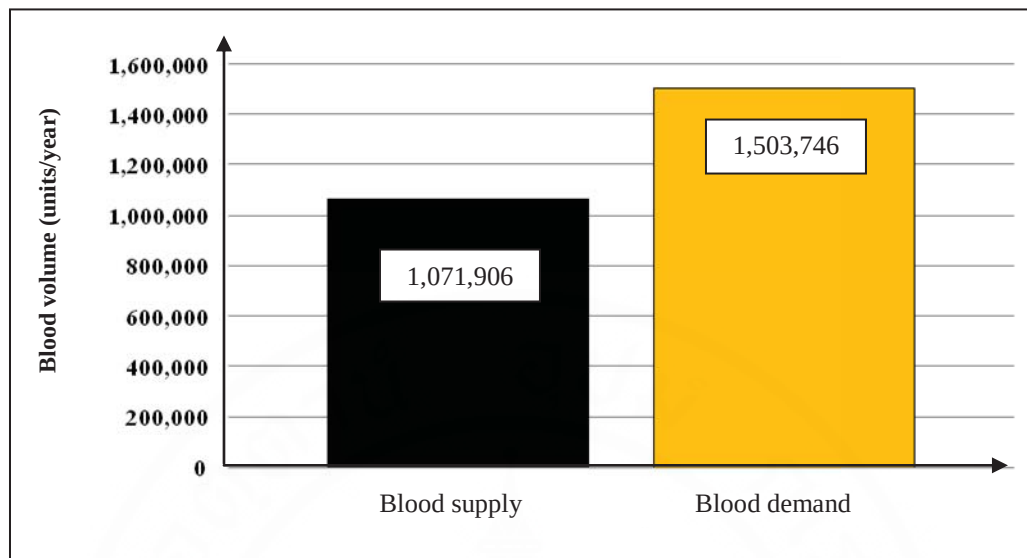


Figure 5.28 A comparison of blood demand and blood supply in Thailand

Therefore, Case 7 is further assumed that each of the entire candidate RBCs is capable to procure and supply blood at the quantity of 1,000,000 units/year ($k_j = 1,000,000$ units/year). This assumption is set in order to find the optimum location of the 14th RBC. The results turn out to locate the new RBC at Saraburi province, rather than Ayutthaya as planned by the NBC. Figure 5.29 shows optimal locations and distribution pattern. It can be seen that Saraburi is actually on the east of Ayutthaya. They share the same border. The data in 2008 show that GDP of the province (Figure F.1 of Appendix F). This high GDP of saraburi province is similar to Chonburi, Ratchaburi, Nakhonratchasima, Khonkaen, Chiangmai, Songkhla and Nakhonsithammarat which are locations of the existing RBCs.

Establishment of RBCs has been based mainly on the construction cost. Mostly, land and buildings (premises) for establishing an RBC are donated from the government in order to save the construction cost. With too high construction cost, it would not be possible to establish an RBC, since the NBC receives only a limited budget from the government. On the other hand, if the donated premises are located in a rural area, it is difficult to find blood donors and inconvenient for blood transportation to hospitals under the RBC's responsibility. It is more likely that the NBC will not permit that establishment. Due to the situation as assumed, Case 7 specifies that all RBCs have a same fixed cost, which is determined in the model to be equal to 0 Baht ($f_j = 0$).

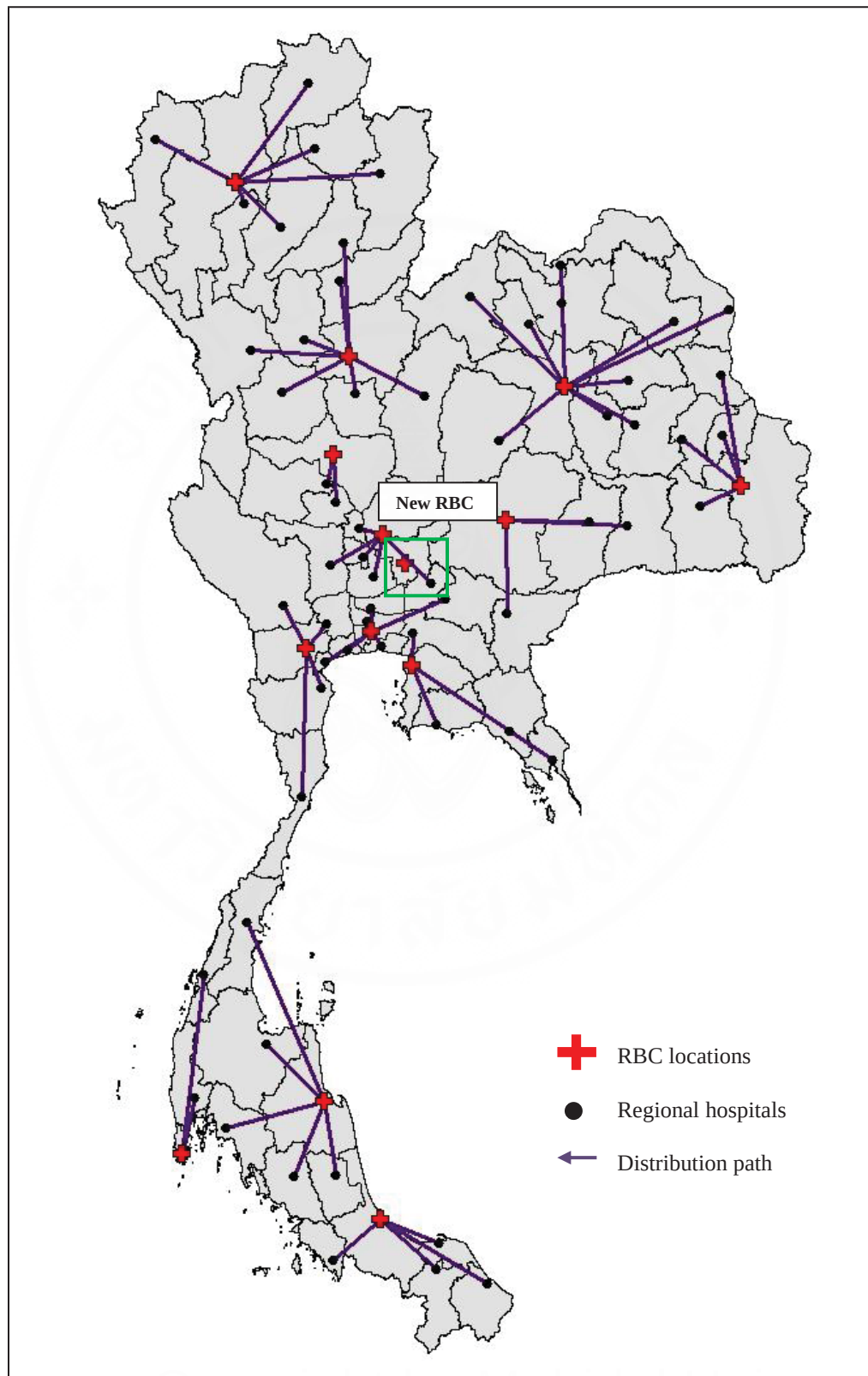


Figure 5.29 Optimal locations and distribution pattern of Case 7

Table 5.11 shows the results from solving the Uncapacitated Fixed Charged Facility Location model with additional constraints (7 and 8). If the new RBC is located in Saraburi instead, the longest distance of blood distribution will decrease to 348.63 km. (or about 33.54 km. shorter), resulting in annual transportation cost of 4.33 Million Baht (or about 1.57 Million Baht cheaper) (as detailed in Tables L.1 and L.2 of Appendix L). The results show another major advantage of locating the new RBC at Saraburi province. In column (7), besides Bangkok NBC, there is also Saraburi RBC that has sufficient blood supply to service demand. There is still 854 units remained after fulfilled total demand of its respective service provinces. By taking a closer look at the blood demand in Saraburi province compared to other province under the responsibility of other RBCs, there is much greater demand for blood supply. While other RBCs can serve several provinces in their areas, the new Saraburi RBC will have to supply blood mainly for hospitals in Saraburi province. Saraburi, thus, may be an ideal location which will grant the new RBC maximum efficiency for blood service to hospitals in Saraburi. Considering its ability in procuring blood, Saraburi province has high density of population since many industrial factories are located here. This factor enables the province to procure higher blood quantity than other regional provinces because there are more population migrated to work in the area. According to the statistical data, blood demand of Saraburi is ranked number 17th in the country, or about 20,748 units/year, which is quite a great amount. In reality, any provinces with high blood demand will require a high blood transportation cost from the nearby RBC. Therefore, in Case 7, if we establish an RBC in Saraburi province, it will be similar to storing blood at the center of demand point. Hence, this will certainly help eliminating unnecessary transportation cost.

Table 5.11 Optimal results for Case 7 in comparison with designated RBCs

Designated RBCs (14 provinces) (1)	Optimal RBCs of Case 7 (14 provinces) (2)	Servicing provinces		Supply (Units/year)			Supply graph (Units/year) (8)
		Designated (3)	Case 7 (4)	Designated (5)	Case 7 (6)	Differ (7)	
Bangkok	Bangkok	1	7	599,705	447,043	152,662	
Lopburi	Lopburi	6	6	27,524	66,965	-39,441	
Chonburi	Chonburi	7	5	59,517	114,635	-55,118	
Ratchaburi	Ratchaburi	7	5	25,948	71,467	-45,519	
Nakhonratchasima	Nakhonratchasima	6	8	65,839	100,442	-34,603	
Khonkaen	Khonkaen	6	11	67,289	184,622	-117,333	
Ubonratchathani	Ubonratchathani	7	5	41,945	62,271	-20,326	
Nakhonsawan	Nakhonsawan	5	3	25,282	76,671	-51,389	
Phitsanulok	Phitsanulok	6	8	25,877	100,134	-74,257	
Chiangmai	Chiangmai	6	7	57,233	154,225	-96,992	
Nakhonsrihammarat	Nakhonsrihammarat	7	6	26,419	76,671	-50,252	
Songkhla	Songkhla	7	5	36,996	49,918	-12,922	
Phuket	Phuket	6	3	10,407	19,297	-8,890	
Ayutthaya	Saraburi	5	1	19,894	20,748	-854	
Distance (km.)		Minimum	Average	Maximum			
Designated RBCs		45.70	144.73	382.17			
Optimal RBCs Case 7		30.10	129.24	348.63			
Transportation cost (Baht/unit)		Minimum	Average	Maximum			
Designated RBCs		1.82	6.97	36.32			
Optimal RBCs Case 7		1.82	5.20	13.64			
Cost (Baht)		Fixed cost	Transportation cost		Total cost		
Designated RBCs		1,247,654,362	5,892,619		1,253,546,981		
Optimal RBCs Case 7		0	4,327,370		4,327,370		

Designated supply

Case 7 supply

The results obtained from Case 6 and Case 7, both of which aim to find the optimum location for an additional RBC, revealed that the new RBC should be located in Trat and Saraburi provinces, respectively. Only one of these two provinces is supposed to replace Ayutthaya province as specified in the original plan of the NBC. Comparing among them, Saraburi seems to be more appropriate than Trat in terms of value and benefits that it will contribute to the blood distribution system. The overall blood transportation distance will be shorter. Moreover, according to the location and population of the two provinces, as mentioned previously, Saraburi is more likely to be able to procure more blood than Trat. This pattern of blood services is the pattern that is closest to the current situation, since the NBC has already planned to establish one more RBC. However, this pattern requires that all RBCs must have sufficient blood supply.

5.12 Summary

The analysis and design of location for the regional blood service in this chapter consist of seven cases. Each case has different objective and expected result. One case may show advantages over another. This research will choose the best choice which is optimal for blood service pattern in Thailand, including the number of RBCs, locations, construction cost, convenience in transport, and importantly, the quality of blood maintained to the destination. Details are explained as follows;

Case 1 was to analyze the optimal pattern from NBC and the 12 currently existing RBCs. The applicable mathematical model is the transportation problem. LINDO 6.1 was used to solve the problem. The result from Case 1 shows the amount of blood transported from RBCs to nationwide hospitals. Some of the routes were changed from the current ones. The total system cost is about four million Baht which suggests that the current pattern of blood service is not optimal and can be further developed.

Case 2 analyzed and designed the whole new system, regardless of the existing RBC locations. This was to find the best location configuration for blood service in terms of number, locations and distribution pattern. Case 2 is modeled by the Uncapitated Fixed Charged Facility Location problem where the blood service capacity of each RBC is unlimited ($K_j = 1,000,000$ units/year). Case 2 was solved to the optimality by using IBM ILOG OPL IDE 6.3. The optimal result suggests that there be only one RBC in Bangkok supplying blood to hospitals nationwide.

Case 3 has a similar objective to Case 2, with the more realistic condition where it is not possible to always collect sufficient blood, due to the limitation on donors such as the interval required between each donation so the red blood cells can produce more blood, blood-borne diseases, and the compatibility between donor's blood and recipients. Case 3 is modeled by the Capacitated Fixed Charged Facility Location problem where each RBC can only collect limited blood supply ($K_j =$ values shown in the Table 5.2). Case 3 was solved by using IBM ILOG OPL IDE 6.3. The result suggests that 36 RBCs be established so as to supply sufficient amount of blood. Unfortunately, in reality, it is not possible to move or to discharge the existing RBCs. Therefore, an alternative Case 4 is presented next.

Case 4 introduces an analysis and design for new RBCs where all 12 existing RBCs (X_1) remain in service; namely, Lopburi (X_{51}), Chonburi (X_9), Ratchaburi (X_{50}), NakhonRatchasima (X_{21}), KhonKaen (X_6), UbonRatchathani (X_{76}), Nakhonsawan (X_{23}), Phitsanulok (X_{37}), NakhonSithammaratch (X_{22}), Chiang Mai (X_{14}), Songkhla (X_{57}) and Phuket (X_{41}). Constraint 6 was added where $X_{CurrentRBCs} = 1$ to the Uncapacitated Fixed Charged Facility Location problem. IBM ILOG OPL IDE 6.3 was used to solve the problem. The optimal result suggests that 12 RBCs (including one NBC) should be established in 13 provinces where the currently existing RBCs and NBC are.

Case 5 shows an analysis with the same objective as that of Case 4, but with an additional condition on the capacity of blood collection according to the Capacitated Fixed Charged Facility Location problem. The problem was solved by using IBM ILOG OPL IDE 6.3. The result of Case 5 suggests that there be 36 RBCs

as well as Case 3, but all the existing RBCs remain in service. The total system cost in Case 5 is the highest among all cases, at 1,800 million Baht. The figure is still huge for the NBC to practically implement the scheme.

Case 6 shows the design of the blood service according to the NBC's original plan to establish one more RBC in Ayutthaya, which currently has not been implemented. Case 6, therefore, analyzes to see in which province the next RBC should be located. Constraint 7 where the total number of RBCs can only be 14 was added ($\sum X_j = 14$). IBM ILOG OPL IDE 6.3 was used to solve the problem. The result suggests that the RBC be located in Trat so as to assist Chonburi RBC to collect and supply blood for hospitals in the Eastern region. Trat RBC will only be responsible only for Trat and Chantaburi province. The transportation cost of Case 6 (14 RBCs) drops from that of Case 4 (13 RBCs) by around 24 million Baht/year if there is another RBC.

Case 7 shows an analysis with the same objective as that of Case 6, but with an addition condition on the limited capacity of blood collection according to the Capacitated Fixed Charged Facility Location problem. The problem was solved by using IBM ILOG OPL IDE 6.3. Initially, the result is infeasible due to the fact that only 14 RBCs are unable to supply blood to all hospitals throughout Thailand. Thus, the presumption in the analysis was adjusted by assigning that RBCs have sufficient blood supply, and adding constraint 8. The result suggests that the 14th RBC be in Saraburi province rather than Ayutthaya as planned by the NBC.

Figure 5.30 summarizes results in one shot. Column 1 is the case number. There are seven in total. Column 2 is the number of RBCs needed in each case. Columns 3, 4, and 5 are fixed cost, transportation cost, and total system cost, respectively. The last column shows the average distance of each case. If there is only one RBC (Case 2), the transportation cost will be highest at 20 million Baht. If there are 36 RBCs (Case 5), the transportation cost will be, in contrast, the lowest at around 4 million Baht. This figure is also the average cost of cases with 13, 14, and 36 RBCs. When the number of RBCs is taken into account with unlimited blood supply, the number of RBCs needed will be respectively lower, such as in Cases 2, 4, and 6. On the other hand, if the blood supply is limited, the number of RBCs will be respectively higher due to heavier responsibility to collect and supply blood to meet demand.

According to Case 7 where the 14th RBC is Saraburi, it is found that its transportation cost is the lowest (4.32 million Baht) among seven cases. And the average distance is 129 km. Logistics of blood is very important and critical to human lived. Good planning of logistic network can effectively provide the right blood products at the right quality, time and cost to the end users (patients). Therefore, the transportation cost and the average distance is importance for choosing how to distribute blood in the regional.

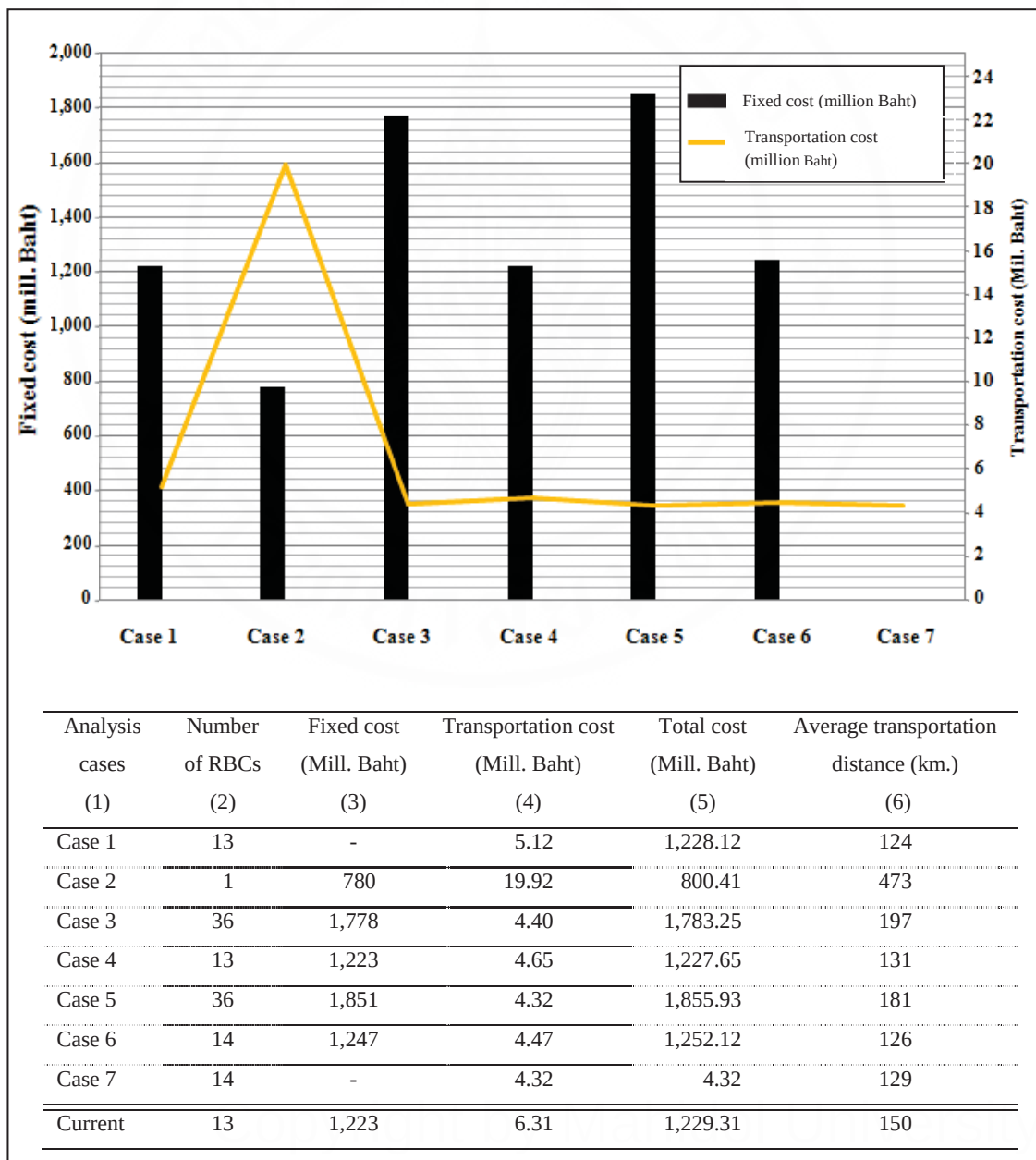


Figure 5.30 Summary of the analyses on seven cases

This chapter shows the results of the analyses and the designs for the optimal the regional blood centers. Each case shows advantages and disadvantages as well as possible improvements in the operation. This will greatly benefit the welfare of blood recipients with better quality of blood supply. In fact, the pattern that the NBC expects to happen is a pattern where RBCs are capable of collecting, examining, and distributing blood by themselves (full function). It is interesting to find out how RBCs can provide sufficient blood supply for the demand. This is a big challenge for the administrator. Next, Chapter 6 will conclude the research, and provides policy implications. The interesting future research is also recommended.

CHAPTER VI

CONCLUSIONS

This research is aimed to analyze and design the appropriate locations of Regional Blood Centers and their distribution patterns. Chapter 1 (Introduction) explained about background and importance of the research problem. The chapter also covers scope and objectives of the research. It introduces the current blood distribution system in Thailand. At present, the NBC (National Blood Center) determines patterns of blood distribution. It has established 12 RBCs to be responsible for distributing blood to hospitals in their service provinces. However, these days the NBC has to assist those RBCs in providing blood directly to some hospitals under their responsibility due to insufficiency of blood procured by them. This situation results in extra delivery cost to the NBC, which should not happen. Therefore, it might be possible to analyze and design more appropriate number and locations of RBCs by means of advanced quantitative techniques. It is also expected that the results will be useful for enhancing efficiency of blood delivery and reducing cost of blood distribution to be much lower than the present.

Chapter 2 (Literature review) contains three sections of discussion. Part 1) is about issues or problems regarding operations on procuring blood donors, setting standards for screening blood transmitted diseases, maintaining quality of blood storage and blood distribution of the blood supply chain. Part 2) talked about the three patterns of blood services. The first pattern is called “Centralized blood services model”. This pattern has only one center that is responsible for providing all kinds of blood services. Therefore, it is appropriate only for small countries. The second pattern is called “Decentralized blood services model”. The responsibility for blood services in this pattern is shared among several organizations. The last one is called “Co-location of small blood centre with hospital mixed blood service model”. This pattern combines the previous two patterns together in order to obtain flexibility in providing blood services. Thailand is among many countries that employ this pattern.

Part 2) also raises some examples of blood service patterns utilized in different countries. Finally, Part 3) describes about previous researches conducted on the design of blood services. It showed that most of the researches were about the design on blood collection and blood distribution. Their research problems were solved by means of various mathematical models such as Set covering, Covering model, Binary integer programming, and Fixed Charged Facility Location model, etc.

Chapter 3 (Methodology) shows four parts of description. The first part describes about framework of the research, which follows the pre-determined objectives of seven cases. Models for solving the problem of each case are also discussed. The second part describes about all processes for collecting data to be analyzed. The third part explains about hardware and software tools used for processing the data and solving the problem. The last part summarizes the research methodology, which comprises five procedures; namely, 1) determining research problems, 2) defining scope of the research, 3) data collection, 4) data analysis, and 5) concluding and reporting the results.

Chapter 4 (Regional blood supply chain) divides its content into four parts. The first part explains about the methods of data collection, which include interviewing operators, accompanying blood-delivery vans, noting down data from observation, and taking photographs of blood delivery. The second part presents details about blood supply change. In general, blood supply chain can be summarized into four steps: 1) donor recruitment and blood collection, 2) testing, processing and storage, 3) delivery of blood and blood components to hospitals, and 4) using blood components. This research will emphasize on blood delivery in Thailand, which is divided into two parts; namely, the delivery in Bangkok Metropolitan Region and in regional area. The third part focuses on the operation of delivering blood to regional area in detail. According to the data collection, three procedures are required for delivering blood: 1) blood request, 2) blood packing, and 3) blood delivery (transportation). There are four modes of blood transportation; namely, NBC' van, public bus, airplane, and public carrier. The last part of Chapter 4 presents the estimation of current blood delivery cost for the four transportation modes. This estimation reveals the real cost of NBC that is wasted.

Chapter 5 (Location design and analysis) discusses about procedures of locating appropriate locations of RBCs. The discussion is separated into six parts. The first part is an explanation about definitions and objectives of the seven cases. The second part is about the mathematical models in the research problems. The third part concerns the parameters in each mathematical model. The fourth part describes the solutions or procedures for solving research problems. The fifth part presents analysis results. The last part is the summary of various results of each case.

This chapter summarizes all processes, knowledge, and analysis results from the previous five chapters of the research. It also provides answers to each of the pre-determined objectives, which are: 1) To study about blood supply chain in Thailand, and 2) To analyze and design locations of Regional Blood Centers and the pattern of their distribution. Additionally, the researcher also provides suggestions that were learned during the course of the thesis. Lastly, the reflections on recommended future research are also given.

6.1 Blood supply chain: blood distribution at regional level

From studying about blood supply chain in Thailand, the involved procedures were found to include blood procurement, collection, storage, distribution, and patient usage. The data collection process revealed complexity of blood distribution. Actually, blood services in Thailand are divided into two parts; namely, the distribution from the NBC to hospitals in Bangkok Metropolitan Region, and the part of distribution from RBCs to provincial hospitals. However, in practice, there are routes of blood distribution from the NBC to provincial hospitals, as to support the operation of RBCs. This extra transportation leads to a total cost of approximately 4,000,000 Baht per year, which is really high. Types of blood transportation can be categorized into two types; namely, land and air transportation. For the purpose of cost calculation, the two types of transportation are divided into four modes as follows;

1) NBC's van. This mode is used for blood transportation from the NBC to bus terminals and airports.

2) Public bus. This mode is used for blood transportation from the origin bus terminal (Mo Chit bus terminal) to the destination bus terminals (provincial terminals)

3) Airplane. This mode is used for blood transportation from the origin airports (Don Muang and Suvarnabhumi airport) to the destination airports (provincial airports)

4) Public carrier. This mode is used for blood transportation from the destination bus terminals/airports to the RBCs or the terminal hospitals.

Details of these modes are illustrated in Figure 6.1.

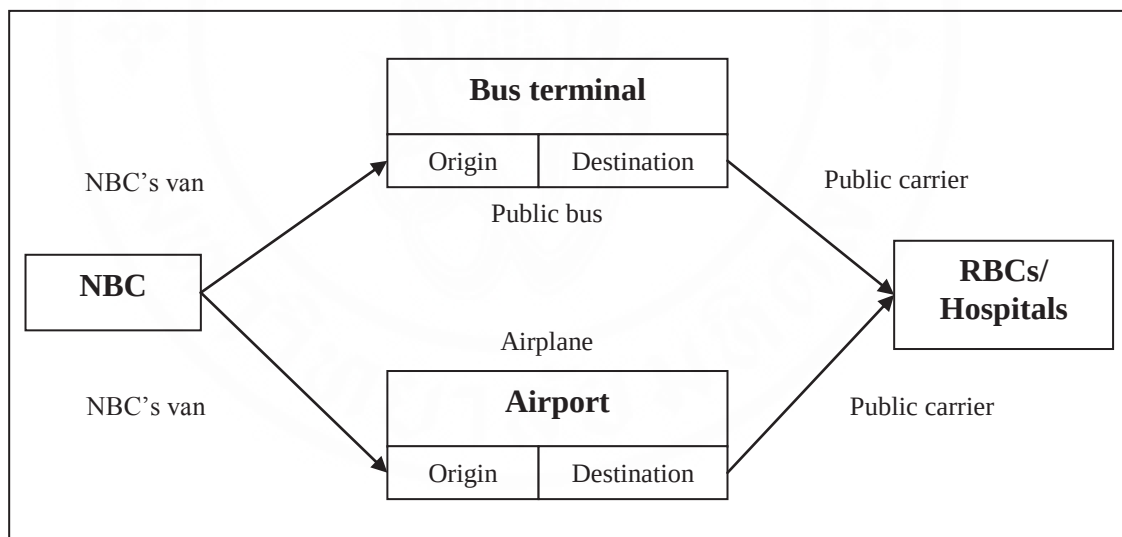


Figure 6.1 Description of the four modes of blood delivery to regional area

At present, blood transportation requires about 14 to 24 hours to finish the whole process (starting from bringing the blood out of the storage, packing, and then distributing the blood packages). The transportation mode that requires the maximum time is public bus. Figure 6.2 compares time usage between two transportation types; namely, air transportation (to Chiang Mai airport) and land transportation (to Nongkhai bus terminal). The distances from Bangkok to these two destination provinces are 760 and 670 km., respectively. According to the collected data, blood

transportation to Chiang Mai RBC took less time than to Nongkhai RBC for 10 hours. That means air transportation can save time for approximately 42% (from NBC to destination RBCs). At present, one third of blood transported daily from the NBC uses public bus mode, and one third of this public bus is for delivering blood to the Northeastern region. Since time usage affects quality of blood being delivered, public bus is considered the riskiest mode among the four modes in term of blood quality. Public bus not only takes longer time, but also has lower standards for controlling blood quality during transportation than any other modes.

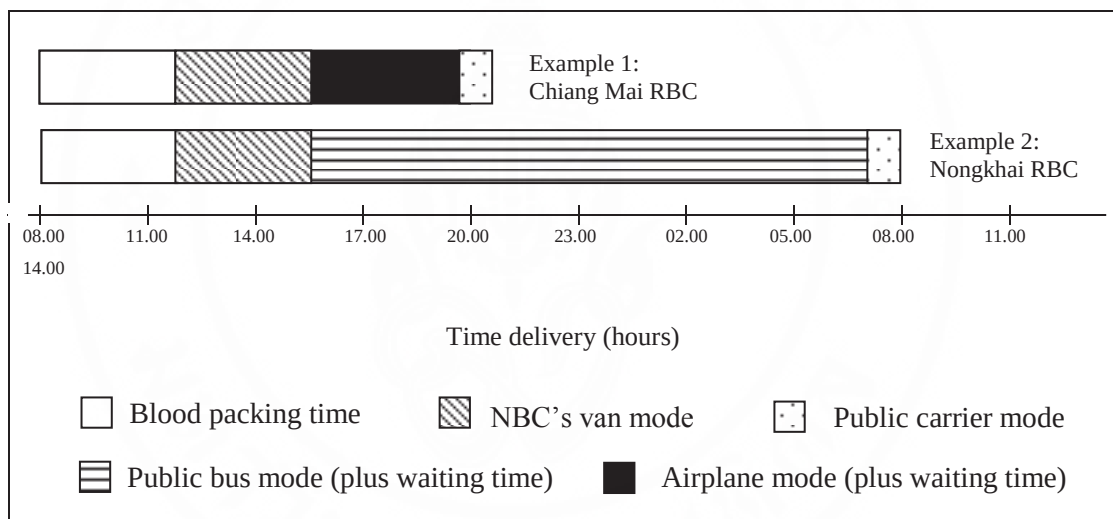


Figure 6.2 The relationship between time and place of blood delivery

These problems should not happen if there is proper planning and designing on the number, location, and pattern of regional centers for the blood service network. Such planning should follow scientific principles and rely on historical data to ensure sufficiency of blood supply. Based on the preliminary study, it was found that the nature of the research problem was Location/Allocation problem. Therefore, this research sets an objective to propose solutions for improving process of blood delivery, while maintaining blood quality at high standards and keeping blood transportation at reasonable costs at present and in the future.

6.2 Analyzing and re-designing the locations of Regional Blood Centers

Seven different cases were analyzed in order to redesign the locations of the RBCs. The results were shown and discussed in Chapter 5, regarding their pros and cons. This section gives suggestions on how to optimally improve the regional blood service in Thailand.

Case 1 was assumed with an objective to analyze for an optimal pattern of blood distribution from the 13 existing RBCs. The analysis result show the reduction in the transportation cost of the NBC for about 50%. In addition, the results also present a new and appropriate of service provinces of each RBC, which is different from the existing as planned by the NBC. However, for efficiency of blood distribution in this new pattern of the RBCs, each of them needs to have sufficient blood quantity to fulfill the demand. At present, the existing RBCs still have some limited blood quantity, which is one of their important problems.

Case 2 was formulated for analyzing and re-designing the pattern of the RBCs, without considering a limitation on blood supply. The result has only the Bangkok NBC as the sole organization that supplies blood for hospitals in all provinces. The result of this case has transportation cost of about 20 million Baht, which is considered the highest among all seven cases. Actually, this pattern of blood distribution used to be implemented by the NBC but ended up in a failure. The reason was because the NBC could not meet blood demand for all the provincial hospitals. Thus the policy of establishing RBCs in various provinces was originated.

Case 3 was analyzed with similar assumptions to those of Case 2, except only having an additional limitation of blood supply. This situation was assumed because sufficient blood quantity is a major current issue of blood distribution. The analysis result of this case had a total system cost of about 1,783 million Baht, of which 99% (or 1,778 million Baht) is the fixed cost and the remaining 1% (or 4.40 million Baht) is the transportation cost. The fixed cost is very high because with these assumptions, 36 RBCs are needed to be established. In reality, 13 RBCs have already been established. The relocation or abolishment of these RBCs according to the result of Case 3 analysis might be impractical in opinion of the NBC. Thus, Case 4 was assumed and analyzed.

Case 4 assumed that all 13 RBCs would remain as the current condition. However, their present ability in acquiring blood was not considered (i.e. blood quantity of these RBCs was unlimited.) The analysis for a new pattern of blood distribution in this case revealed that only the existing 13 RBCs were needed. Of the total system cost of about 1,227 million Baht, 99% accounts for the fixed cost and 1% is for the transportation cost, or equivalent to 1,223 and 4.65 million Baht, respectively. Considering in terms of transportation cost, the results of Case 3 and Case 4 are not much different. That means the total transportation cost of about 4 million Baht is required, regardless of whether 13 RBCs or 36 RBCs would be needed.

Case 5 represented an analysis that assumed fixed locations of the 13 RBCs as same as Case 4. However, this case also assumed that there was a limitation on the acquired blood quantity by the RBCs. The result revealed that 36 RBCs in total are needed to be established. The transportation cost is about 4.32 million Baht. This result has confirmed that, with as many as 36 RBCs, transportation cost could not be reduced as much as expected. Thus it can be concluded that, with so much fixed cost needed for construction of those many RBCs, the saving in transportation cost is not worthy of that expensive investment.

Case 6 represents an analysis that assumes an establishment of one additional RBC, which the NBC planned to be established in Ayutthaya province. The acquired blood quantity is assumed to be unlimited in this case. However, based on the lowest total system cost, the analysis result revealed that the new 14th RBC should be located in Trat province instead of Ayutthaya. Trat was chosen because the construction cost in the area is low; making the total cost for establishing the new RBC in this province becomes lower than other candidate provinces. However, in reality, due to its low quantity of population, Trat might have a problem regarding blood procurement. In general, most RBCs were located in big provinces in each region, such as Chiangmai, Nakhonratchasima, and Songkhla provinces, which have high population.

Case 7 represents an analysis that is similar to Case 6, but is more realistic. The acquired blood quantity of RBCs is limited in this case. This solution is considered an infeasible solution. With current capability in procuring blood of the RBCs, blood demand of all hospitals in the country cannot be sufficiently supplied by

having only 14 RBCs. Therefore, the assumptions of this case were adjusted. This case also assumed that the quantity of blood supply of the additional RBC can be high enough to meet the blood demand. This quantity might be unrealistic, but the purpose was just to fulfill to demand requirement. In addition, this case also assumed an equal construction cost in all candidate RBCs. This assumption is quite realistic because, practically, most RBCs have been established in a donated land or allowed to share the building with other governmental organizations. Therefore, the construction cost could be reduced greatly. On the other hand, if the land donated to the NBC is in a rural area with little population or poor transportation system, the NBC would not allow the construction because the investment will not be worthy. Based on these assumptions, the result of Case 7 analysis revealed that the 14th RBC should be located in Saraburi province. The total transportation cost is 4.32 million Baht, which is equal to Case 5 that requires the establishment of 36 RBCs. However, this pattern requires that all RBCs must have sufficient blood supply. However, this pattern requires that all RBCs must have sufficient blood supply.

The main findings indicate that the current RBC locations may not be the best for Thai society as compared to the optimal locations obtained from the mathematical models. Regarding the planned Ayutthaya RBC, the results suggest an alternative location at Saraburi province which is located to the east of Ayutthaya. All key performance indicators of Saraburi province are superior to Ayutthaya's. Therefore, if the NBC is about to establish a new RBC, the result of this analysis highly recommended that Saraburi be the most appropriate in terms of location and the capability of blood collection.

6.3 Suggestion for better supply of blood in Thailand

The important note is the concern about the balance between blood supply and demand. Based on the results, only Bangkok NBC has sufficient blood supply. This can be explained by the fact that Bangkok is the capital city with large economic activities and very dense population. In addition, the NBC also uses mass media to communicate with donors and thus is able to collect greater amount of blood.

Therefore, if the RBCs seek to increase blood supply, there should be a similar campaign to communicate with donors like NBC does. As long as there is not sufficient blood supply, the long-distance transportation between the NBC and RBCs is inevitable. Quality control of blood during transportation is therefore very critical in the short-to-median term. By doing so the benefits of re-designing the appropriate RBC locations can be materialized.

6.4 Recommended future research

After studying about blood supply chain, it is found that there are still many problems needed to be solved. These are problems regarding blood procurement, quality of screening process for safe blood, compatibility of donor's blood and patient's blood, and blood delivery, etc. These problems should receive much attention since blood is a sensitive product and has direct impact on live or death. According to findings in this research, future research can be developed upon these following aspects.

6.4.1 Forecasting of blood demand

Some cases were analyzed by assuming that the quantity of blood supply was unlimited. The calculated quantities were not real quantities, but just the figures to fulfill blood demand. In addition, the acquired blood quantities by the existing RBCs were also the estimated figures. For several years ago, the NBC has been able to increase its donated blood quantity. However, quantity of blood use also gets higher every year. If this trend continues, quantity of the total blood demand in the country might be uncontrollable. However, this quantity might not represent the real blood demand. Many hospitals might be able to acquire some quantity of blood by themselves. The quantity they request from the NBC might be just a part of the total demand that their patients need. According to available data, the NBC does not know the exact quantity of total blood demand in Thailand. Therefore, it is very interesting to conduct a future research by focusing on a forecast of blood demand quantity of Thailand.

6.4.2 Quantity of blood inventory

Blood remained in the inventory is brought out in a form of FIFO (First In – First Out), while the NBC has to distribute blood to RBCs and hospitals every day. Most of the time blood supply of the NBC is insufficient for the demand of hospitals who request for blood. In that case, the NBC has to try to equalize the supply to all hospitals, which may not meet their demand. However, there are certain times when the blood supply is higher than the demand, such as during the National Father's Day and the National Mother's Day. However, beyond these special events, blood supply will return to a deficient state. Intentionally, the NBC prefers that donors come to donate blood regularly rather than coming a lot only during special events. Thus it tries to promote and publicize about blood donation continuously. Suppose the NBC utilize and analyze its data on donated blood in previous years, it should be able to predict blood supply and demand throughout the year. With accurate prediction, efficient management of blood inventory can be achieved in the future.

6.4.3 Improvement of blood quality control during transportation

Obtaining sufficient blood for the overall demand of all patients in the country may take a long time to accomplish. This is because there are many limitations relating to blood donors, blood screening, public relations for donation campaign, etc. However, it might be easier and faster to improve the existing process so that resources are utilized at the maximum capability. Therefore, intention should also be focused on blood quality control during transportation. The valuable blood should be ensured that its quality will not be degraded while being transported, which is the most sensitive period of temperature control. According to the field observation, it was found that the NBC has much concern on this issue. It therefore randomly puts data loggers in some blood boxes in order to record blood temperature throughout the transportation. This allows them to have a record of changing temperature, but it does not allow them to fix the problem at the time when temperature is too high. Therefore, it is interesting to conduct future research to apply this finding for improving quality of blood transportation. The improvement can be made in terms of packaging design, method of storage, and method of delivery, etc. to ensure the quality of blood until it reaches the destination.

6.4.4 Application of this research's methodology to industrial sector

The methodology used for this study regarding the optimum locations and distribution pattern of Regional Blood Centers in Thailand can be applied to many other kinds of service stations. For example, the location of emergency center, hospital, and the elderly station can be determined appropriately by applying this methodology. Industrial sector can also apply it to their product delivery, particularly for products that are sensitive to temperature like blood. Last but not least, the problem regarding Location/Allocation remains to be an interesting and challenging topic to be studied further.

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The seal of Mahidol University is a large, faint circular emblem in the background. It features a central five-tiered umbrella (parasol) with a flame-like finial. The Thai text "มหาวิทยาลัยมหิดล" (Mahavithayalai Mahidol) is written in a circle around the central image.

APPENDICES

APPENDIX A

THE BLOOD DONOR APPLICATION FORM

ใบสมัครผู้บริจาคโลหิต ศูนย์บริการโลหิตแห่งชาติ สภากาชาดไทย		หน้า 1
☐ ผู้บริจาคโลหิตครั้งแรก	☐ ผู้บริจาคโลหิตประจำ	วันที่ (ว/ด/ป) _____
เฉพาะผู้บริจาคโลหิตประจำ ครั้งที่แล้วท่านได้บริจาค : ☐ โลหิตทั่วไป ☐ โลหิตเฉพาะส่วนกรุณาธิคุณ : ☐ เม็ดโลหิตแดง ☐ เกล็ดโลหิต ☐ พลาสมา การบริจาคครั้งที่ผ่านมา : ☐ ไม่มีปัญหา ☐ มีปัญหา : ☐ เป็นลม ☐ เขียวซ้ำ ☐ หาสันโลหิตยาก ☐ ได้รับแจ้งให้งดบริจาคชั่วคราวเนื่องจาก _____ ☐ อื่นๆ _____		
เลขที่บัตรประจำตัวประชาชน - - - เลขประจำตัวผู้บริจาคโลหิต _____		หมู่โลหิต Rh
วัน/เดือน/ปีเกิด _____ อายุ _____ ปี เพศ _____ น้ำหนัก _____ กิโลกรัม (ช่วงอายุบริจาคได้ 17-70 ปี) ถ้าอายุ 17 ปี ต้องมีหนังสือยินยอมจากผู้ปกครอง ☐ มี ☐ ไม่มี ถ้าอายุ ≥ 60-70 ปี ต้องมีหนังสือรับรองจากแพทย์ ☐ มี ☐ ไม่มี สถานที่ติดต่อได้ ☐ ที่อยู่เดิม ☐ ที่อยู่ปัจจุบัน ระบุ _____ รหัสไปรษณีย์ _____ หมายเลขโทรศัพท์ _____ โทรศัพท์เคลื่อนที่ _____ E-Mail address _____ อาชีพ : ☐ นักเรียน, นักศึกษา ☐ ข้าราชการ, ทหาร, ตำรวจ, พนักงานรัฐวิสาหกิจ ☐ พนักงานบริษัท, รับจ้าง ☐ พระภิกษุ, สามเณร ☐ อื่นๆ _____ ลงชื่อ _____ (นาย, นาง, นางสาว) _____ (กรุณาเขียนตัวบรรจง) ชื่อ-นามสกุลเดิม (ถ้ามี) _____ (โปรดพลิกเพื่อตอบคำถามหน้า 2 ด้วย)		
สำหรับเจ้าหน้าที่กรอกข้อมูล		
เลขประจำตัวผู้บริจาคโลหิต _____ บริจาคครั้งที่ _____ กรณีผู้บริจาคโลหิตประจำไม่มีบัตรประจำตัวผู้บริจาคโลหิต บริจาคโลหิตครั้งแรกเมื่อ (วันที่/เดือน/ปี) _____ สถานที่บริจาค _____ บริจาคโลหิตครั้งสุดท้ายเมื่อ (วันที่/เดือน/ปี) _____ สถานที่บริจาค _____		
Unit Number	ความดันโลหิต _____ มม.ปรอท ชีพจร ☐ ปกติ ☐ ไม่ปกติ หัวใจ/ปอด ☐ ปกติ ☐ ไม่ปกติ ความเข้มข้นโลหิต ☐ ผ่าน ☐ ไม่ผ่าน Hb _____ mg/dL ☐ ผ่าน ☐ ไม่ผ่าน	☐ Deferred due to _____ ☐ กินยาที่มีผลต่อเกล็ดโลหิต ☐ Under volume ☐ High volume ☐ Discarded
หมายเหตุ _____ เจ้าหน้าที่ทะเบียน _____ เจ้าหน้าที่เตรียมถุง _____ เจ้าหน้าที่ผู้เจาะเก็บ _____ เจ้าหน้าที่เก็บตัวอย่างโลหิต _____ เจ้าหน้าที่ผู้ตรวจสอบ _____		

แบบฟอร์มเลขที่ DSP001/001

แก้ไขครั้งที่ 08/0352

Figure A.1 The blood donor application form (page 1)

ผู้บริจาคโลหิตกรุณาขีดเครื่องหมาย ✓ ในช่อง □ ตามความเป็นจริง		หน้า 2	
เพื่อความปลอดภัยของตัวเองและความปลอดภัยของผู้ป่วยที่จะรับโลหิตของท่าน โปรดตอบคำถามตามความเป็นจริง และหากไม่แน่ใจว่าโลหิตของท่านปลอดภัย กรุณาขอปรึกษาโลหิต			
หมวดที่ 1 (เฉพาะสุภาพสตรี)	ใช่	ไม่ใช่	
1. อยู่ในระหว่างตั้งครรภ์.....	☐	☐	
2. อยู่ในระยะให้นมบุตร.....	☐	☐	
3. คลอดบุตร หรือแท้งบุตร ภายใน 6 เดือน ที่ผ่านมา.....	☐	☐	
หมวดที่ 2			
4. ท้องเสีย ท้องร่วง ภายใน 7 วัน ที่ผ่านมา.....	☐	☐	
5. น้ำหนักลดลงอย่างรวดเร็วในระยะ 3 เดือน ที่ผ่านมาโดยไม่ทราบสาเหตุ.....	☐	☐	
6. อ่อนเพลีย อุดตัน ขูดหินปูนและรักษารากฟัน ภายใน 3 วัน ที่ผ่านมา.....	☐	☐	
7. ได้รับการผ่าตัดใหญ่ ภายใน 6 เดือน หรือผ่าตัดเล็ก ภายใน 7 วัน ที่ผ่านมา (ระบุ).....	☐	☐	
8. มีอาการมีนมาจากอาการคลื่นไส้ อาเจียน หรืออื่นๆ.....	☐	☐	
9. เคยมีประวัติติดยาเสพติด หรือพึ่งพันโทษ ในระยะ 3 ปี.....	☐	☐	
10. เคยเจ็บป่วยต้องรับโลหิตของผู้อื่น ในระยะ 1 ปี ที่ผ่านมา.....	☐	☐	
11. เข้าไปในพื้นที่ที่มีเชื้อมาลาเรียชุกชุม ในระยะ 1 ปี หรือป่วยเป็นมาลาเรียในระยะ 3 ปี ที่ผ่านมา.....	☐	☐	
12. พฤติกรรมเสี่ยงทางเพศ			
12.1 ท่านมีเพศสัมพันธ์กับผู้อื่นที่ไม่ใช่คู่ของท่าน.....	☐	☐	
12.2 ท่านมีเพศสัมพันธ์กับเพศเดียวกัน (ตอบเฉพาะเพศชาย).....	☐	☐	
12.3 คู่ของท่านมีเพศสัมพันธ์กับผู้อื่น.....	☐	☐	
12.4 คู่ของท่านมีเพศสัมพันธ์กับเพศเดียวกัน (ตอบเฉพาะเพศหญิงที่มีคู่เป็นชาย).....	☐	☐	
13. เคยเจ็บป่วยต้องรับโลหิตของผู้อื่นที่ประเทศอังกฤษ ในระหว่าง ปี พ.ศ. 2523-2539.....	☐	☐	
14. เคยทำแท้งอยู่ที่ประเทศอังกฤษ ในระหว่างปี พ.ศ. 2523-2539 เป็นระยะเวลา 6 เดือนขึ้นไป.....	☐	☐	
หมวดที่ 3			
15. อยู่ในระหว่างมีรอบเดือน (เฉพาะสุภาพสตรี).....	☐	☐	
16. สุขภาพสมบูรณ์และพักผ่อนเพียงพอ พร้อมที่จะบริจาคโลหิต.....	☐	☐	
17. เพิ่งรับประทานอาหารที่มีไขมันสูง ภายใน 6 ชม.	☐	☐	
18. รับประทานยาแอสไพริน ยาคลายกล้ามเนื้อ ยาแก้ปวดข้อ หรือยาอื่นๆ.....	☐	☐	
19. รับประทานยาแก้แสบ หรือยาอื่นๆ.....	☐	☐	
20. เคยเป็นโรคตับอักเสบหรือมีคนในครอบครัวเป็น.....	☐	☐	
21. เป็นโรคหอบหืด ลมชัก โรคผิวหนังเรื้อรัง ไอเรื้อรัง วัณโรค ภูมิแพ้ โรคความดันโลหิตสูง เบาหวาน หัวใจ ไทรอยด์ มะเร็ง โรคโลหิตออกง่าย-หยุดยาก หรือโรคอื่นๆ (ระบุ).....	☐	☐	
22. เจาะหูหรือวัยระอื้น สัก สบรอยสัก ผิวงู.....	☐	☐	
23. เคยรับวัคซีน เพื่อป้องกันโรค ภายใน 2 เดือน.....	☐	☐	
24. เคยรับเชรุ่ม ภายใน 1 ปี.....	☐	☐	
25. อื่นๆ.....	☐	☐	
ข้าพเจ้าขอรับรองว่า ได้ให้ข้อมูลและตอบคำถามตามความเป็นจริง ข้าพเจ้ามั่นใจว่าโลหิตของข้าพเจ้าปลอดภัยต่อผู้ป่วยและรับทราบว่าโลหิตต้องได้รับการตรวจการติดเชื้อซีพีอี, ไวรัสตับอักเสบบี, ซีและเอชวี ก่อนจะนำไปใช้ในการแพทย์ ข้าพเจ้าขอบริจาคโลหิตให้กับศูนย์บริการโลหิตแห่งชาติ สภากาชาดไทย นำไปใช้ตามแต่สภากาชาดไทยจะเห็นสมควร ด้วยความสมัครใจและไม่เรียกร้องหากเกิดกรณีใดๆทั้งสิ้น ลงชื่อผู้สมัคร.....			
เหตุผลที่อนุญาตให้บริจาคได้เป็นกรณีพิเศษ.....			
ลงชื่อแพทย์หรือเจ้าหน้าที่ผู้สัมภาษณ์คัดกรอง.....			

Figure A.2 The blood donor application form (page 2)

APPENDIX B

ORIGIN – DESTINATION COST MATRIX ANALYSIS

1. Open ArcGIS 9.3. To add the dataset of roads, click at the button , and select the file RoadTH_ND.nd, as shown in Figure B.1.

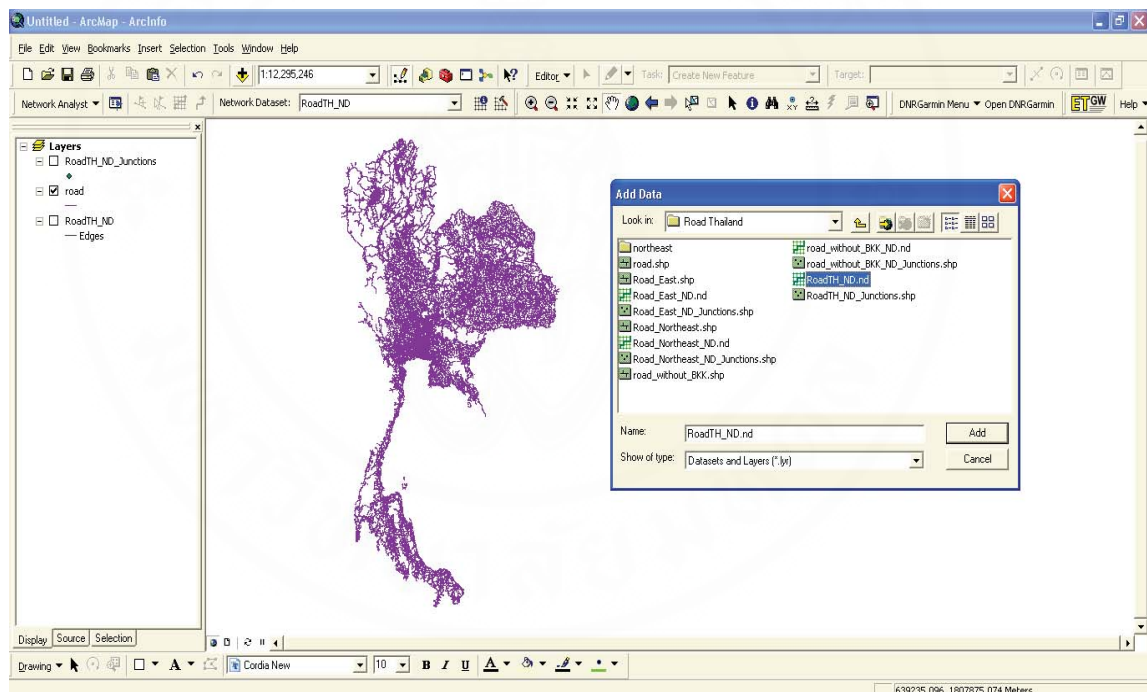


Figure B.1 Road network data in Thailand

2. Click at the button  to add more places (Points) that we want to calculate for distance, such as stations/airports of origin/destination, the NBC, RBCs, hospitals, etc, as shown in Figure B.2. After the origin and destination (Original-destination points) have been selected, we can see their additional information from their attribute table. This can be done by right-clicking at the layer's name, select Open attribute table. Then the information of features in the layer will be shown as in Figure B.3.

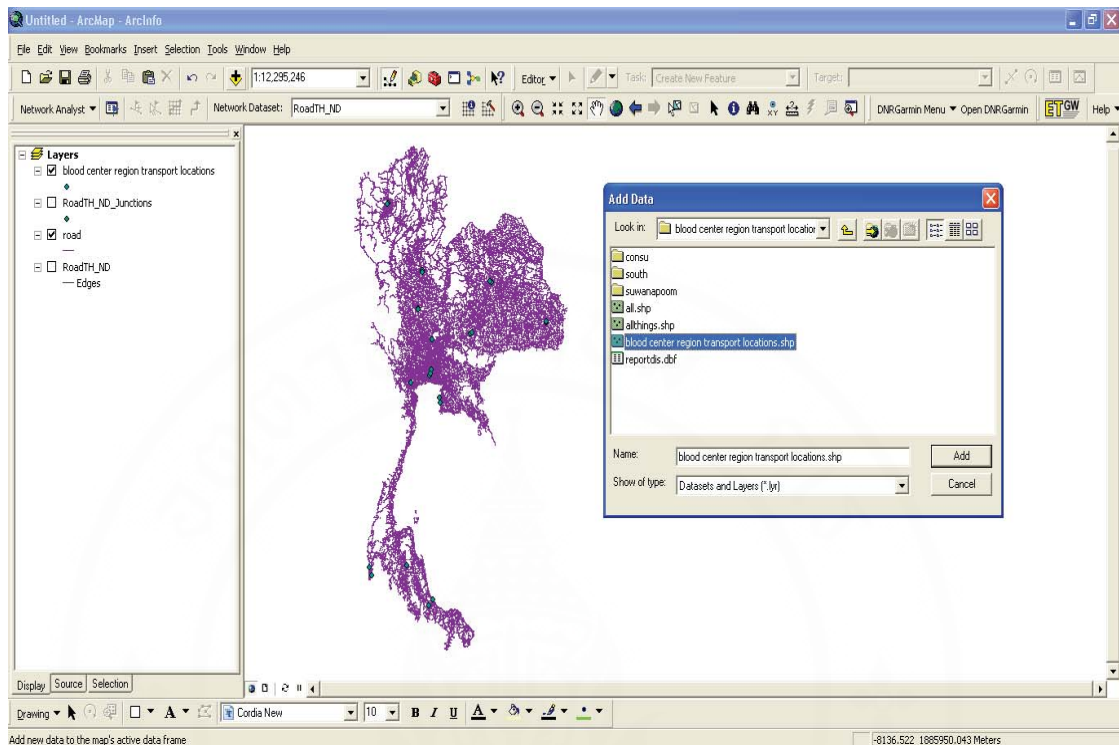


Figure B.2 Add data points

Attributes of blood center region transport locations								
	FID	Shape	TYPE	IDENT	LAT	LONG	Y_PROJ	X_PROJ
	0	Point	WAYPOIN	Nation blood center	13.73357	100.532444	1518483.593705	666030.38122
	1	Point	WAYPOIN	Doung Meung	13.913609	100.599242	1538448.513878	673121.77758
	2	Point	WAYPOIN	Nakhon Sawan transport	15.710488	100.125238	1736928.700683	620903.68399
	3	Point	WAYPOIN	Ratchaburi transport	13.536888	99.819558	1496354.522355	589015.91120
	4	Point	WAYPOIN	Phuket Airport	8.107582	98.30658	895954.958917	423938.67241
	5	Point	WAYPOIN	Lop Buri transport	14.801967	100.616902	1636746.753495	674342.3032
	6	Point	WAYPOIN	Nakhon Si Thammarat tran	8.164364	99.680222	902230.246563	575265.20868
	7	Point	WAYPOIN	Nakorn Ratchasima trans	14.956313	102.045862	1655439.514057	827988.03406
	8	Point	WAYPOIN	Blood Region 2	14.800233	100.629103	1636564.443756	675657.12814
	9	Point	WAYPOIN	Blood Region 3	12.948108	100.896056	1431856.744446	706021.45473
	10	Point	WAYPOIN	Blood Region 4	12.541015	99.817052	1406000.000865	588840.20248

Figure B.3 Open attribute table

3. Select “Network Analyst”, and then choose “New OD Cost Matrix” from the menu bar, as shown in Figure B.4.

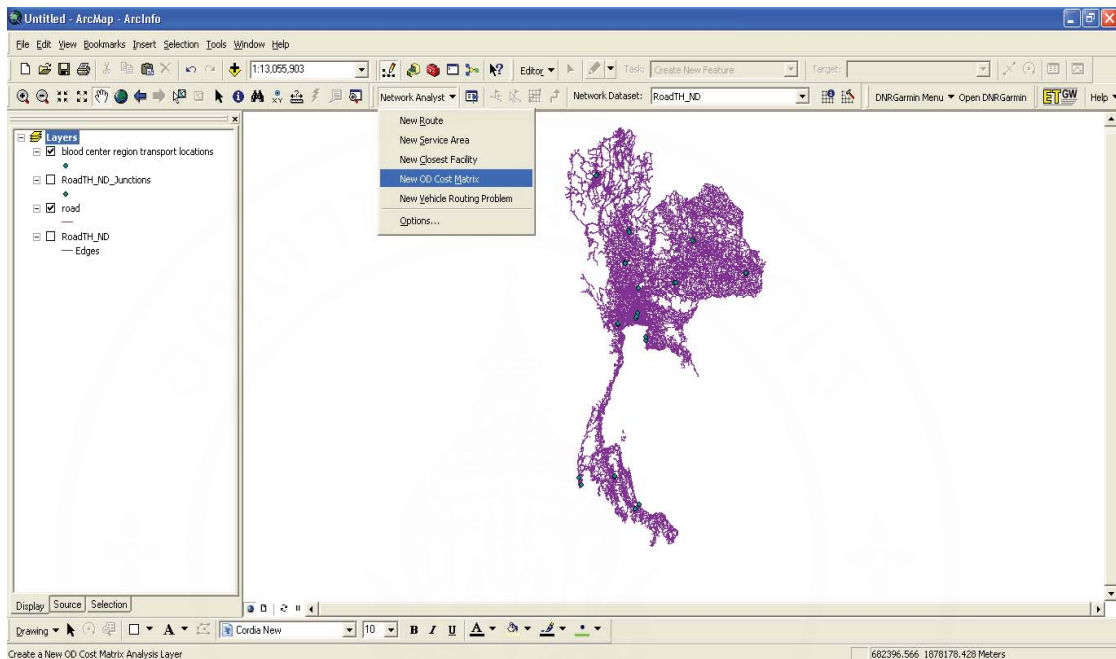


Figure B.4 Open OD cost matrix

4. The screen will display a window as shown in Figure B.5. Click at the button  to set the parameters in Layer properties.

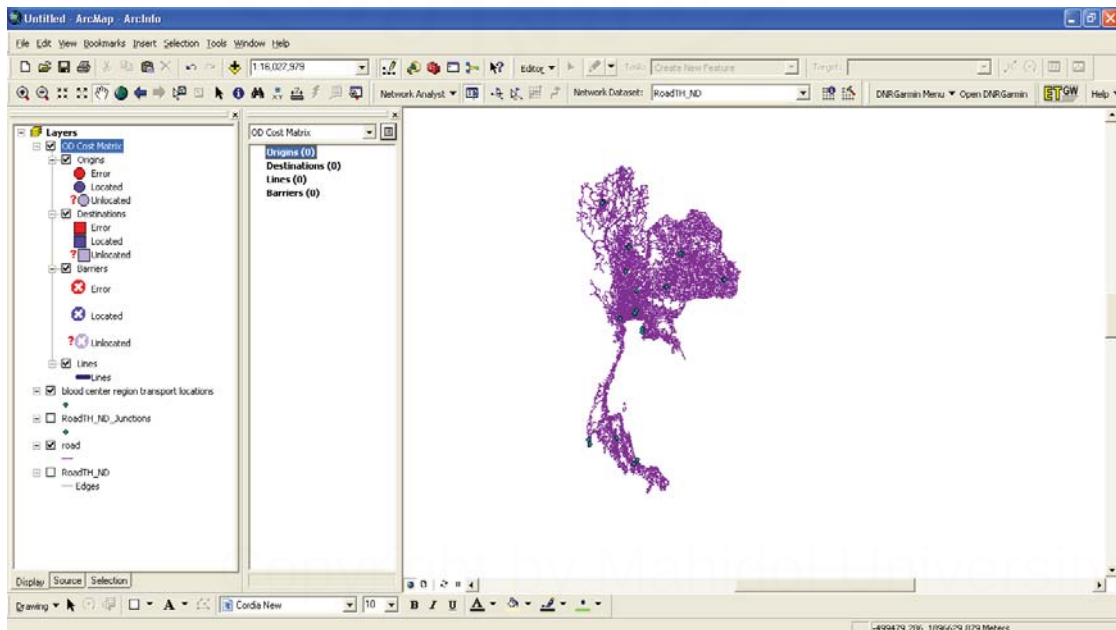


Figure B.5 Layer properties setting

5. To set parameters in Layer Properties, select the “Accumulation”, check the boxes of Meters and Minutes, as shown in Figure B.6. Then select network locations, and set parameters as shown in Figure B.7.

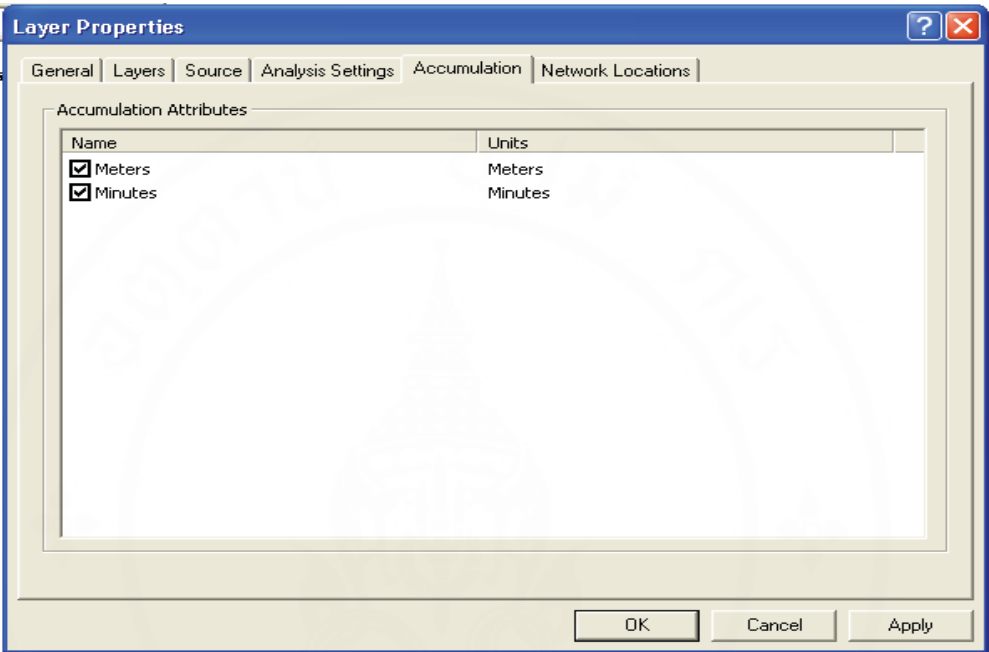


Figure B.6 Accumulation setting

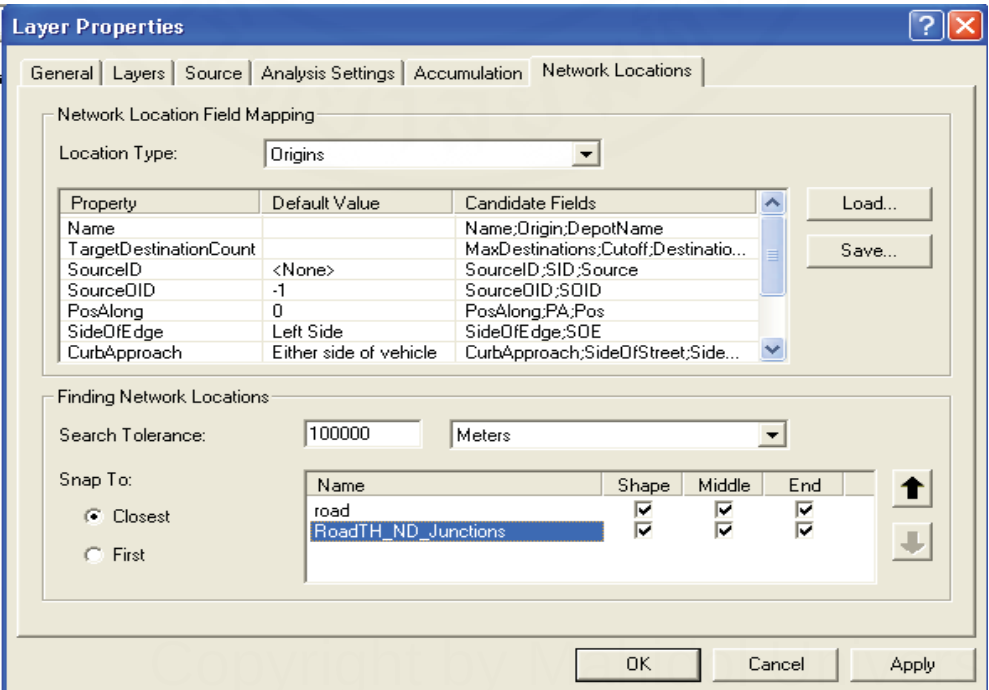


Figure B.7 Network locations setting

6. Select the places for distance calculation, right click at Origin, and select Load Locations, as shown in Figure B.8. The Load Locations window will pop up, as shown in Figure B.9. Select the file that we want to use as the origin in the “Load From” box.

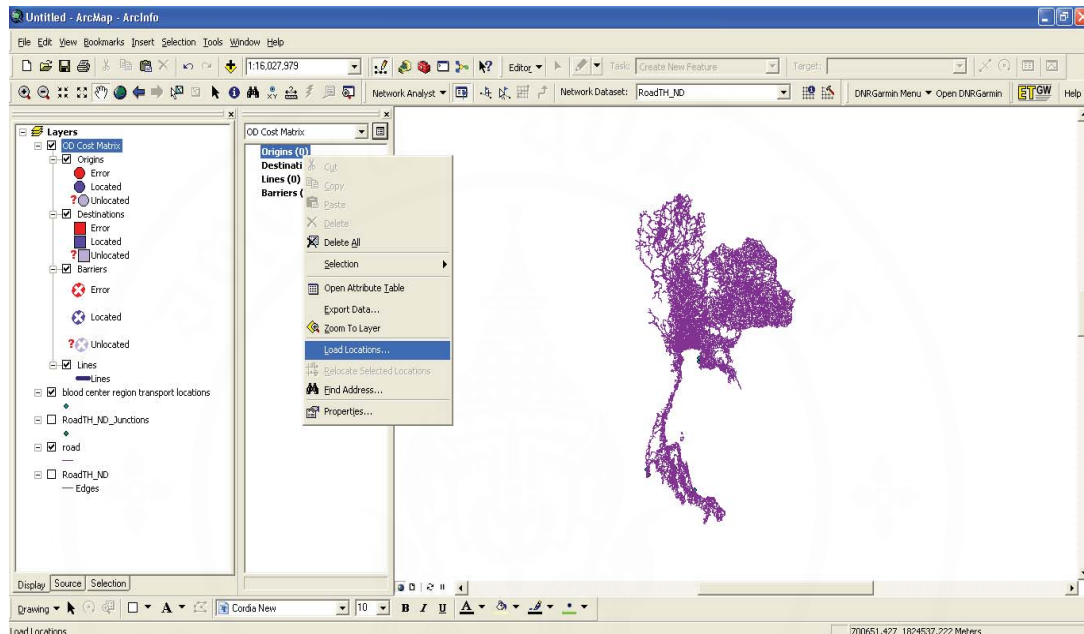


Figure B.8 Load locations

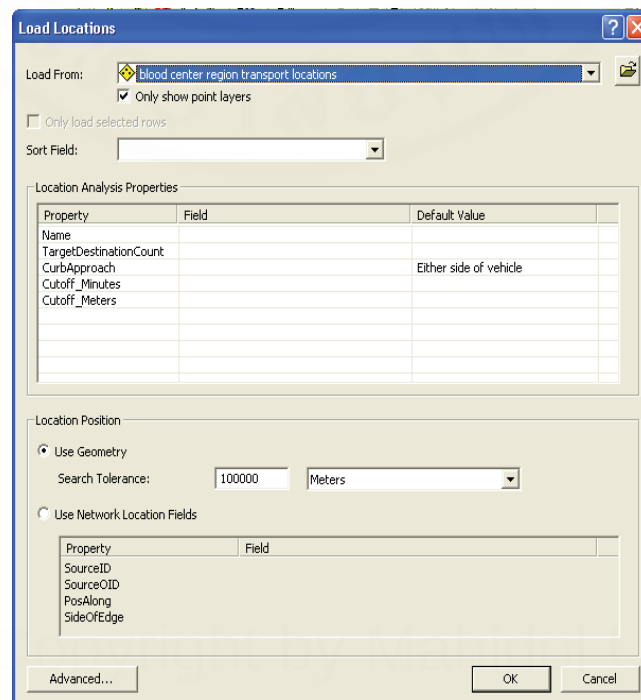


Figure B.9 Load locations setting

7. Similarly, the points of Destinations can be specified in the same way as the Origins. After finished, click at the button  to start analyzing for the origin-destination cost matrix, as shown in Figure B.10.

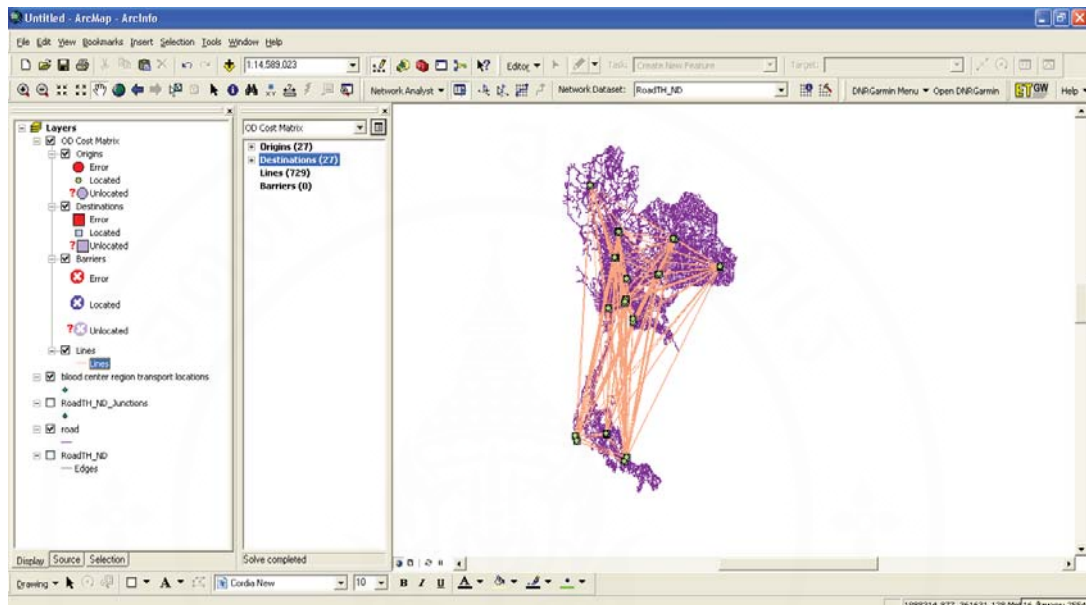


Figure B.10 Origin-destination cost matrix analysis

8. To save the distance data from the analysis, right click at Lines, then select “Open Attribution Table”, as shown in Figure B.11.

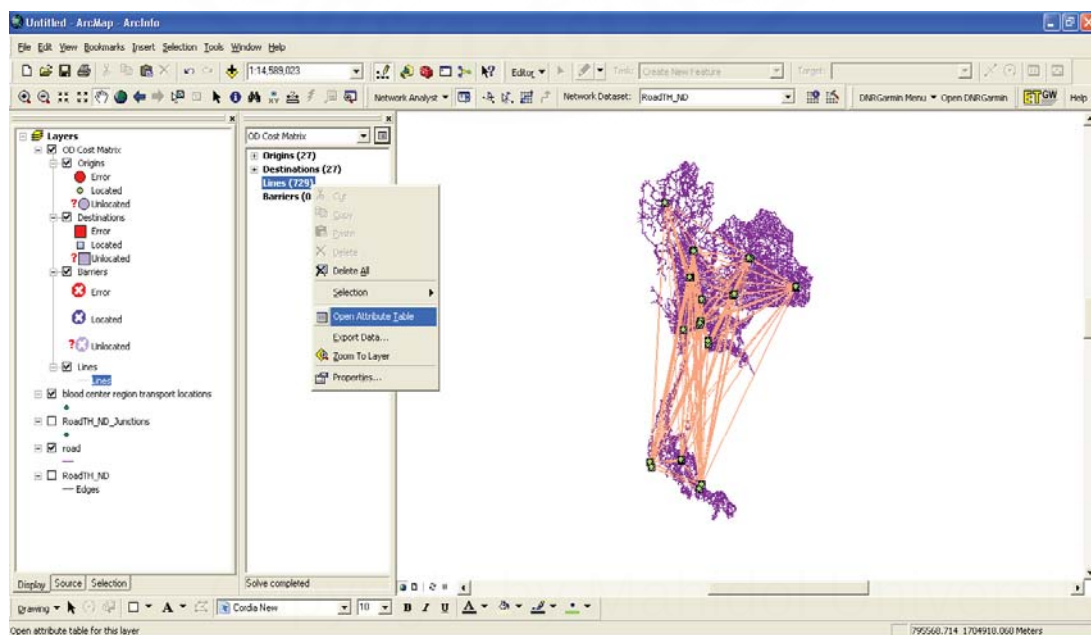


Figure B.11 Open attribute table

9. Click at the menu Options, then select Export, as shown in Figure B.12.

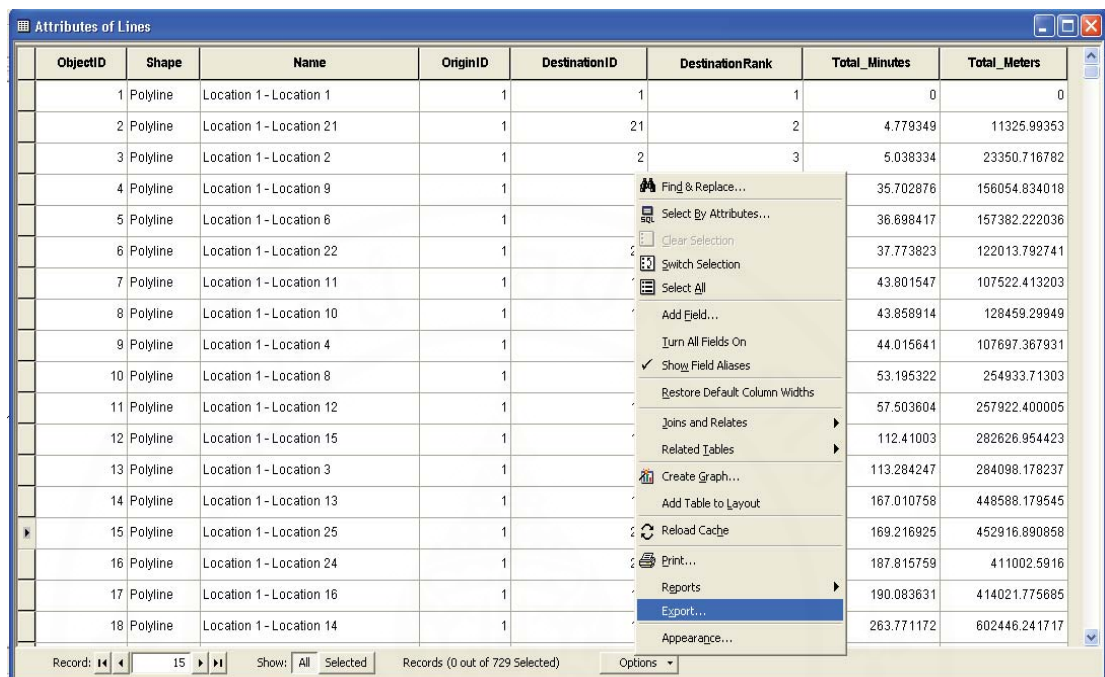


Figure B.12 Export files

10. The Export data dialog will show up. Click at the button  in order to specify the location for saving the data. Then click OK, as shown in Figure B.13.

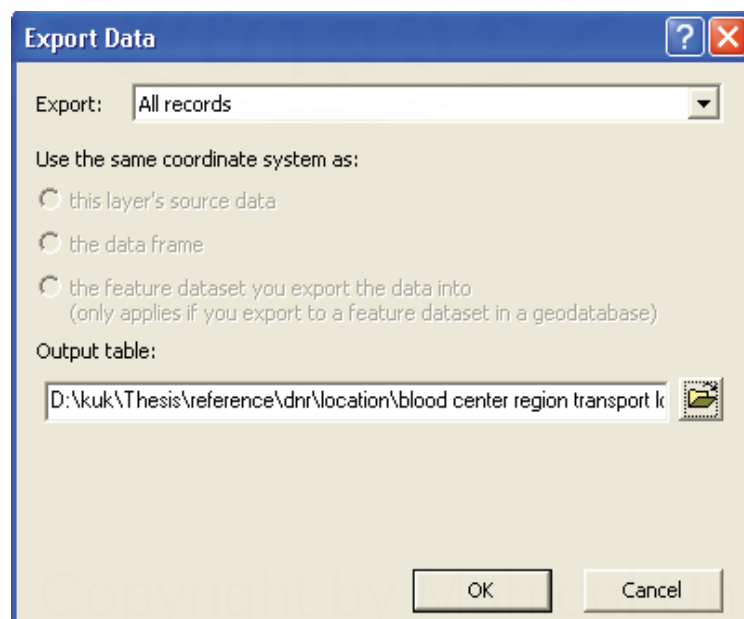


Figure B.13 Saved output files

APPENDIX C

THE PROCEDURE FOR CONVERTING A POLYGON DATASET TO A POINT FEATURE CLASS

1. Click at the button  to add the file of boundaries of districts in Thailand (Polygon data), as shown in Figure C.1.

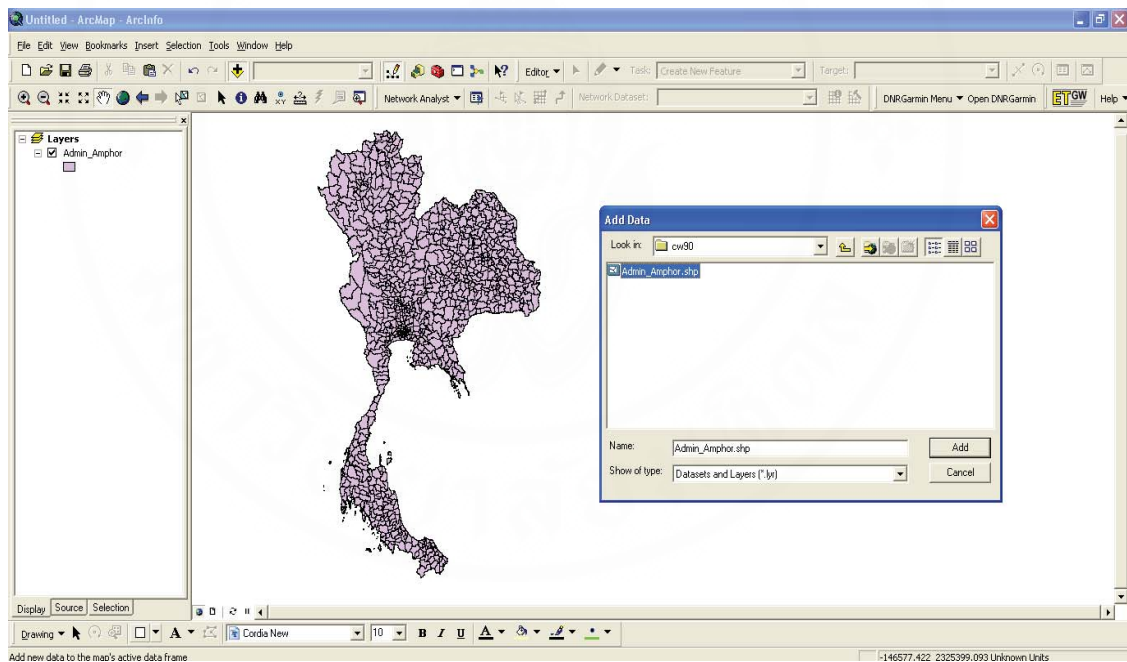


Figure C.1 Open polygon data

2. Right click at Adam_Amphor > Open Attribute Table > Attribute of Adam_Amphor, as shown in Figure C.2.

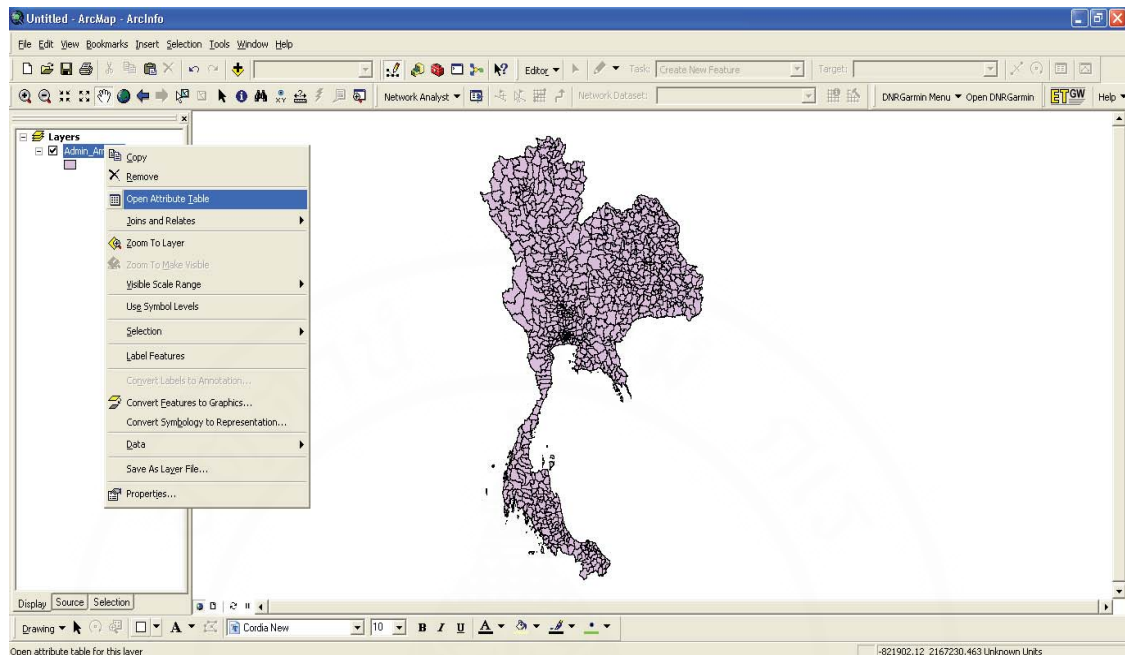


Figure C.2 Open attribute table

3. Right click at the “AMP_NAMT” column in the attribute of Admin_Amphor window, then select AMP_NAMET > Sort Ascending in order to select only Muang district of each province, as shown in Figure C.3.

Attributes of Admin_Amphor									
FID	Shape	PROV_CODE	AMP_CODE	PROV_NAMT	PROV_NAME	AMP_NAMT	AMP_NAME	AREA_CODE	LABELCLASS
96	Polygon	40	17	ขอนแก่น	KHON KAEN	เมืองขอนแก่น		4017	2
897	Polygon	94	05	ปัตตานี	PATTANI	มาบอง		9405	2
437	Polygon	10	10	กรุงเทพมหานคร	BANGKOK	มีนบุรี		1010	1
183	Polygon	45	15	ร้อยเอ็ด	ROI ET	เมืองร้อยเอ็ด		4515	2
798	Polygon	81	01	กระบี่	KRABI	เมืองกระบี่		8101	2
723	Polygon	71	01	กาญจนบุรี	KANCHANABURI	เมืองกาญจนบุรี		7101	2
189	Polygon	46	01	กาฬสินธุ์	KALASIN	เมืองกาฬสินธุ์		4601	2
378	Polygon	62	01	กำแพงเพชร	KAMPHAENG PHET	เมืองกำแพงเพชร		6201	2
80	Polygon	40	01	ขอนแก่น	KHON KAEN	เมืองขอนแก่น		4001	2
577	Polygon	22	01	จันทบุรี	CHANTHABURI	เมืองจันทบุรี		2201	2
12	Polygon	34	18	ศรีสะเกษ	SI SA KET	เมืองศรีสะเกษ		3318	2
594	Polygon	24	01	ฉะเชิงเทรา	CHACHOENGSAO	เมืองฉะเชิงเทรา	MUEANG CHACHOENGSAO	2401	2
568	Polygon	20	01	ชลบุรี	CHON BURI	เมืองชลบุรี	MUEANG CHON BURI	2001	2
537	Polygon	18	01	ชัยนาท	CHAI NAT	เมืองชัยนาท	MUEANG CHAI NAT	1801	2
51	Polygon	36	01	ชัยภูมิ	CHAIYAPHUM	เมืองชัยภูมิ	MUEANG CHAIYAPHUM	3601	2
841	Polygon	86	01	ชุมพร	CHUMPHON	เมืองชุมพร	MUEANG CHUMPHON	8601	2
330	Polygon	57	01	เชียงราย	CHIANG RAI	เมืองเชียงราย	MUEANG CHIANG RAI	5701	2
244	Polygon	50	01	เชียงใหม่	CHIANG MAI	เมืองเชียงใหม่	MUEANG CHIANG MAI	5001	2
872	Polygon	92	01	ตรัง	TRANG	เมืองตรัง	MUEANG TRANG	9201	2
587	Polygon	23	01	ตาก	TRAT	เมืองตาก	MUEANG TAK	2301	2
389	Polygon	63	01	ตาก	TAK	เมืองตาก	MUEANG TAK	6301	2
649	Polygon	66	04	น่าน	NAN	เมืองน่าน	MUEANG NAN	6604	2

Figure C.3 Selection Ampher Mueang of each province

4. Right click at the layer of Adam_Amphor > Data > Export Data, in order to export only the selected features into another file.

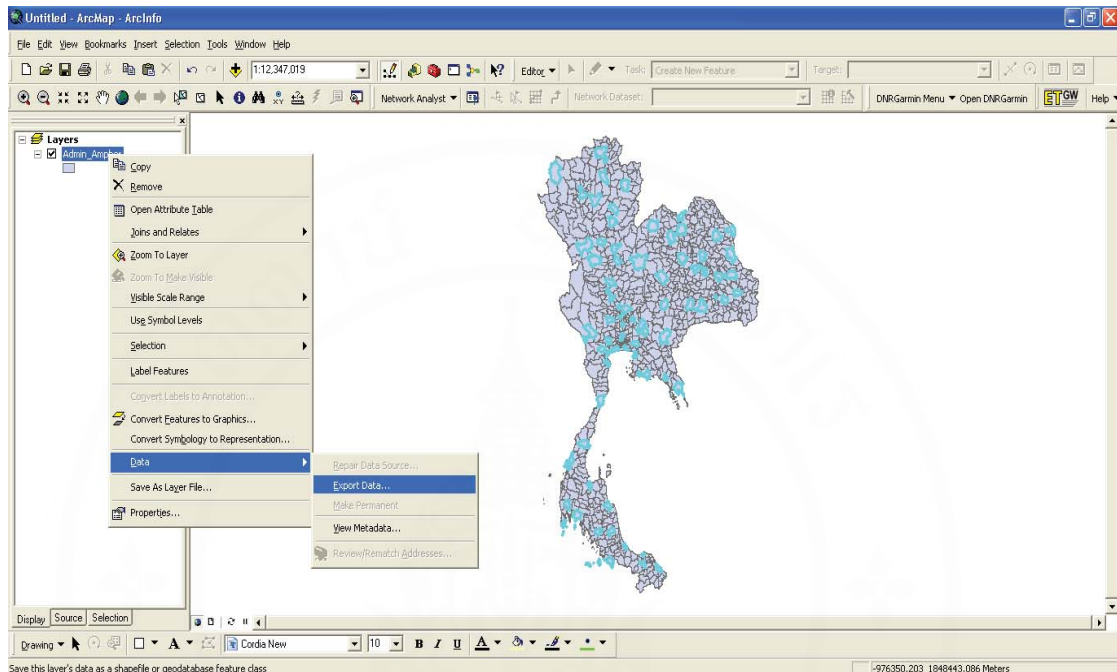


Figure C.4 Exporting Amphor Mueang data

5. In the Export Data window, click the button  in order to specify the folder to save the data. When done, click at the OK button, as shown in Figure C.5.

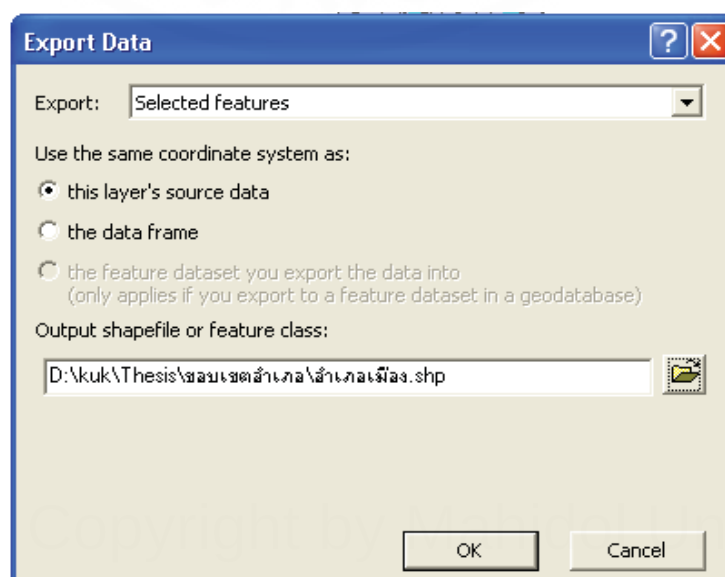


Figure C.5 Saved output data files

6. Open the software ET Geo Wizards by clicking the button  > Polygon to Point > Go, as shown in Figure C.6.

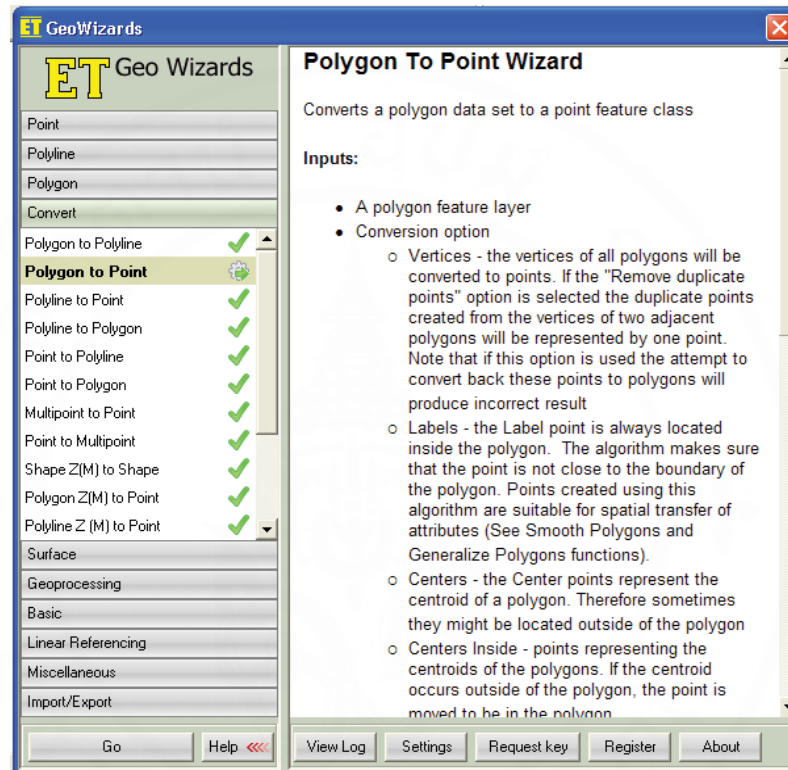


Figure C.6 Open ET Geo Wizards

7. At the “Select polygon layer” box, select the file of polygons to be converted. In the “Specify output feature class or shapefile”, select the location for saving the output data, as shown in Figure C.7.

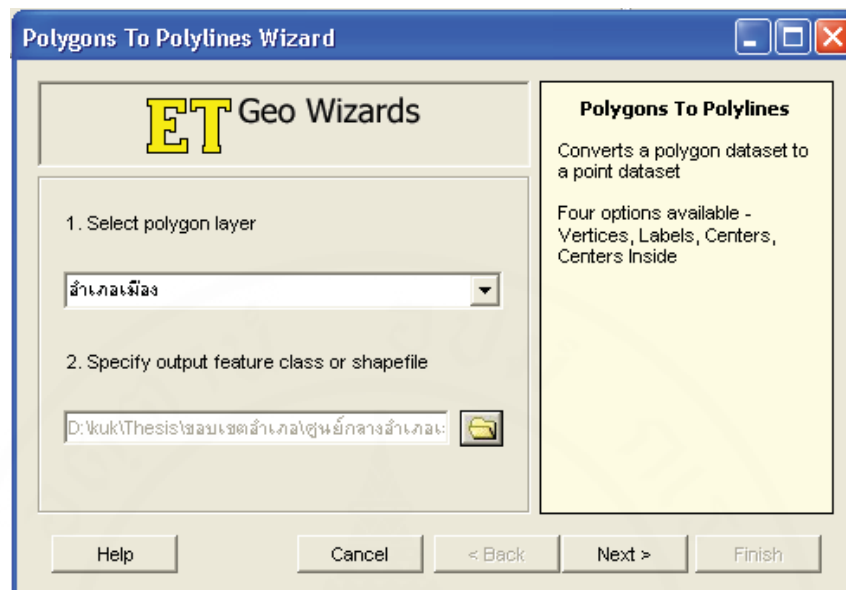


Figure C.7 Select polygon layer

8. In the “Specify conversion option” box, select Centers In, then click Finish, as shown in Figure C.8.

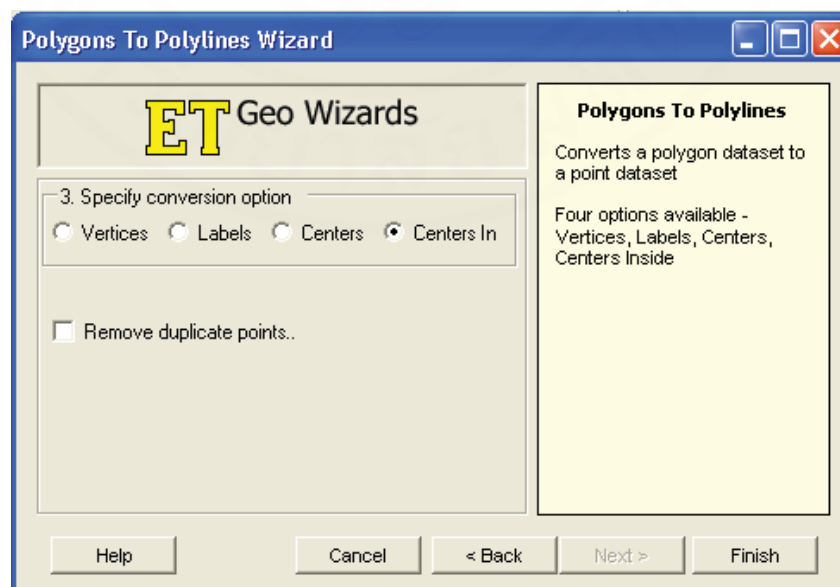


Figure C.8 Specify conversion option

9. After the process of converting polygons to point has completed, the new point dataset can be displayed, as shown in Figure C.9. This point data will be used for the distance matrix calculation, as discussed in Appendix B.

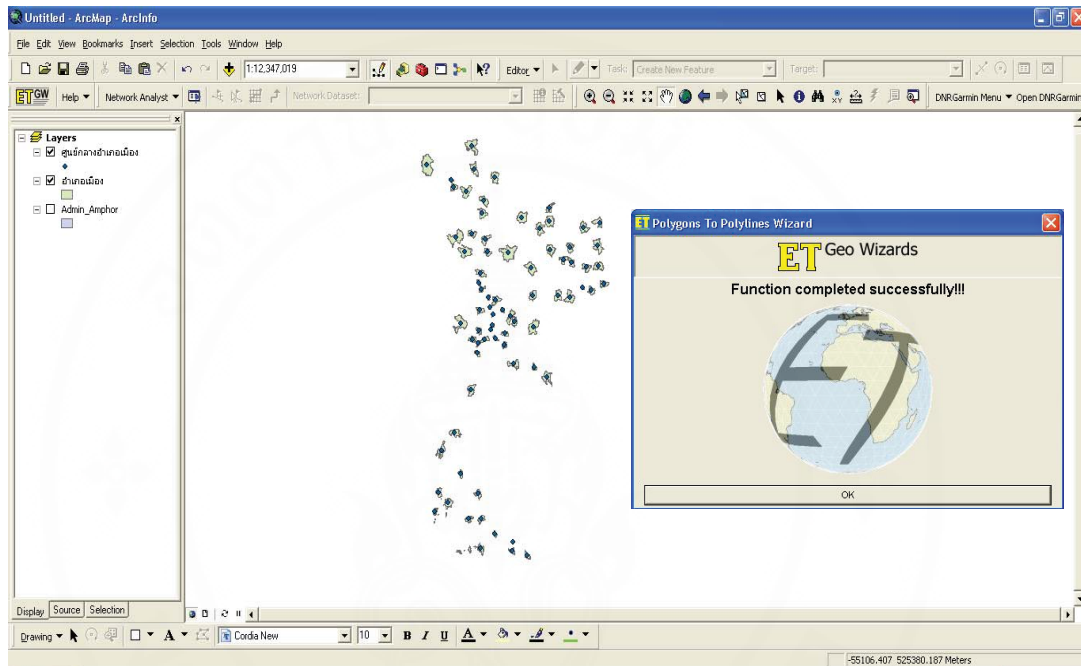


Figure C.9 Function completed successfully

APPENDIX D

DOMESTIC FLIGHT DISTANCE

ตารางแสดงระยะทางการบินภายในประเทศ และอัตราค่าโดยสารรวมค่าธรรมเนียมต่าง ๆ สูงสุด				
เส้นทางบิน	ระยะทาง กม.	อัตราค่าโดยสารรวม ค่าธรรมเนียมต่าง ๆ สูงสุด (บาท) เฉลี่ย/ก.ม	อัตราค่าโดยสารรวม ค่าธรรมเนียมต่าง ๆ สูงสุด ที่เรียกเก็บได้ (บาท)	
1. กรุงเทพฯ - เชียงใหม่	566	10	5,660	
2. กรุงเทพฯ - เชียงราย	678	10	6,780	
3. กรุงเทพฯ - หาดใหญ่	770	10	7,770	
4. กรุงเทพฯ - ขอนแก่น	387	10	3,870	
5. กรุงเทพฯ - กระบี่	667	10	6,670	
6. กรุงเทพฯ - นครศรีธรรมราช	607	10	6,070	
7. กรุงเทพฯ - พิษณุโลก	332	10	3,320	
8. กรุงเทพฯ - สุโขทัย	455	10	4,550	
9. กรุงเทพฯ - ภูเก็ต	696	10	6,960	
10. กรุงเทพฯ - สุราษฎร์ธานี	552	10	5,520	
11. กรุงเทพฯ - ตรัง	728	10	7,280	
12. กรุงเทพฯ - อุบลราชธานี	483	10	4,830	
13. กรุงเทพฯ - อุตรธานี	457	10	4,570	
14. สุโขทัย - เชียงใหม่	193	กำหนดอัตราค่าโดยสารเสรี	กำหนดอัตราค่าโดยสารเสรี	
15. สมุย - ภูเก็ต	265	10	2,650	
16. เชียงใหม่ - สมุย	1,054 (1)	กำหนดอัตราค่าโดยสารเสรี	กำหนดอัตราค่าโดยสารเสรี	
17. สมุย - อุตะเปา	364 (1)	กำหนดอัตราค่าโดยสารเสรี	กำหนดอัตราค่าโดยสารเสรี	
18. สมุย - กระบี่	226	10	2,260	
19. ภูเก็ต - อุตะเปา	595 (1)	กำหนดอัตราค่าโดยสารเสรี	กำหนดอัตราค่าโดยสารเสรี	
20. กรุงเทพฯ - ตราด	298	10	2,980	
21. เชียงใหม่ - แม่ฮ่องสอน	126	อากาศยานไม่เกิน 19 ที่นั่ง 20 บาท /กม. อากาศยานอื่น ๆ 17 บาท/กม.	- 2,520 บาท(อากาศยานไม่เกิน 19 ที่นั่ง) - 2,142 บาท(อากาศยานอื่น ๆ)	
22. เชียงใหม่ - ภูเก็ต	1,263 (1)	กำหนดอัตราค่าโดยสารเสรี	กำหนดอัตราค่าโดยสารเสรี	
23. กรุงเทพฯ - สมุย	489	10	4,890	
24. กรุงเทพฯ - ร้อยเอ็ด	422	10	4,220	
25. กรุงเทพฯ - สกลนคร	552	10	5,520	
26. กรุงเทพฯ - นครพนม	579	10	5,790	
27. กรุงเทพฯ - ลำปาง	509	10	5,090	
28. กรุงเทพฯ - น่าน	574	10	5,740	
29. กรุงเทพฯ - แม่ฮ่องสอน	693	10	6,930	
30. กรุงเทพฯ - บุรีรัมย์	332	10	3,320	
31. กรุงเทพฯ - นครราชสีมา	843	10	8,430	
32. กรุงเทพฯ - เลย	420	10	4,200	
33. เลย - อุตรธานี	113	กำหนดอัตราค่าโดยสารเสรี	กำหนดอัตราค่าโดยสารเสรี	
34. เชียงใหม่ - อุตรธานี	461(1)	กำหนดอัตราค่าโดยสารเสรี	กำหนดอัตราค่าโดยสารเสรี	
35. ภูเก็ต - หาดใหญ่	267	10	2,670	
36. เชียงใหม่ - เชียงราย	163	กำหนดอัตราค่าโดยสารเสรี	กำหนดอัตราค่าโดยสารเสรี	
37. กรุงเทพฯ - หัวหิน	161	กำหนดอัตราค่าโดยสารเสรี	กำหนดอัตราค่าโดยสารเสรี	
38. เชียงใหม่ - ปาย	94	อากาศยานไม่เกิน 19 ที่นั่ง 20 บาท/กม. อากาศยานอื่น ๆ 17 บาท/กม.	- 1,880 บาท(อากาศยานไม่เกิน 19 ที่นั่ง) - 1,598 บาท (อากาศยานอื่น ๆ)	

หมายเหตุ (1) เส้นทางบินเชื่อมระหว่างภาคโดยไม่จอดแวะกรุงเทพฯ
(2) หลักเกณฑ์การคำนวณระยะทางคำนวณจากจุดไปจุดตามเส้นทางบิน(Airway) ที่ประกาศใน AIP ที่เหมาะสม และสั้นที่สุด หากไม่มีเส้นทางบินให้คำนวณระยะทางตรงจากสถานีเครื่องช่วยเดินอากาศหรือ Coordinate ของท่าอากาศยานนี้

Figure D.1 Flight distance from department of civil aviation (DCA)

APPENDIX E

DATA ON BLOOD QUANTITY

ตาราง เปรียบเทียบปริมาณการจ่ายส่วนประกอบโลหิต ตั้งแต่ปีงบประมาณ พ.ศ. 2551 - 2554					
ปีงบประมาณ	พ.ศ.2551	พ.ศ.2552	พ.ศ.2553	พ.ศ.2554	
ปริมาณโลหิต บริจาค	✓ 497,385 ยูนิต ✓	539,094 ยูนิต	571,094 ยูนิต	588,748 ยูนิต	
ปริมาณ ส่วนประกอบ โลหิตที่จ่าย	Red blood cells 478,489 ยูนิต Platelet 125,222 ยูนิต Plasma 294,905 ยูนิต <u>รวมทั้งสิ้น 898,616 ยูนิต</u>	Red blood cells 517,417 ยูนิต Platelet 124,638 ยูนิต Plasma 319,641 ยูนิต <u>รวมทั้งสิ้น 961,696 ยูนิต</u>	Red blood cells 551,104 ยูนิต Platelet 147,840 ยูนิต Plasma 350,306 ยูนิต <u>รวมทั้งสิ้น 1,049,250 ยูนิต</u>	Red blood cells 567,944 ยูนิต Platelet 153,254 ยูนิต Plasma 426,841 ยูนิต <u>รวมทั้งสิ้น 1,148,039 ยูนิต</u>	
จำนวน โรงพยาบาล	- รัฐบาล และเอกชน ใน กทม. รวม 113 โรง ✓ - รัฐบาล และเอกชน ใน ตจว. รวม 187 โรง - ภาคบริการโลหิตแห่งชาติ รวม 11 ภาค <u>รวมทั้งสิ้น 311 แห่ง</u>	- รัฐบาล และเอกชน ใน กทม. รวม 109 โรง - รัฐบาล และเอกชน ใน ตจว. รวม 202 โรง - ภาคบริการโลหิตแห่งชาติ รวม 12 ภาค <u>รวมทั้งสิ้น 323 แห่ง</u>	- รัฐบาล และเอกชน ใน กทม. รวม 112 โรง - รัฐบาล และเอกชน ใน ตจว. รวม 208 โรง - ภาคบริการโลหิตแห่งชาติ รวม 12 ภาค <u>รวมทั้งสิ้น 332 แห่ง</u>	- รัฐบาล และเอกชน ใน กทม. รวม 112 โรง - รัฐบาล และเอกชน ใน ตจว. รวม 237 โรง - ภาคบริการโลหิตแห่งชาติ รวม 13 ภาค <u>รวมทั้งสิ้น 362 แห่ง</u>	

Figure E.1 Blood donation and blood distribution by the NBC during
fiscal year 2008 – 2011 from National Blood Center

APPENDIX F

THAILAND GROSS DOMESTIC PRODUCT IN 2010

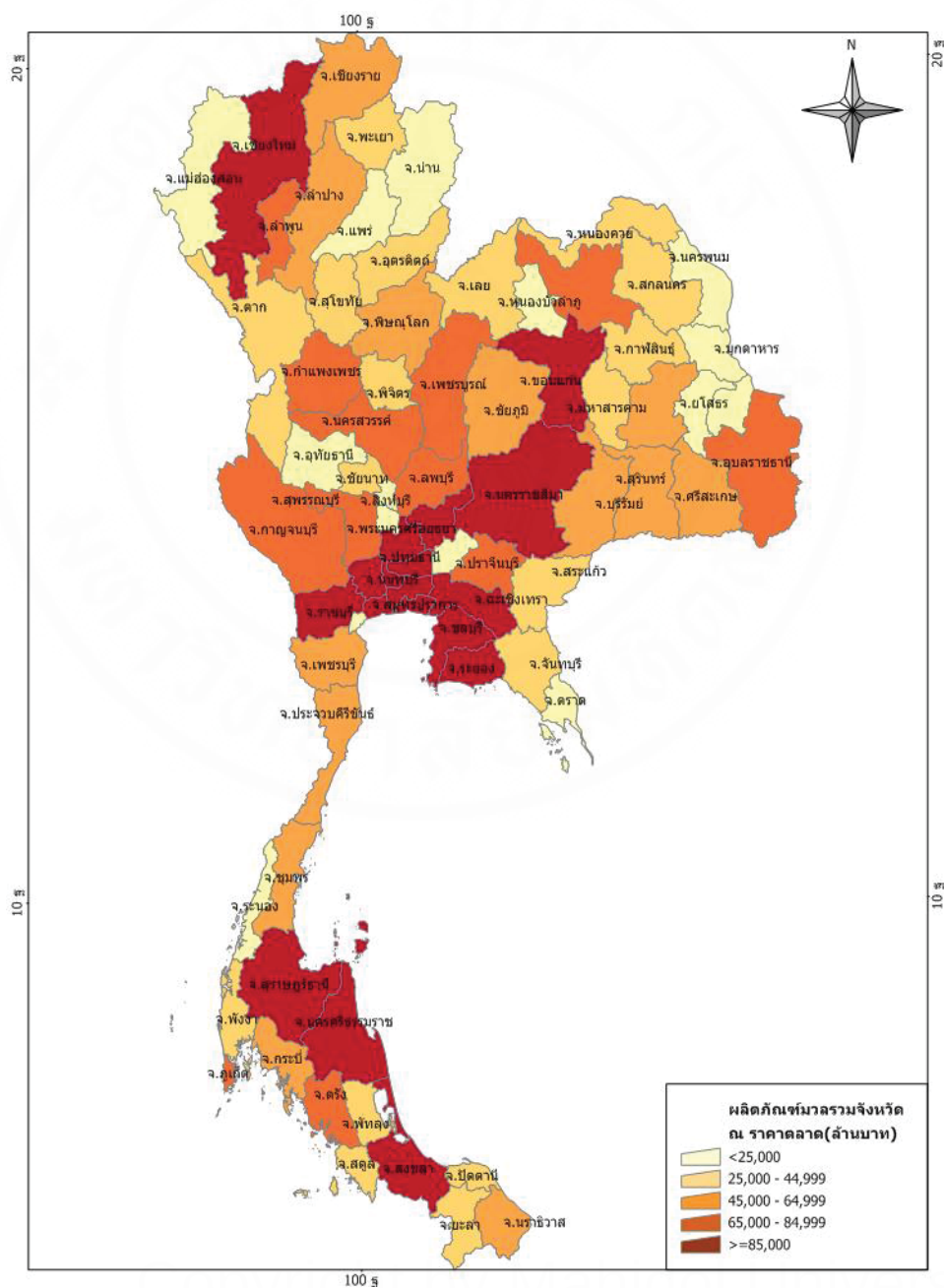


Figure F.1 Gross domestic product (GDP) from Gross domestic product in 2010

APPENDIX G

OPTIMAL RESULTS FOR CASE 2: NEW NETWORK DESIGN WITH UNLIMITED BLOOD SUPPLY

Case 2 locates only one center at the NBC in Bangkok. The total system cost of the designed network of blood distribution according to the Case 2 is 800,417,932 Baht. The fixed cost is 780,490,116 Baht. Table G.1 shows blood transportation cost from each RBC to its responsible provinces. Column 1 of the table is the number of the RBC. Column 2 contains the routes from each RBC to its service provinces. Column 3 presents unit delivery cost for transporting blood from each RBC to the terminal hospitals. Column 4 shows quantities of blood that each terminal province requires in each year. Column 5 shows ratios (or fractions) of blood demand that each terminal province receives from each RBC. Column 6 contains the total transportation cost as derived from Case 2. Finally, the last column shows the distribution distance from location to allocation (i_j). The grand total transportation cost at the bottom line is 19,927,816 Baht/year. The problem was solved within 0.60 seconds, as shown in Figure G.1.

Table G.1 Results from solving the Uncapacitated Fixed Charge Facility Location model of case 2

RBC (1)	Allocation_Location (i_j) (2)	Delivery cost: C_{ij} (Baht/unit) (3)	Demand: h_i (units/year) (4)	Fraction of demand at demand point i : Y_{ij} (5)	The demand point - weighted distance (Baht) (6)	Distance (km.) (7)
01	Bangkok_Bangkok	0	370,594	1.00	0	0
	Krabi_Bangkok	19.33	5,395	1.00	104,285	778.75
	Kanchanaburi_Bangkok	7.51	13,437	1.00	100,912	284.99
	Kalasin_Bangkok	21.78	11,740	1.00	255,697	547.11
	Kamphaengphet_Bangkok	15.29	8,978	1.00	137,274	392.84
	Khonkaen_Bangkok	12.37	59,208	1.00	732,403	467.34
	Chanthaburi_Bangkok	10.51	25,989	1.00	273,144	241.07
	Chachoengsao_Bangkok	14.92	14,656	1.00	218,668	123.77
	Chonburi_Bangkok	28.74	53,923	1.00	1,549,747	111.62
	Chai Nat_Bangkok	11.1	6,143	1.00	68,187	285.63
	Chaiyaphum_Bangkok	15.45	14,346	1.00	221,646	421.77
	Chumphon_Bangkok	17.09	17,575	1.00	300,357	518.11
	Chiang Rai_Bangkok	18.11	31,213	1.00	565,267	809.64
	Chiang Mai_Bangkok	15.46	64,631	1.00	999,195	762.29
	Trang_Bangkok	24.9	7,893	1.00	196,536	863.37
	Trat_Bangkok	13.88	3,668	1.00	50,912	307.57

Table G.1 Results from solving the Uncapacitated Fixed Charge Facility Location model of case 2 (cont.)

RBC (1)	Allocation_Location (i_j) (2)	Delivery cost: C_{ij} (Baht/unit) (3)	Demand: h_i (units/year) (4)	Fraction of demand at demand point i : Y_{ij} (5)	The demand point - weighted distance (Baht) (6)	Distance (km.) (7)
	Tak_Bangkok	17.19	7,601	1.00	130,661	504.28
	Nakhonnayok_Bangkok	9.23	4,350	1.00	40,151	135.24
	Nakhonpathom_Bangkok	15.63	17,758	1.00	277,558	94.77
	Nakhonphanom_Bangkok	23.89	6,678	1.00	159,537	698.65
	Nakhonratchasima_Bangkok	10.85	57,304	1.00	621,748	260.37
	Nakhonsithammarat_Bangkok	32.01	20,252	1.00	648,267	792.83
	Nakhonsawan_Bangkok	11.89	23,153	1.00	275,289	286.03
	Nonthaburi_Bangkok	4.22	12,092	1.00	51,028	50.17
	Narathiwat_Bangkok	55.33	7,261	1.00	401,751	1,184.58
	Nan_Bangkok	23.13	9,619	1.00	222,487	709.60
	Buriram_Bangkok	50.94	20,402	1.00	1,039,278	385.00
	Pathumthani_Bangkok	7.72	21,197	1.00	163,641	47.45
	Phachuap_Bangkok	12.46	9,087	1.00	113,224	321.41
	Prachiburi_Bangkok	8.77	11,078	1.00	97,154	192.70
	Pattani_Bangkok	39.33	5,510	1.00	216,708	1,080.20
	Ayutthaya_Bangkok	16.19	19,594	1.00	317,227	171.35

Table G.1 Results from solving the Uncapacitated Fixed Charge Facility Location model of case 2 (cont.)

RBC (1)	Allocation_Location (i_j) (2)	Delivery cost: C_{ij} (Baht/unit) (3)	Demand: h_i (units/year) (4)	Fraction of demand at demand point i : Y_{ij} (5)	The demand point - weighted distance (Baht) (6)	Distance (km.) (7)
	Phayao_Bangkok	34.74	11,488	1.00	399,093	734.47
	Phangnga_Bangkok	28.76	4,160	1.00	119,642	783.63
	Phatthalung_Bangkok	34.95	7,578	1.00	264,851	887.07
	Phichit_Bangkok	14.69	8,100	1.00	118,989	358.30
	Phitsanulok_Bangkok	16.01	22,832	1.00	365,540	439.64
	Phetchaburi_Bangkok	6.39	7,592	1.00	48,513	212.54
	Phetchabun_Bangkok	13.94	18,423	1.00	256,817	332.84
	Phare_Bangkok	22.17	11,491	1.00	254,755	590.19
	Phuket_Bangkok	22.85	11,390	1.00	260,262	858.32
	Mahasarakham_Bangkok	18.14	10,886	1.00	197,472	454.61
	Mukdahan_Bangkok	23.32	5,843	1.00	136,259	630.52
	Mae Hong Son_Bangkok	31.28	3,599	1.00	112,577	844.73
	Yasothon_Bangkok	19.43	7,049	1.00	136,962	581.82
	Yala_Bangkok	42.48	9,144	1.00	388,437	1,084.00
	Roi Et_Bangkok	18.11	18,030	1.00	326,523	513.51
	Ranong_Bangkok	21.77	3,747	1.00	81,572	608.29

Table G.1 Results from solving the Uncapacitated Fixed Charge Facility Location model of case 2 (cont.)

RBC (1)	Allocation_Location (i_j) (2)	Delivery cost: C_{ij} (Baht/unit) (3)	Demand: h_i (units/year) (4)	Fraction of demand at demand point i : Y_{ij} (5)	The demand point - weighted distance (Baht) (6)	Distance (km.) (7)
	Rayong_Bangkok	7.92	16,399	1.00	129,880	166.93
	Ratchaburi_Bangkok	5.88	23,593	1.00	138,727	170.47
	Lopburi_Bangkok	7.77	23,368	1.00	181,569	182.63
	Lampang_Bangkok	22.79	21,583	1.00	491,877	652.04
	Lamphun_Bangkok	24.34	12,122	1.00	295,049	646.78
	Loei_Bangkok	17.22	9,711	1.00	167,223	530.33
	Sisaket_Bangkok	20.2	15,275	1.00	308,555	548.66
	Sakonakhon_Bangkok	23.54	12,813	1.00	301,618	652.42
	Songkhla_Bangkok	20.9	25,701	1.00	537,151	978.13
	Satun_Bangkok	39.56	2,302	1.00	91,067	972.91
	Samutprakan_Bangkok	7.18	17,634	1.00	126,612	30.15
	Samutsongkhram_Bangkok	13.64	4,375	1.00	59,675	122.56
	Samutsakhon_Bangkok	7.99	10,073	1.00	80,483	92.36
	Sakao_Bangkok	11.22	6,628	1.00	74,366	224.89
	Saraburi_Bangkok	19.11	20,748	1.00	396,494	131.20
	Singburi_Bangkok	8.42	6,575	1.00	55,362	198.68

Table G.1 Results from solving the Uncapacitated Fixed Charge Facility Location model of case 2 (cont.)

RBC (1)	Allocation_Location (i_j) (2)	Delivery cost: C_{ij} (Baht/unit) (3)	Demand: h_i (units/year) (4)	Fraction of demand at demand point $i : Y_{ij}$ (5)	The demand point - weighted distance (Baht) (6)	Distance (km.) (7)
	Sukhothai_Bangkok	17.51	9,219	1.00	161,425	496.99
	Suphanburi_Bangkok	8.04	8,241	1.00	66,258	166.58
	Suratthani_Bangkok	18.32	17,978	1.00	329,357	670.48
	Surin_Bangkok	16.27	16,108	1.00	262,077	448.83
	Nongkhai_Bangkok	23.08	9,840	1.00	227,107	669.05
	Nongbualamphu_Bangkok	22.14	4,151	1.00	91,903	562.30
	Angthong_Bangkok	6.57	4,837	1.00	31,779	199.44
	Amnatcharoen_Bangkok	20.87	3,312	1.00	69,121	603.47
	Udonthani_Bangkok	12.21	27,219	1.00	332,344	571.92
	Uttaradit_Bangkok	20.8	13,490	1.00	280,592	547.21
	Uthaithani_Bangkok	10.8	5,982	1.00	64,606	350.49
	Ubonratchathani_Bangkok	18.1	30,792	1.00	557,335	632.28
	The total demand point – weighted distance ($\sum \sum C_{ij} h_i Y_{ij} : \text{Baht}$)				19,927,816	

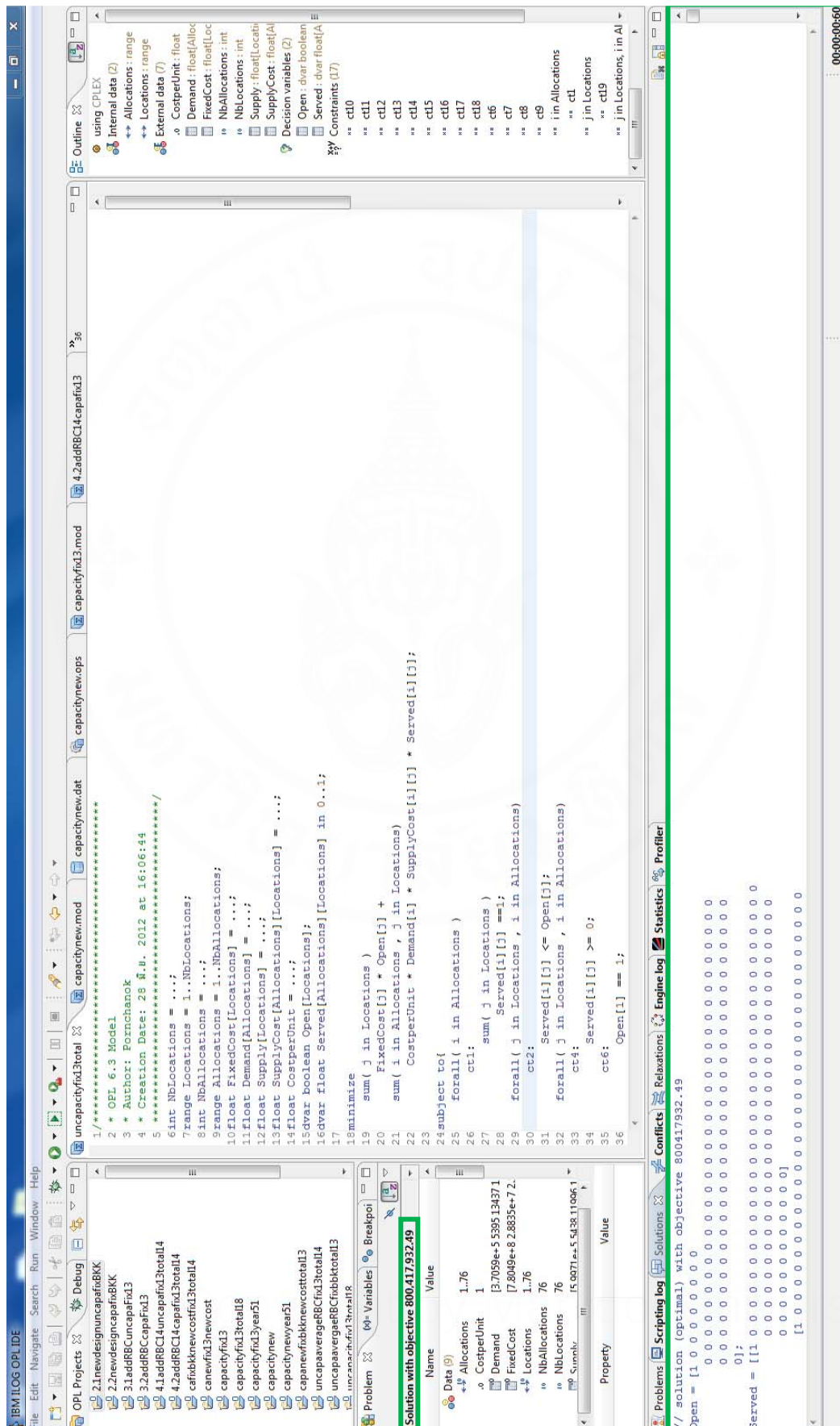


Figure G.1 Captured screen of IBM ILOG OPL IDE 6.3 in Case 2

APPENDIX H

OPTIMAL RESULTS FOR CASE 3: NEW DESIGN WITH LIMITED BLOOD SUPPLY

Case 3 locates thirty-six RBCs at the NBC in Bangkok, Nakhonsawan, Nonthaburi, Pathumthani, Ayutthaya, Lopburi, Samutprakan, Samutsakhon, saraburi, Phitsanulok, Phetchabun, Chanthaburi, Chachoengsao, Chonburi, Rayong, Khonkaen, Chaiyaphum, Nakhonratchasima, Burirum, Mahasarakham, Roi et, Sisaket, Sakonnakhon, Surin, Udonthani, Ubonratchathani, Chiang Rai, Chiang Mai, Lampang, Uttaradit, Chumphon, Nakhonsithammarat, Songkhla, Suratthani, Kanchanaburi and Ratchaburi. The total system cost of the designed blood distribution network according to the Case 3 is 1,783,254,044 Baht. According to the cost for establishing RBCs as shown in Table H.1, the fixed cost is 1,778,840,146 Baht. Table H.2 shows blood transportation cost from each RBC to its responsible provinces. Column 1 of the table is the number of the RBC. Column 2 contains the routes from each RBC to its service province. Column 3 presents delivery costs for transporting blood from each RBC to the terminal hospitals. Column 4 shows quantities of blood that each terminal province requires in each year. Column 5 shows ratios (or fractions) of blood demand that each terminal province receives from each RBC. Column 6 contains the total transportation cost as derived from Case 3. Finally, the last column shows the distribution distance from location to allocation (i_j). The grand total transportation cost at the bottom line is 4,413,858 Baht/year. The problem was solved within 4.55 seconds, as shown in Figure H.1.

Table H.1 Fixed cost of RBC locations in Case 3

RBCs (1)	Provinces (2)	Region (3)	No. of service provinces (4)	Fixed cost (Baht) (5)	The total regional fixed cost (Baht) (6)
01	Bangkok	Center	30	780,490,116	1,081,368,535 (60%)
02	Nakhonsawan	Center	2	28,212,297	
03	Nonthaburi	Center	2	35,259,189	
04	Pathumthani	Center	1	30,507,189	
05	Ayuthaya	Center	1	24,347,189	
06	Lopburi	Center	6	32,267,189	
07	Samutprakan	Center	1	32,055,989	
08	Samutsakhon	Center	1	25,227,189	
09	Saraburi	Center	1	25,825,589	
10	Phitsanulok	Center	2	41,421,410	
11	Phetchabun	Center	6	25,755,189	
12	Chanthaburi	East	4	28,219,189	109,481,073 (6%)
13	Chachoengsao	East	5	26,459,189	
14	Chonburi	East	3	27,815,506	
15	Rayong	East	2	26,987,189	294,631,924 (17%)
16	Khonkaen	Northeast	2	25,139,189	
17	Chaiyaphum	Northeast	1	25,667,189	

Table H.1 Fixed cost of RBC locations in Case 3 (cont.)

RBCs (1)	Provinces (2)	Region (3)	No. of service provinces (4)	Fixed cost (Baht) (5)	The total regional fixed cost (Baht) (6)
18	Nakhonratchasima	Northeast	2	28,923,189	
19	Buriram	Northeast	2	25,403,189	
20	Maharakham	Northeast	2	26,635,189	
21	Roi Et	Northeast	2	28,219,189	
22	Sisaket	Northeast	2	25,227,189	
23	Sakonakhon	Northeast	2	26,459,189	
24	Surin	Northeast	1	26,107,189	
25	Udonthani	Northeast	2	25,227,189	
26	Ubonratchathani	Northeast	2	31,624,034	
27	Chiang Rai	North	2	31,035,189	118,860,756 (7%)
28	Chiang Mai	North	3	34,027,189	
29	Lampang	North	1	27,515,189	
30	Uttaradit	North	2	26,283,189	117,364,756 (7%)
31	Chumphon	South	2	25,667,189	
32	Nakhonsithammarat	South	2	29,451,189	
33	Songkhla	South	2	33,147,189	
34	Suratthani	South	4	29,099,189	

Table H.1 Fixed cost of RBC locations in Case 3 (cont.)

RBCs (1)	Provinces (2)	Region (3)	No. of service provinces (4)	Fixed cost (Baht) (5)	The total regional fixed cost (Baht) (6)
35	Kanchanaburi	West	2	25,752,189	57,133,102 (3%)
36	Ratchaburi	West	4	31,380,913	
Total fixed cost ($\sum f_j X_j$: Baht)					1,778,840,146

Table H.2 Results from solving the Capacitated Fixed Charge Facility Location model of case 3

RBCs (1)	Allocation_Location (i,j) (2)	Delivery cost: C _{ij} (Baht/unit) (3)	Demand: h _i (units/year) (4)	Fraction of demand at demand point i : Y _{ij} (5)	The demand point - weighted distance (Baht) (6)	Distance (km.) (7)
01	Bangkok_Bangkok	0	370,594	1.0000	0	0
	Krabi_Bangkok	19.33	5,395	1.0000	104,285	778.75
	Kanchanaburi_Bangkok	7.51	13,437	0.2906	29,325	284.99
	Kamphaengphet_Bangkok	15.29	8,978	1.0000	137,274	392.84
	Chai Nat_Bangkok	11.1	6,143	1.0000	68,187	285.63
	Chumphon_Bangkok	17.09	17,575	0.0302	9,071	518.11

Table H.2 Results from solving the Capacitated Fixed Charge Facility Location model of case 3 (cont.)

RBCs (1)	Allocation_Location (i_j) (2)	Delivery cost: C_{ij} (Baht/unit) (3)	Demand: h_i (units/year) (4)	Fraction of demand at demand point $i : Y_{ij}$ (5)	The demand point - weighted distance (Baht) (6)	Distance (km.) (7)
	Chiang Rai_Bangkok	18.11	31,213	0.1014	57,318	809.64
	Chiang Mai_Bangkok	15.46	64,631	0.5355	535,069	762.29
	Tak_Bangkok	17.19	7,601	0.9605	125,500	504.28
	Nakhonnayok_Bangkok	9.23	4,350	1.0000	40,151	135.24
	Nan_Bangkok	23.13	9,619	0.6342	141,102	709.60
	Phachuap_Bangkok	12.46	9,087	1.0000	113,224	321.41
	Prachiburi_Bangkok	8.77	11,078	1.0000	97,154	192.70
	Phangnga_Bangkok	28.76	4,160	1.0000	119,642	783.63
	Phichit_Bangkok	14.69	8,100	1.0000	118,989	358.30
	Phetchaburi_Bangkok	6.39	7,592	1.0000	48,513	212.54
	Phare_Bangkok	22.17	11,491	0.1813	46,187	590.19
	Phuket_Bangkok	22.85	11,390	1.0000	260,262	858.32
	Ranong_Bangkok	21.77	3,747	1.0000	81,572	608.29
	Ratchaburi_Bangkok	5.88	23,593	0.6529	90,575	170.47
	Loei_Bangkok	17.22	9,711	0.5672	94,849	530.33
	Songkhla_Bangkok	20.9	25,701	0.7690	413,069	978.13

Table H.2 Results from solving the Capacitated Fixed Charge Facility Location model of case 3 (cont.)

RBCs (1)	Allocation_Location (i_j) (2)	Delivery cost: C_{ij} (Baht/unit) (3)	Demand: h_i (units/year) (4)	Fraction of demand at demand point i : Y_{ij} (5)	The demand point - weighted distance (Baht) (6)	Distance (km) (7)
	Samutprakan_Bangkok	7.18	17,634	0.2160	27,348	30.15
	Sakaeo_Bangkok	11.22	6,628	0.9000	66,930	224.89
	Singburi_Bangkok	8.42	6,575	0.3679	20,368	198.68
	Sukhothai_Bangkok	17.51	9,219	0.7691	124,152	496.99
	Suphanburi_Bangkok	8.04	8,241	1.0000	66,258	166.58
	Angthong_Bangkok	6.57	4,837	0.7176	22,805	199.44
	Udonthani_Bangkok	12.21	27,219	0.5051	167,867	571.92
	Uthaitani_Bangkok	10.8	5,982	1.0000	64,606	350.49
02	Kanchanaburi_ Kanchanaburi	0	13,437	0.7094	0	0
	Samutsongkhram_ Kanchanaburi	5.59	4,375	0.5632	13,774	237.69
03	Kalasin_Khonkaen	6.53	10,551	0.6883	47,423	143.37
	Khonkaen_Khonkaen	0	67,289	1.0000	0	0
04	Chanthaburi_Chanthaburi	0	25,828	0.9938	0	0

Table H.2 Results from solving the Capacitated Fixed Charge Facility Location model of case 3 (cont.)

RBCs (1)	Allocation_Location (i_j) (2)	Delivery cost: C_{ij} (Baht/unit) (3)	Demand: h_i (units/year) (4)	Fraction of demand at demand point i : Y_{ij} (5)	The demand point - weighted distance (Baht) (6)	Distance (km.) (7)
05	Chachoengsao_ Chachoengsao	0	14,158	0.9660	0	0
	Chanthaburi_ Chonburi	9.77	25,828	0.0062	1,565	148.82
06	Chachoengsao_ Chonburi	9.52	14,158	0.0340	4,583	71.96
	Chonburi_ Chonburi	0	59,517	1.0000	0	0
	Trat_ Chonburi	13.3	3,737	1.0000	49,702	215.33
	Rayong_ Chonburi	6.06	15,795	0.0368	3,522	67.14
07	Sakaeo_ Chonburi	12.87	6,941	0.1000	8,933	186.86
	Chaiyaphum_ Chaiyaphum	0	12,195	0.8501	0	0
08	Chumphon_ Chumphon	0	17,575	0.9698	0	0
09	Chiang Rai_ Chiang Rai	0	31,213	0.8986	0	0
10	Chiang Mai_ Chiang Mai	0	64,631	0.4645	0	0
	Phayao_ Chiang Mai	5.12	11,488	1.0000	58,819	248.99
	Mae Hong Son_ Chiang Mai	9.13	3,599	1.0000	32,859	230.71
	Lamphun_ Chiang Mai	2.53	12,122	1.0000	30,669	131.53
11	Kalasin_ Nakhonratchasima	12.24	11,740	0.2126	30,550	290.18

Table H.2 Results from solving the Capacitated Fixed Charge Facility Location model of case 3 (cont.)

RBCs (1)	Allocation_Location (i_j) (2)	Delivery cost: C_{ij} (Baht/unit) (3)	Demand: h_i (units/year) (4)	Fraction of demand at demand point i : Y_{ij} (5)	The demand point - weighted distance (Baht) (6)	Distance (km.) (7)
12	Chaiyaphum_ Nakhonratchasima	5.9	14,346	0.1499	12,688	164.84
	Nakhonratchasima_ Nakhonratchasima	0	57,304	1.0000	0	0
	Buriram_ Nakhonratchasima	5.72	20,402	0.0753	8,787	129.99
	Loei_ Nakhonratchasima	11	9,711	0.2421	25,861	337.99
	Trang_ Nakhonsithammarat	3.13	7,893	0.6881	17,000	125.38
13	Nakhonsithammarat_ Nakhonsithammarat	0	20,252	1.0000	0	0
	Phatthalung_ Nakhonsithammarat	5.77	7,578	0.0971	4,246	115.08
	Nakhonsawan_ Nakhonsawan	0	23,153	1.0000	0	0
14	Sukhothai_ Nakhonsawan	7.54	9,219	0.2309	16,050	490.5
	Nonthaburi_ Nonthaburi	0	12,092	1.0000	0	0
	Nan_ Nonthaburi	19.28	9,619	0.3658	67,839	731.11

Table H.2 Results from solving the Capacitated Fixed Charge Facility Location model of case 3 (cont.)

RBCs	Allocation_Location (i_j) (2)	Delivery cost: C_{ij} (Baht/unit) (3)	Demand: h_i (units/year) (4)	Fraction of demand at demand point i : Y_{ij} (5)	The demand point - weighted distance (Baht) (6)	Distance (km.) (7)
(1)						
15	Buriram_Buriram	0	20,402	0.9247	0	0
16	Pathumthani_Pathumthani	0	21,197	1.0000	0	0
	Phitsanulok_Pathumthani	12.48	22,832	0.2414	68,785	406.43
17	Tak_Ayutthaya	12.06	7,601	0.0395	3,621	381.18
	Ayutthaya_Ayutthaya	0	19,594	1.0000	0	0
18	Phitsanulok_Phitsanulok	0	22,832	0.7586	0	0
	Phare_Phitsanulok	8.11	11,491	0.7446	69,391	199.81
19	Phetchabun_Phetchabun	0	18,423	1.0000	0	0
	Loei_Phetchabun	7.07	9,711	0.1907	13,093	200.86
20	Kalasin_Mahasarakham	6.89	11,740	0.0991	8,016	113.25
	Mahasarakham_Mahasarakham	0	10,886	1.0000	0	0
21	Nakhonphanom_Roi Et	11.17	6,678	0.0630	4,699	224.42
	Roi Et_Roi Et	0	18,030	1.0000	0	0
22	Rayong_Rayong	0	16,399	0.9632	0	0
23	Nakhonpathom_Ratchaburi	2.87	17,758	1.0000	50,965	93.22

Table H.2 Results from solving the Capacitated Fixed Charge Facility Location model of case 3 (cont.)

RBCs (1)	Allocation_Location (i_j) (2)	Delivery cost: C_{ij} (Baht/unit) (3)	Demand: h_i (units/year) (4)	Fraction of demand at demand point i : Y_{ij} (5)	The demand point - weighted distance (Baht) (6)	Distance (km.) (7)
	Ratchaburi_Ratchaburi	0	23,593	0.3471	0	0
24	Lopburi_Lopburi	0	23,368	1.0000	0	0
	Singburi_Lopburi	1.82	6,575	0.6321	7,564	80.37
25	Phare_Lampang	6.83	11,491	0.0118	926	102.44
	Lampang_Lampang	0	21,583	1.0000	0	0
26	Nakhonphanom_Sisaket	13.55	6,678	0.0168	1,520	363.21
	Yasothon_Sisaket	5.67	7,049	0.4490	17,946	155.26
	Sisaket_Sisaket	0	15,275	1.0000	0	0
27	Nakhonphanom_Sakonnakhon	7.87	6,678	0.0291	1,529	83.00
	Sakonnakhon_Sakonnakhon	0	12,813	1.0000	0	0
28	Narathiwat_Songkhla	7.25	7,261	1.0000	52,642	210.50
	Pattani_Songkhla	3.93	5,510	1.0000	21,654	106.12
	Phatthalung_Songkhla	5.81	7,578	0.9029	39,753	92.47
	Yala_Songkhla	5.22	9,144	1.0000	47,732	128.00

Table H.2 Results from solving the Capacitated Fixed Charge Facility Location model of case 3 (cont.)

RBCs	Allocation_Location (i_j) (2)	Delivery cost: C_{ij} (Baht/unit) (3)	Demand: h_i (units/year) (4)	Fraction of demand at demand point i : Y_{ij} (5)	The demand point - weighted distance (Baht) (6)	Distance (km.) (7)
(1)						
	Songkhla_ Songkhla	0	25,701	0.2310	0	0
	Satun_ Songkhla	4.64	2,302	1.0000	10,681	107.83
29	Samutprakan_ Samutprakan	0	17,634	0.7841	0	0
30	Samutsongkhram_ Samutsakhon	6.6	4,375	0.4368	12,613	42.20
	Samutsakhon_ Samutsakhon	0	10,073	1.0000	0	0
31	Saraburi_ Saraburi	0	20,748	1.0000	0	0
	Angthong_ Saraburi	14.17	4,837	0.2824	19,356	132.15
32	Trang_ Suratthani	7.24	7,893	0.3119	17,824	211.59
	Suratthani_ Suratthani	0	17,978	1.0000	0	0
33	Yasothon_ Surin	5.84	7,049	0.5510	22,683	177.92
	Surin_ Surin	0	16,108	1.0000	0	0
34	Nakhonphanom_ Udonthani	11.03	6,678	0.5919	43,598	195.95
	Nongkhai_ Udonthani	4.2	9,840	1.0000	41,328	109.12

Table H.2 Results from solving the Capacitated Fixed Charge Facility Location model of case 3 (cont.)

RBCs (1)	Allocation_Location (i_j) (2)	Delivery cost: C_{ij} (Baht/unit) (3)	Demand: h_i (units/year) (4)	Fraction of demand at demand point $i : Y_{ij}$ (5)	The demand point - weighted distance (Baht) (6)	Distance (km.) (7)
	Nongbualamphu_ Udonthani	3.3	4,151	1.0000	13,698	78.24
	Udonthani_ Udonthani	0	27,219	0.4949	0	0.00
	Phare_ Uttaradit	7.37	11,491	0.0623	5,276	119.26
35	Uttaradit_ Uttaradit	0	13,490	1.0000	0	0
36	Nakhonphanom_ Ubonratchathani	12.34	6,678	0.2992	24,656	331.06
	Mukdahan_ Ubonratchathani	8.02	5,843	1.0000	46,861	222.83
	Amnatcharoen_ Ubonratchathani	4.44	3,312	1.0000	14,705	123.42
	Ubonratchathani_ Ubonratchathani	0	30,792	1.0000	0	0
	The total demand point – weighted distance ($\sum \sum C_{ij} h_i Y_{ij} : \text{Baht}$)					4,413,858

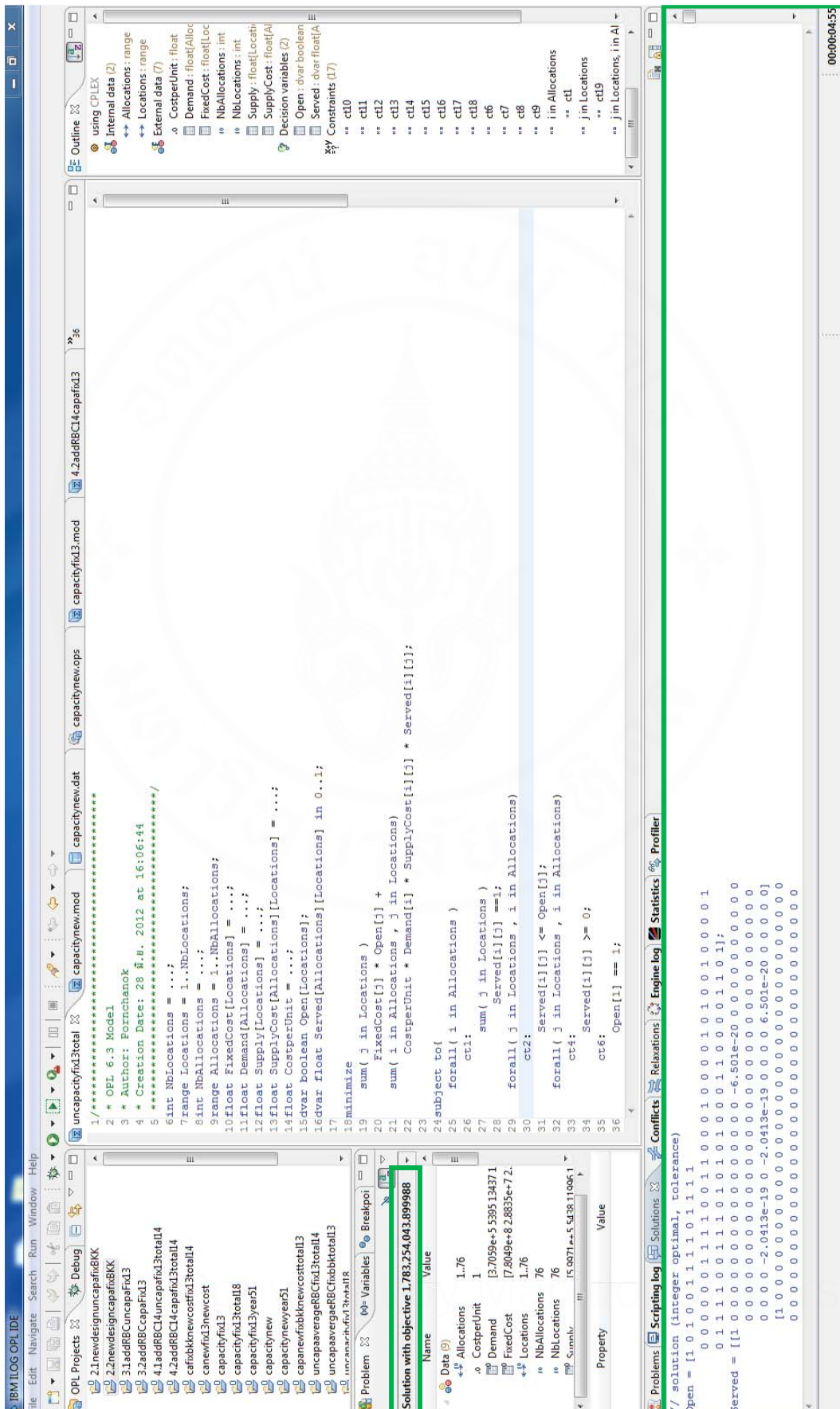


Figure H.1 Captured screen of IBM ILOG OPL IDE 6.3 in Case 3

APPENDIX I

OPTIMAL RESULTS FOR CASE 4: EXISTING CONFIGURATION PLUS ADDITIONAL NEW RBCS WITH UNLIMITED BLOOD SUPPLY

Case 4 locates 13 RBCs at the NBC in Bangkok, Lopburi, Nakhonsawan, Phitsanulok, Chonburi, Ratchaburi, Nakhonratchasima, Khonkaen, Ubonratchathani, Chiang Mai, Nakhonsithammarat, Songkhla and Phuket. All the RBC locations are the same current locations. The total system cost of the designed network of blood distribution according to the Case 4 is 1,227,960,079 Baht. According to the cost for establishing RBCs as shown in Table I.1. the fixed cost is 1,223,307,173 Baht. Table I.2 shows blood transportation cost from each RBC to its responsible provinces. Column 1 of the table is the number of the RBCs. Column 2 contains the routes from each RBC to its service provinces. Column 3 presents delivery costs for transporting blood from each RBC to the terminal hospitals. Column 4 shows quantities of blood that each terminal province requires in each year. Column 5 shows ratios (or fractions) of blood demand that each terminal province receives from each RBC. Column 6 contains the total transportation cost as derived from Case 4. Finally, the last column shows the distribution distance from location to allocation (i_j). The grand total transportation cost at the bottom line is 4,652,906 Baht/year. The problem was solved within 0.57 seconds, as shown in Figure I.1.

Table I.1 Fixed cost of RBC locations in Case 4

RBCs (1)	Provinces (2)	Region (3)	No. of service provinces (4)	Fixed cost (Baht) (5)	Fixed cost of the region (Baht) (6)
01	Bangkok	Center	7	780,490,116	882,391,012 (72%)
02	Lopburi	Center	7	32,267,189	
03	Nakhonsawan	Center	3	28,212,297	
04	Phitsanulok	Center	8	41,421,410	
05	Chonburi	East	5	27,815,506	27,815,506 (2%)
06	Ratchaburi	West	5	31,380,913	31,380,913 (3%)
07	Nakhonratchasima	Northeast	4	28,923,189	85,686,412 (7%)
08	Khonkaen	Northeast	11	25,139,189	
09	Ubonratchathani	Northeast	5	31,624,034	
10	Chiang Mai	North	7	34,027,189	34,027,189 (3%)
11	Nakhonsithammarat	South	6	29,451,189	162,006,141 (13%)
12	Songkhla	South	5	33,147,189	
13	Phuket	South	3	99,407,763	
Total Fixed cost (Baht)				1,223,307,173	

Table I.2 Results from solving the Uncapacitated Fixed Charge Facility Location model of case 4

RBC	Allocation_Location ($i - j$) (2)	Delivery cost: C_{ij} (Baht/unit) (3)	Demand: h_i (units/year) (4)	Fraction of demand at demand point $i : Y_{ij}$ (5)	The demand point - weighted distance (Baht) (6)	Distance (km.) (7)
01	Bangkok_Bangkok	0	370,594	1.00	0	0
	Nonthaburi_Bangkok	4.22	12,092	1.00	51,028	50.17
	Pathumthani_Bangkok	7.72	21,197	1.00	163,641	47.45
	Prachiburi_Bangkok	8.77	11,078	1.00	97,154	192.7
	Samutprakan_Bangkok	7.18	17,634	1.00	126,612	30.15
	Samutsongkhram_Bangkok	13.64	4,375	1.00	59,675	122.56
	Samutsakhon_Bangkok	7.99	10,073	1.00	80,483	92.36
	Kalasin_Khonkaen	6.53	11,740	1.00	76,662	143.37
02	Khonkaen_Khonkaen	0	59,208	1.00	0	0
	Chaiyaphum_Khonkaen	5.52	14,346	1.00	79,190	129.25
	Nakhonphanom_Khonkaen	11.85	6,678	1.00	79,134	294.92
	Maharakham_Khonkaen	4.15	10,886	1.00	45,177	104.83
	Roi Et_Khonkaen	4.85	18,030	1.00	87,446	160.58
	Loei_Khonkaen	7.07	9,711	1.00	68,657	190.07
	Sakonnakhon_Khonkaen	8.29	12,813	1.00	106,220	239.07

Table I.2 Results from solving the Uncapacitated Fixed Charge Facility Location model of case 4 (cont.)

RBC	Allocation_Location ($i - j$) (2)	Delivery cost: C_{ij} (Baht/unit) (3)	Demand: h_i (units/year) (4)	Fraction of demand at demand point $i : Y_{ij}$ (5)	The demand point - weighted distance (Baht) (6)	Distance (km.) (7)
(1)	Nongkhai_Khonkaen	7.73	9,840	1.00	76,063	255.70
	Nongbualamphu_Khonkaen	5.00	4,151	1.00	20,755	129.08
	Udonthani_Khonkaen	4.63	27,219	1.00	126,024	158.57
03	Chanthaburi_Chonburi	9.77	25,989	1.00	253,913	148.82
	Chachoengsao_Chonburi	9.52	14,656	1.00	139,525	71.96
	Chonburi_Chonburi	0	53,923	1.00	0	0
	Trat_Chonburi	13.3	3,668	1.00	48,784	215.33
	Rayong_Chonburi	6.06	16,399	1.00	99,378	67.14
04	Chiang Rai_Chiang Mai	6.36	31,213	1.00	198,515	235.82
	Chiang Mai_Chiang Mai	0	64,631	1.00	0	0
	Nan_Chiang Mai	12.13	9,619	1.00	116,678	348.63
	Phayao_Chiang Mai	5.12	11,488	1.00	58,819	248.99
	Mae Hong Son_Chiang Mai	9.13	3,599	1.00	32,859	230.71
	Lampang_Chiang Mai	4.72	21,583	1.00	101,872	145.35
	Lamphun_Chiang Mai	2.53	12,122	1.00	30,669	131.53

Table I.2 Results from solving the Uncapacitated Fixed Charge Facility Location model of case 4 (cont.)

RBC	Allocation_Location ($i - j$) (2)	Delivery cost: C_{ij} (Baht/unit) (3)	Demand: h_i (units/year) (4)	Fraction of demand at demand point i : Y_{ij} (5)	The demand point - weighted distance (Baht) (6)	Distance (km.) (7)
(1) 05	Nakhonratchasima_					
	Nakhonratchasima	0	57,304	1.00	0	0
	Buriram_ Nakhonratchasima	5.72	20,402	1.00	116,699	129.99
	Sakao_ Nakhonratchasima	7.87	6,628	1.00	52,162	231.04
	Surin_ Nakhonratchasima	6.49	16,108	1.00	104,541	190.72
(1) 06	Krabi_ Nakhonsithammarat	5.47	5,395	1.00	29,511	110.51
	Chumphon_					
	Nakhonsithammarat	10.41	17,575	1.00	182,956	282.99
	Trang_ Nakhonsithammarat	3.13	7,893	1.00	24,705	125.38
	Nakhonsithammarat_					
	Nakhonsithammarat	0	20,252	1.00	0	0
	Phatthalung_					
(1) 07	Nakhonsithammarat	5.77	7,578	1.00	43,725	115.08
	Suratthani_					
	Nakhonsithammarat	5.66	17,978	1.00	101,755	141.04
07	Chai Nat_ Nakhonsawan	4.25	6,143	1.00	26,108	80.48

Table I.2 Results from solving the Uncapacitated Fixed Charge Facility Location model of case 4 (cont.)

RBC	Allocation_Location ($i - j$) (2)	Delivery cost: C_{ij} (Baht/unit) (3)	Demand: h_i (units/year) (4)	Fraction of demand at demand point $i : Y_{ij}$ (5)	The demand point - weighted distance (Baht) (6)	Distance (km.) (7)
(1)						
08	Nakhonsawan_ Nakhonsawan	0	23,153	1.00	0	0
	Uthaitani_ Nakhonsawan	2.32	5,982	1.00	13,878	99.4
	Kamphaengphet_ Phitsanulok	4.66	8,978	1.00	41,837	171.05
	Tak_ Phitsanulok	5.38	7,601	1.00	40,893	341.13
	Phichit_ Phitsanulok	3.51	8,100	1.00	28,431	125.32
	Phitsanulok_ Phitsanulok	0	22,832	1.00	0	0
	Phetchabun_ Phitsanulok	6.56	18,423	1.00	120,855	148.93
	Phare_ Phitsanulok	8.11	11,491	1.00	93,192	199.81
	Sukhothai_ Phitsanulok	3.45	9,219	1.00	31,806	147.03
09	Uttaradit_ Phitsanulok	6.74	13,490	1.00	90,923	143.05
	Phangnga_ Phuket	13.02	4,160	1.00	54,163	107.89
	Phuket_ Phuket	0	11,390	1.00	0	0
	Ranong_ Phuket	11.18	3,747	1.00	41,891	348.49
10	Kanchanaburi_ Ratchaburi	3.08	13,437	1.00	41,386	199
	Nakhonpathom_ Ratchaburi	2.87	17,758	1.00	50,965	93.22
	Phachuap_ Ratchaburi	8.26	9,087	1.00	75,059	236.47

Table I.2 Results from solving the Uncapacitated Fixed Charge Facility Location model of case 4 (cont.)

RBC	Allocation_Location ($i - j$) (2)	Delivery cost: C_{ij} (Baht/unit) (3)	Demand: h_i (units/year) (4)	Fraction of demand at demand point $i : Y_{ij}$ (5)	The demand point - weighted distance (Baht) (6)	Distance (km.) (7)
(1)						
	Phetchaburi_Ratchaburi	2.25	7,592	1.00	17,082	112.58
	Ratchaburi_Ratchaburi	0	23,593	1.00	0	0
11	Nakhonnayok_Lopburi	8.83	4,350	1.00	38,411	207.88
	Ayutthaya_Lopburi	3.43	19,594	1.00	67,207	151.50
	Lopburi_Lopburi	0	23,368	1.00	0	0
	Saraburi_Lopburi	15.69	20,748	1.00	325,536	71.21
	Singburi_Lopburi	1.82	6,575	1.00	11,967	80.37
	Suphanburi_Lopburi	4.96	8,241	1.00	40,875	149.99
	Angthong_Lopburi	2.40	4,837	1.00	11,609	100.69
12	Narathiwat_Songkhla	7.25	7,261	1.00	52,642	210.50
	Pattani_Songkhla	3.93	5,510	1.00	21,654	106.12
	Yala_Songkhla	5.22	9,144	1.00	47,732	128.00
	Songkhla_Songkhla	0	25,701	1.00	0	0
	Satun_Songkhla	4.64	2,302	1.00	10,681	107.83
13	Mukdahan_Ubonratchathani	8.02	5,843	1.00	46,861	222.83
	Yasothon_Ubonratchathani	5.58	7,049	1.00	39,333	157.77

Table I.2 Results from solving the Uncapacitated Fixed Charge Facility Location model of case 4 (cont.)

RBC (1)	Allocation_Location (i_j) (2)	Delivery cost: C_{ij} (Baht/unit) (3)	Demand: h_i (units/year) (4)	Fraction of demand at demand point $i : Y_{ij}$ (5)	The demand point - weighted distance (Baht) (6)	Distance (km.) (7)
	Sisaket_Ubonratchathani	4.86	15,275	1.00	74,237	109.54
	Amnatcharoen_Ubonratchathani	4.44	3,312	1.00	14,705	123.42
	Ubonratchathani_Ubonratchathani	0	30,792	1.00	0	0
The total demand point – weighted distance ($\sum \sum C_{ij} h_i Y_{ij} : \text{Baht}$)						4,652,906

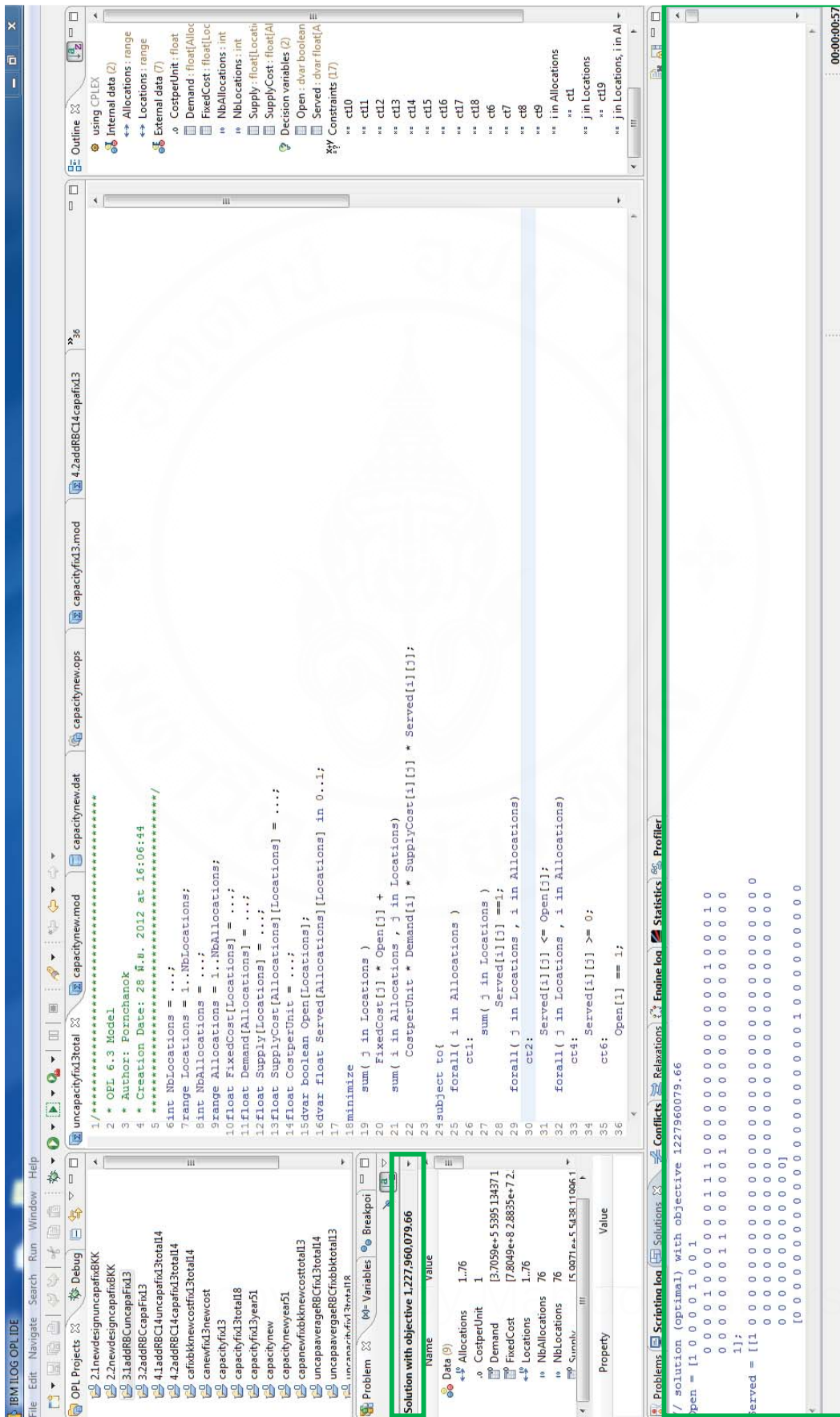


Figure I.1 Captured screen of IBM ILOG OPL IDE 6.3 in Case 4

APPENDIX J

OPTIMAL RESULTS FOR CASE 5:

EXISTING CONFIGURATION PLUS ADDITIONAL NEW RBCS

WITH LIMITED BLOOD SUPPLY

In this case, there are 13 existing RBCs. The optimal results locate 23 new RBCs at Pathumthani, Ayutthaya, Nonthaburi, Samutprakan, Samutsakhon, Saraburi, Phetchabun, Chiang Rai, Lampang, Uttaradit, Chumphon, Suratthani, Chanthaburi, Chachoengsao, Rayong, Kanchaaburi, Chaiyaphum, Buriram, Roi et, Sisaket, Sakonnakhon, Surin and Udonthai. Totally, there would be 36 RBCs. The total system cost is 1,855,935,936 Baht of which (in Table J.1) the fixed cost is 1,851,612,720 Baht. Table J.2 shows blood transportation cost from each RBC to its responsible provinces. Column 1 of the table is the number of the RBCs. Column 2 contains the routes from each RBC to its service provinces. Column 3 presents delivery costs for transporting blood from each RBC to the terminal hospitals. Column 4 shows quantities of blood that each terminal province requires in each year. Column 5 shows ratios (or fractions) of blood demand that each terminal province receives from each RBC. Column 6 contains the total transportation cost as derived from Case 5. Finally, the last column shows the distribution distance from location to allocation (i_j). The grand total transportation cost at the bottom line is 4,323,216 Baht/year. The problem was solved within 9.36 seconds, as shown in Figure J.1.

Table J.1 Fixed cost of RBC locations in Case 5

RBCs (1)	Provinces (2)	Region (3)	No. of service provinces (4)	Fixed cost (Baht) (5)	Fixed cost of the region (Baht) (6)
01	Bangkok	Center	29	780,490,116	1,078,411,735 (58%)
02	Nakhonsawan	Center	2	28,212,297	
03	Pathumthani	Center	2	30,507,189	
04	Ayutthaya	Center	2	24,347,189	
05	Nonthaburi	Center	2	35,259,189	
06	Lopburi	Center	2	32,267,189	
07	Samutprakan	Center	1	25,227,189	
08	Samutsakhon	Center	2	25,825,589	
09	Saraburi	Center	2	29,099,189	
10	Phitsanulok	Center	3	41,421,410	
11	Phetchabun	Center	2	25,755,189	
12	Chiang Rai	North	1	31,035,189	118,860,756 (7%)
13	Chiang Mai	North	4	34,027,189	
14	Lampang	North	2	27,515,189	
15	Uttaradit	North	2	26,283,189	
16	Chumphon	South	1	25,667,189	212,689,319 (11%)
17	Nakhonsithammarat	South	3	29,451,189	

Table J.1 Fixed cost of RBC locations in Case 5 (cont.)

RBCs (1)	Provinces (2)	Region (3)	No. of service provinces (4)	Fixed cost (Baht) (5)	Fixed cost of the region (Baht) (6)
18	Phuket	South	2	99,407,763	
19	Songkhla	South	6	32,055,989	
20	Suratthani	South	2	26,107,189	
21	Chanthaburi	East	1	28,219,189	109,481,073 (6%)
22	Chachoengsao	East	1	26,459,189	
23	Chonburi	East	6	27,815,506	
24	Rayong	East	1	26,987,189	
25	Kanchanaburi	West	2	25,139,189	56,520,102 (3%)
26	Ratchaburi	West	2	31,380,913	
27	Khonkaen	Northeast	3	25,752,189	275,649,735 (15%)
28	Chaiyaphum	Northeast	1	25,667,189	
29	Nakhonratchasima	Northeast	4	28,923,189	
30	Buriram	Northeast	1	25,403,189	
31	Roi Et	Northeast	2	28,219,189	
32	Sisaket	Northeast	2	25,227,189	
33	Sakonnakhon	Northeast	2	26,459,189	
34	Surin	Northeast	3	33,147,189	

Table J.1 Fixed cost of RBC locations in Case 5 (cont.)

RBCs (1)	Provinces (2)	Region (3)	No. of service provinces (4)	Fixed cost (Baht) (5)	Fixed cost of the region (Baht) (6)
35	Udonthani	Northeast	4	25,227,189	
36	Ubonratchathani	Northeast	4	31,624,034	
Total fixed cost ($\sum f_j X_j$: Baht)					1,851,612,720

Table J.2 Results from solving the Capacitated Fixed Charge Facility Location model of case 5

RBC (1)	Allocation_Location (i, j) (2)	Delivery cost: C_{ij} (Baht/unit) (3)	Demand: h_i (units/year) (4)	Fraction of demand at demand point i : Y_{ij} (5)	The demand point – weighted distance (Baht) (6)	Distance (km.) (7)
01	Bangkok_Bangkok	0	370,594	1.0000	0	0
	Krabi_Bangkok	19.33	5,395	1.0000	104,285	778.75
	Kanchanaburi_Bangkok	7.51	13,437	0.2906	29,325	284.99
	Kamphaengphet_Bangkok	15.29	8,978	1.0000	137,274	392.84
	Khonkaen_Bangkok	12.37	59,208	0.1548	113,376	467.34

Table J.2 Results from solving the Capacitated Fixed Charge Facility Location model of case 5 (cont.)

RBC (1)	Allocation_Location (i_j) (2)	Delivery cost: C_{ij} (Baht/unit) (3)	Demand: h_i (units/year) (4)	Fraction of demand at demand point i : Y_{ij} (5)	The demand point – weighted distance (Baht) (6)	Distance (km.) (7)
	Chai Nat_Bangkok	11.10	6,143	1.0000	68,187	285.63
	Chumphon_Bangkok	17.09	17,575	0.0302	9,071	518.11
	Chiang Rai_Bangkok	18.11	31,213	0.1014	57,318	809.64
	Chiang Mai_Bangkok	15.46	64,631	0.5355	535,069	762.29
	Tak_Bangkok	17.19	7,601	0.9605	125,500	504.28
	Nakhonnayok_Bangkok	9.23	4,350	1.0000	40,151	135.24
	Nan_Bangkok	23.13	9,619	0.6342	141,102	709.60
	Phachuap_Bangkok	12.46	9,087	1.0000	113,224	321.41
	Prachiburi_Bangkok	8.77	11,078	1.0000	97,154	192.70
	Phangnga_Bangkok	28.76	4,160	0.7736	92,555	783.63
	Phichit_Bangkok	14.69	8,100	1.0000	118,989	358.30
	Phetchaburi_Bangkok	6.39	7,592	1.0000	48,513	212.54
	Phare_Bangkok	22.17	11,491	0.7983	203,371	590.19
	Ranong_Bangkok	21.77	3,747	1.0000	81,572	608.29
	Ratchaburi_Bangkok	5.88	23,593	0.6529	90,575	170.47
	Loei_Bangkok	17.22	9,711	0.8093	135,334	530.33

Table J.2 Results from solving the Capacitated Fixed Charge Facility Location model of case 5 (cont.)

RBC	Allocation_Location (i_j) (2)	Delivery cost: C_{ij} (Baht/unit) (3)	Demand: h_i (units/year) (4)	Fraction of demand at demand point i : Y_{ij} (5)	The demand point – weighted distance (Baht) (6)	Distance (km.) (7)
(1)						
	Songkhla_Bangkok	20.90	25,701	0.7690	413,069	978.13
	Samutprakan_Bangkok	7.18	17,634	0.2160	27,348	30.15
	Sakaeo_Bangkok	11.22	6,628	0.9000	66,930	224.89
	Singburi_Bangkok	8.42	6,575	0.2032	11,249	198.68
	Suphanburi_Bangkok	8.04	8,241	1.0000	66,258	166.58
	Angthong_Bangkok	6.57	4,837	1.0000	31,779	199.44
	Udonthani_Bangkok	12.21	27,219	0.5247	174,381	571.92
	Uthaitani_Bangkok	10.8	5,982	1.0000	64,606	350.49
02	Kanchanaburi_Kanchanaburi	0	13,437	0.7094	0	0
	Samutsongkhram_Kanchanaburi	5.59	4,375	0.5632	13,774	237.69
03	Kalasin_Khonkaen	6.53	11,740	1.0000	76,662	143.37
	Khonkaen_Khonkaen	0	59,208	0.8452	0	0
	Mahasarakham_Khonkaen	4.15	10,886	0.5058	22,850	104.83
04	Chanthaburi_Chanthaburi	0	25,989	0.9938	0	0

Table J.2 Results from solving the Capacitated Fixed Charge Facility Location model of case 5 (cont.)

RBC	Allocation_Location (i_j) (2)	Delivery cost: C_{ij} (Baht/unit) (3)	Demand: h_i (units/year) (4)	Fraction of demand at demand point i : Y_{ij} (5)	The demand point - weighted distance (Baht) (6)	Distance (km.) (7)
(1)						
05	Chachoengsao_ Chachoengsao	0	14,656	0.9660	0	0
06	Chanthaburi_ Chonburi	9.77	25,989	0.0062	1,574	148.82
	Chachoengsao_ Chonburi	9.52	14,656	0.0340	4,744	71.96
	Chonburi_ Chonburi	0	53,923	1.0000	0	0
	Trat_ Chonburi	13.3	3,668	1.0000	48,784	215.33
	Rayong_ Chonburi	6.06	16,399	0.0368	3,657	67.14
	Sakaeo_ Chonburi	12.87	6,628	0.1000	8,530	186.86
07	Chaiyaphum_ Chaiyaphum	0	14,346	0.8501	0	0
08	Chumphon_ Chumphon	0	17,575	0.9698	0	0
09	Chiang Rai_ Chiang Rai	0	31,213	0.8986	0	0
10	Chiang Mai_ Chiang Mai	0	64,631	0.4645	0	0
	Phayao_ Chiang Mai	5.12	11,488	1.0000	58,819	248.99
	Mae Hong Son_ Chiang Mai	9.13	3,599	1.0000	32,859	230.71
	Lamphun_ Chiang Mai	2.53	12,122	1.0000	30,669	131.53

Table J.2 Results from solving the Capacitated Fixed Charge Facility Location model of case 5 (cont.)

RBC (1)	Allocation_Location (i_j) (2)	Delivery cost: C_{ij} (Baht/unit) (3)	Demand: h_i (units/year) (4)	Fraction of demand at demand point i : Y_{ij} (5)	The demand point - weighted distance (Baht) (6)	Distance (km.) (7)
11	Chaiyaphum_					
	Nakhonratchasima	5.90	14,346	0.1499	12,688	164.84
	Nakhonratchasima_					
	Nakhonratchasima	0	57,304	1.0000	0	0
	Buriram_ Nakhonratchasima	5.72	20,402	0.0698	8,146	129.99
12	Mahasarakham_					
	Nakhonratchasima	8.63	10,886	0.4555	42,792	197.68
	Trang_ Nakhonsithammarat	3.13	7,893	0.6881	17,000	125.38
	Nakhonsithammarat_					
	Nakhonsithammarat	0	20,252	1.0000	0	0
13	Phatthalung_					
	Nakhonsithammarat	5.77	7,578	0.0971	4,246	115.08
	Nakhonsawan_ Nakhonsawan	0	23,153	1.0000	0	0
14	Sukhothai_ Nakhonsawan	7.54	9,219	0.2309	16,050	214.35
	Nonthaburi_ Nonthaburi	0	12,092	1.0000	0	0
	Nan_ Nonthaburi	19.28	9,619	0.3658	67,839	731.11

Table J.2 Results from solving the Capacitated Fixed Charge Facility Location model of case 5 (cont.)

RBC	Allocation_Location (i_j) (2)	Delivery cost: C_{ij} (Baht/unit) (3)	Demand: h_i (units/year) (4)	Fraction of demand at demand point i : Y_{ij} (5)	The demand point - weighted distance (Baht) (6)	Distance (km.) (7)
(1)						
15	Buriram_Buriram	0	20,402	0.9247	0	0
16	Pathumthani_Pathumthani	0	21,197	1.0000	0	0
	Phitsanulok_Pathumthani	12.48	22,832	0.2414	68,785	406.43
17	Tak_Ayutthaya	12.06	7,601	0.0395	3,621	381.18
	Ayutthaya_Ayutthaya	0	19,594	1.0000	0	0
18	Phitsanulok_Phitsanulok	0	22,832	0.7586	0	0
	Phare_Phitsanulok	8.11	11,491	0.1276	11,891	199.81
	Sukhothai_Phitsanulok	3.45	9,219	0.7691	24,462	147.03
19	Phetchabun_Phetchabun	0	18,423	1.0000	0	0
	Loei_Phetchabun	7.07	9,711	0.1907	13,093	200.86
20	Phangnga_Phuket	13.02	4,160	0.2264	12,263	107.89
	Phuket_Phuket	0	11,390	1.0000	0	0
21	Maharakham_Roi Et	3.93	10,886	0.0387	1,656	102.19
	Roi Et_Roi Et	0	18,030	1.0000	0	0
22	Rayong_Rayong	0	16,399	0.9632	0	0
23	Nakhonpathom_Ratchaburi	2.87	17,758	1.0000	50,965	93.22

Table J.2 Results from solving the Capacitated Fixed Charge Facility Location model of case 5 (cont.)

RBC	Allocation_Location (i_j) (2)	Delivery cost: C_{ij} (Baht/unit) (3)	Demand: h_i (units/year) (4)	Fraction of demand at demand point $i : Y_{ij}$ (5)	The demand point - weighted distance (Baht) (6)	Distance (km.) (7)
(1)	Ratchaburi_Ratchaburi	0	23,593	0.3471	0	0
24	Lopburi_Lopburi	0	23,368	1.0000	0	0
	Singburi_Lopburi	1.82	6,575	0.6321	7,564	80.37
25	Phare_Lampang	6.83	11,491	0.0118	926	102.44
	Lampang_Lampang	0	21,583	1.0000	0	0
26	Yasothon_Sisaket	5.67	7,049	0.4649	18,581	155.26
	Sisaket_Sisaket	0	15,275	1.0000	0	0
27	Nakhonphanom_Sakonnakhon	7.87	6,678	0.0291	1,529	83.00
	Sakonnakhon_Sakonnakhon	0	12,813	1.0000	0	0
28	Narathiwat_Songkhla	7.25	7,261	1.0000	52,642	210.50
	Pattani_Songkhla	3.93	5,510	1.0000	21,654	106.12
	Phatthalung_Songkhla	5.81	7,578	0.9029	39,753	92.47
	Yala_Songkhla	5.22	9,144	1.0000	47,732	128.00
	Songkhla_Songkhla	0	25,701	0.231	0	0
	Satun_Songkhla	4.64	2,302	1.0000	10,681	107.83

Table J.2 Results from solving the Capacitated Fixed Charge Facility Location model of case 5 (cont.)

RBC	Allocation_Location (i_j) (2)	Delivery cost: C_{ij} (Baht/unit) (3)	Demand: h_i (units/year) (4)	Fraction of demand at demand point $i : Y_{ij}$ (5)	The demand point - weighted distance (Baht) (6)	Distance (km.) (7)
(1)						
29	Samutprakan_ Samutprakan	0	17,634	0.7841	0	0
30	Samutsongkhram_ Samutsakhon	6.60	4,375	0.4368	12,613	42.20
	Samutsakhon_ Samutsakhon	0	10,073	1.0000	0	0
31	Saraburi_ Saraburi	0	20,748	1.0000	0	0
	Singburi_ Saraburi	16.02	6,575	0.1647	17,348	88.18
32	Trang_ Suratthani	7.24	7,893	0.3119	17,824	211.59
	Suratthani_ Suratthani	0	17,978	1.0000	0	0
33	Buriram_ Surin	3.81	20,402	0.0055	428	90.37
	Yasothon_ Surin	5.84	7,049	0.5351	22,028	177.92
	Surin_ Surin	0	16,108	1.0000	0	0
34	Nakhonphanom_ Udonthani	11.03	6,678	0.6718	49,484	195.95
	Nongkhai_ Udonthani	4.20	9,840	1.0000	41,328	109.12
	Nongbualamphu_ Udonthani	3.30	4,151	1.0000	13,698	78.24
	Udonthani_ Udonthani	0	27,219	0.4753	0	0
35	Phare_ Uttaradit	7.37	11,491	0.0623	5,276	119.26

Table J.2 Results from solving the Capacitated Fixed Charge Facility Location model of case 5 (cont.)

RBC	Allocation_Location (i_j) (2)	Delivery cost: C_{ij} (Baht/unit) (3)	Demand: h_i (units/year) (4)	Fraction of demand at demand point $i : Y_{ij}$ (5)	The demand point - weighted distance (Baht) (6)	Distance (km.) (7)
(1)	Uttaradit_ Uttaradit	0	13,490	1.0000	0	0
36	Nakhonphanom_ Ubonratchathani	12.34	6,678	0.2992	24,656	331.06
	Mukdahan_ Ubonratchathani	8.02	5,843	1.0000	46,861	222.83
	Amnatcharoen_ Ubonratchathani	4.44	3,312	1.0000	14,705	123.42
	Ubonratchathani_ Ubonratchathani	0	30,792	1.0000	0	0
	The total demand point – weighted distance ($\sum \sum C_{ij} h_i Y_{ij} : \text{Baht}$)					4,323,216

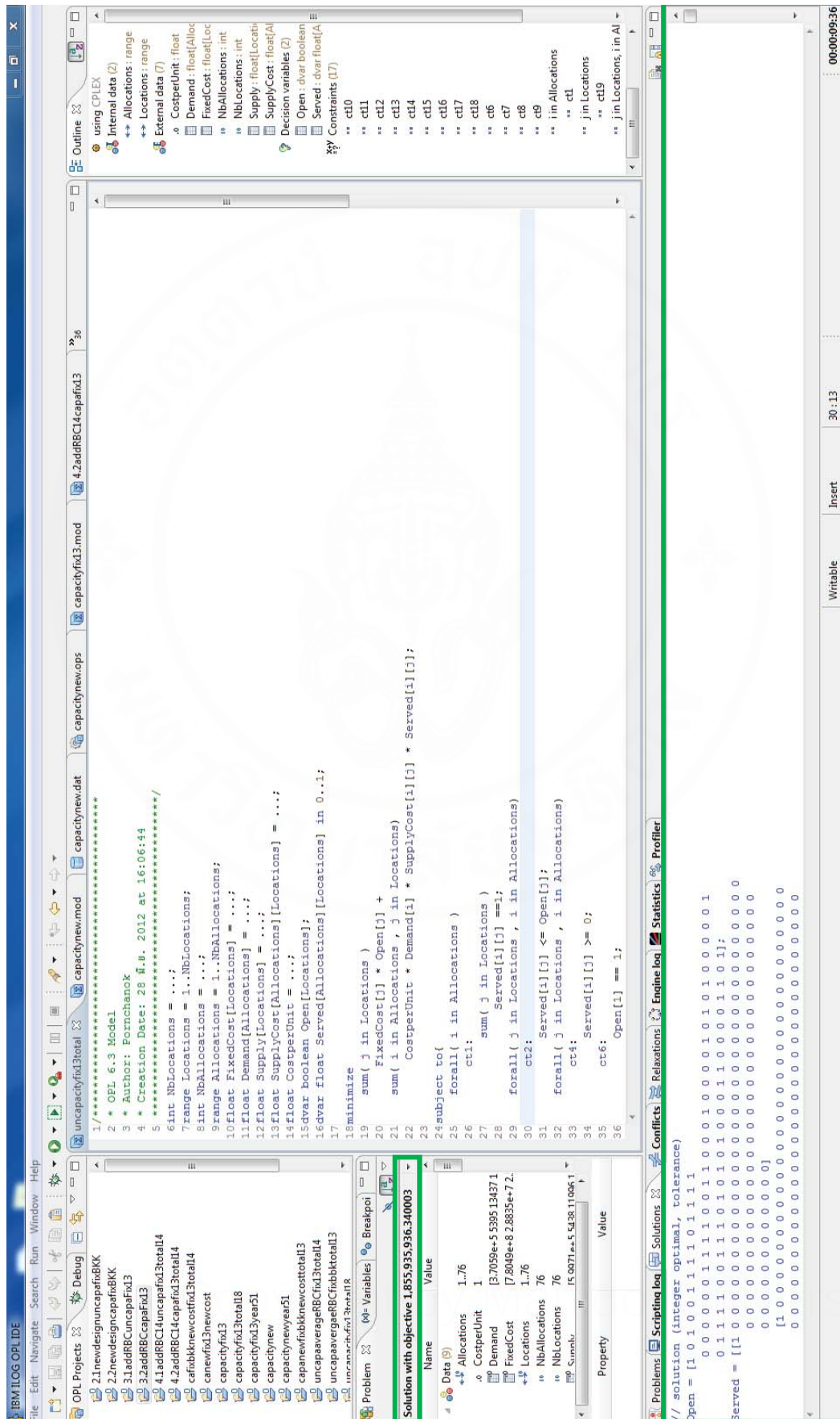


Figure J.1 Captured screen of IBM ILOG OPL IDE 6.3 in Case 5

APPENDIX K

OPTIMAL RESULTS FOR CASE 6: LOCATING AN ADDITIONAL RBC INTO THE CURRENT NETWORK WITH UNLIMITED BLOOD SUPPLY

In this case, there are 13 existing RBCs. An additional RBC is located by the model. The last RBC is aimed to compare with the planned RBC by the NBC at Ayutthaya. It turns out that the model chooses to locate the new RBC at Trat. The total system cost is 1,252,128,279 Baht of which (in Table K.1) the fixed cost is 1,247,654,362 Baht. Table K.2 shows blood transportation cost from each RBC to their responsible provinces. Column 1 of the table is the number of the RBCs. Column 2 contains the routes from each RBC to its service provinces. Column 3 presents delivery costs for transporting blood from each RBC to the terminal hospitals. Column 4 shows quantities of blood that each terminal province requires in each year. Column 5 shows ratios (or fractions) of blood demand that each terminal province receives from each RBC. Column 6 contains the total transportation cost as derived from Case 6. Finally, the last column shows the distribution distance from location to allocation (i_j). The grand total at the bottom line is 4,473,917 Baht/year. The problem was solved within 0.62 seconds, as shown in Figure K.1.

Table K.1 Fixed cost of RBC locations in Case 6

RBCs (1)	Provinces (2)	Region (3)	No. of service provinces (4)	Fixed cost (Baht) (5)	Fixed cost of the region (Baht) (6)
01	Bangkok	Center	7	780,490,116	882,391,012 (70%)
02	Lopburi	Center	7	32,267,189	
03	Nakhonsawan	Center	3	28,212,297	
04	Phitsanulok	Center	8	41,421,410	
05	Chonburi	East	5	27,815,506	52,162,695 (4%)
06	Trat	East	2	24,347,189	
07	Ratchaburi	West	5	31,380,913	31,380,913 (3%)
08	Nakhonratchasima	Northeast	4	28,923,189	85,686,412 (7%)
09	Khonkaen	Northeast	11	25,139,189	
10	Ubonratchathani	Northeast	5	31,624,034	
11	Chiang Mai	North	7	34,027,189	34,027,189 (3%)
12	Nakhonsithammarat	South	6	29,451,189	162,006,141 (13%)
13	Songkhla	South	5	33,147,189	
14	Phuket	South	3	99,407,763	
Total fixed cost ($\sum f_j X_j$: Baht)				1,247,654,362	

Table K.2 Results from solving the Uncapacitated Fixed Charge Facility Location model of case 6

RBC	Allocation_Location (i_j) (2)	Delivery cost: C_{ij} (Baht/unit) (3)	Demand: h_i (units/year) (4)	Fraction of demand at demand point $i : Y_{ij}$ (5)	The demand point - weighted distance (Baht) (6)	Distance (km.) (7)
(1)						
01	Bangkok_Bangkok	0	370,594	1.00	0	0
	Nonhaburi_Bangkok	4.22	12,092	1.00	51,028	50.17
	Pathumthani_Bangkok	7.72	21,197	1.00	163,641	47.45
	Prachiburi_Bangkok	8.77	11,078	1.00	97,154	192.70
	Samutprakan_Bangkok	7.18	17,634	1.00	126,612	30.15
	Samutsongkhram_Bangkok	13.64	4,375	1.00	59,675	122.56
	Samutsakhon_Bangkok	7.99	10,073	1.00	80,483	92.36
	Kalasin_Khonkaen	6.53	11,740	1.00	76,662	143.37
02	Khonkaen_Khonkaen	0	59,208	1.00	0	0
	Chaiyaphum_Khonkaen	5.52	14,346	1.00	79,190	129.25
	Nakhonphanom_Khonkaen	11.85	6,678	1.00	79,134	294.92
	Mahasarakham_Khonkaen	4.15	10,886	1.00	45,177	104.83
	Roi Et_Khonkaen	4.85	18,030	1.00	87,446	160.58
	Loei_Khonkaen	7.07	9,711	1.00	68,657	190.07
	Sakonnakhon_Khonkaen	8.29	12,813	1.00	106,220	239.07
	Nongkhai_Khonkaen	7.73	9,840	1.00	76,063	255.70

Table K.2 Results from solving the Uncapacitated Fixed Charge Facility Location model of case 6 (cont.)

RBC	Allocation_Location (i_j) (2)	Delivery cost: C_{ij} (Baht/unit) (3)	Demand: h_i (units/year) (4)	Fraction of demand at demand point $i : Y_{ij}$ (5)	The demand point - weighted distance (Baht) (6)	Distance (km.) (7)
(1)	Nongbualamphu_Khonkaen	5.00	4,151	1.00	20,755	129.08
	Udonthani_Khonkaen	4.63	27,219	1.00	126,024	158.57
03	Chantaburi_Chonburi	9.77	25,989	1.00	253,913	148.82
	Chachoengsao_Chonburi	9.52	14,656	1.00	139,525	71.96
	Chonburi_Chonburi	0	53,923	1.00	0	0
	Trat_Chonburi	13.30	3,668	1.00	48,748	215.33
	Rayong_Chonburi	6.06	16,399	1.00	99,378	67.14
04	Chiang Rai_Chiang Mai	6.36	31,213	1.00	198,515	235.82
	Chiang Mai_Chiang Mai	0	64,631	1.00	0	0
	Nan_Chiang Mai	12.13	9,619	1.00	116,678	348.63
	Phayao_Chiang Mai	5.12	11,488	1.00	58,819	248.99
	Mae Hong Son_Chiang Mai	9.13	3,599	1.00	32,859	230.71
	Lampang_Chiang Mai	4.72	21,583	1.00	101,872	145.35
	Lamphun_Chiang Mai	2.53	12,122	1.00	30,669	131.53
05	Nakhonrat_Nakhonrat	0	57,304	1.00	0	0
	Buriram_Nakhonratchasima	5.72	20,402	1.00	116,699	129.99

Table K.2 Results from solving the Uncapacitated Fixed Charge Facility Location model of case 6 (cont.)

RBC	Allocation_Location (i_j) (2)	Delivery cost: C_{ij} (Baht/unit) (3)	Demand: h_i (units/year) (4)	Fraction of demand at demand point $i : Y_{ij}$ (5)	The demand point - weighted distance (Baht) (6)	Distance (km.) (7)
(1)						
06	Sakao_ Nakhonratchasima	7.87	6,628	1.00	52,162	231.04
	Surin_ Nakhonratchasima	6.49	16,108	1.00	104,541	190.72
	Krabi_ Nakhonsithammarat	5.47	5,395	1.00	29,511	110.51
	Chumphon_ Nakhonsithammarat	10.41	17,575	1.00	182,956	282.99
	Trang_ Nakhonsithammarat	3.13	7,893	1.00	24,705	125.38
	Nakhonsit_ Nakhonsit	0	20,252	1.00	0	0
	Phatthalung_ Nakhonsit	5.77	7,578	1.00	43,725	115.08
07	Suratthani_ Nakhonsithammarat	5.66	17,978	1.00	101,755	141.04
	Chai Nat_ Nakhonsawan	4.25	6,143	1.00	26,108	80.48
	Nakhonsawan_ Nakhonsawan	0	23,153	1.00	0	0
	Uthaithani_ Nakhonsawan	2.32	5,982	1.00	13,878	99.40
	Kamphaengphet_ Phitsanulok	4.66	8,978	1.00	41,837	171.05
08	Tak_ Phitsanulok	5.38	7,601	1.00	40,893	341.13
	Phichit_ Phitsanulok	3.51	8,100	1.00	28,431	125.32
	Phitsanulok_ Phitsanulok	0	22,832	1.00	0	0
	Phetchabun_ Phitsanulok	6.56	18,423	1.00	120,855	148.93

Table K.2 Results from solving the Uncapacitated Fixed Charge Facility Location model of case 6 (cont.)

RBC	Allocation_Location (i_j) (2)	Delivery cost: C_{ij} (Baht/unit) (3)	Demand: h_i (units/year) (4)	Fraction of demand at demand point $i : Y_{ij}$ (5)	The demand point - weighted distance (Baht) (6)	Distance (km.) (7)
(1)						
	Phare_Phitsanulok	8.11	11,491	1.00	93,192	199.81
	Sukhothai_Phitsanulok	3.45	9,219	1.00	31,806	147.03
	Uttaradit_Phitsanulok	6.74	13,490	1.00	90,923	143.05
09	Phangnga_Phuket	13.02	4,160	1.00	54,163	107.89
	Phuket_Phuket	0	11,390	1.00	0	0
	Ranong_Phuket	11.18	3,747	1.00	41,891	348.49
10	Kanchanaburi_Ratchaburi	3.08	13,437	1.00	41,386	199.00
	Nakhonpathom_Ratchaburi	2.87	17,758	1.00	50,965	93.22
	Phachuap_Ratchaburi	8.26	9,087	1.00	75,059	236.47
	Phetchaburi_Ratchaburi	2.25	7,592	1.00	17,082	112.58
	Ratchaburi_Ratchaburi	0	23,593	1.00	0	0
11	Nakhonnayok_Lopburi	8.83	4,350	1.00	38,411	207.88
	Lopburi_Lopburi	0	23,368	1.00	0	151.50
	Saraburi_Lopburi	15.69	20,748	1.00	325,536	0
	Singburi_Lopburi	1.82	6,575	1.00	11,967	71.21
	Suphanburi_Lopburi	4.96	8,241	1.00	40,875	80.37

Table K.2 Results from solving the Uncapacitated Fixed Charge Facility Location model of case 6 (cont.)

RB C	Allocation_Location (i_j) (2)	Delivery cost: C_{ij} (Baht/unit) (3)	Demand: h_i (units/year) (4)	Fraction of demand at demand point $i : Y_{ij}$ (5)	The demand point - weighted distance (Baht) (6)	Distance (km.) (7)
(1)	Angthong_Lopburi	2.40	4,837	1.00	11,609	149.99
12	Narathiwat_ Songkhla	7.25	7,261	1.00	52,642	100.69
	Pattani_ Songkhla	3.93	5,510	1.00	21,654	210.50
	Yala_ Songkhla	5.22	9,144	1.00	47,732	106.12
	Songkhla_ Songkhla	0	25,701	1.00	0	128.00
	Satun_ Songkhla	4.64	2,302	1.00	10,681	0
13	Mukdahan_ Ubonratchathani	8.02	5,843	1.00	46,861	107.83
	Yasothon_ Ubonratchathani	5.58	7,049	1.00	39,333	222.83
	Sisaket_ Ubonratchathani	4.86	15,275	1.00	74,237	157.77
	Amnatcharoen_ Ubonratchathani	4.44	3,312	1.00	14,705	109.54
	Ubonratchathani_ Ubonratchathani	0	30,792	1.00	0	123.42
14	Chanthaburi_Trat	4.76	25,989	1.00	123,707	0
	Trat_Trat	0	3,668	1.00	0	149.99
The total demand point – weighted distance ($\sum \sum C_{ij} h_i Y_{ij} : \text{Baht}$)					4,473,917	

APPENDIX L

OPTIMAL RESULTS FOR CASE 7: LOCATING AN ADDITIONAL RBC INTO THE CURRENT NETWORK WITH LIMITED BLOOD SUPPLY

In this case, there are 13 existing RBCs. An additional RBC is located by the model. The last RBC is aimed to compare with the planned RBC by the NBC at Ayutthaya. Initially, the result appeared to be the infeasible solution (Figure L.1). This is because the blood supply of these mere 14 RBCs is insufficient to meet the total blood demand. Therefore, Case 7 is further assumed that each of the entire candidate RBCs is capable to procure and supply blood at the quantity of 1,000,000 units/year. The analysis result reveals that Saraburi is mostly appropriate for being the location of the new RBC, as shown in Figure L.2. The total system cost is 4,327,370 Baht of which in (Table L.1) the fixed cost is 0 Baht. Because in case 7 it was assumed that the fixed cost of all candidate RBCs are identical equivalent. Table L.2 shows blood transportation cost from each RBC to its responsible provinces. Column 1 of the table is the number of the RBCs. Column 2 contains the routes from each RBC to its service provinces. Column 3 presents delivery costs for transporting blood from each RBC to the terminal hospitals. Column 4 shows quantities of blood that each terminal province requires in each year. Column 5 shows ratios (or fractions) of blood demand that each terminal province receives from each RBC. Column 6 contains the total transportation cost as derived from Case 7. Finally, the last column shows the distribution distance from location to allocation (i_j). The grand total transportation cost at the bottom line is 4,327,370 Baht/year. The problem was solved within 0.57 seconds, as shown in Figure L.2

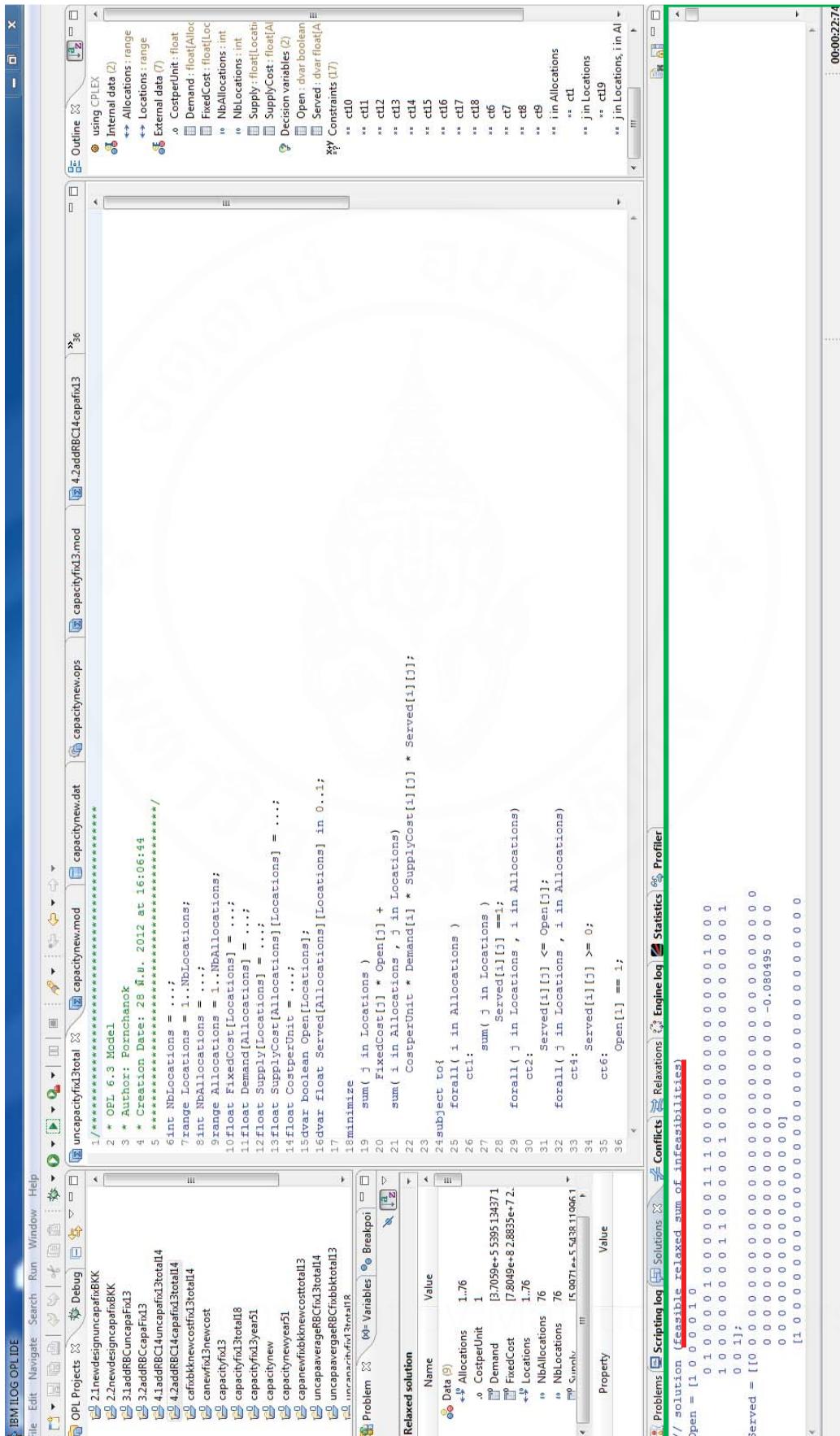


Figure L.1 Captured screen of IBM ILOG OPL IDE 6.3 in Case 7 (Infeasible solution)

Table L.1 Fixed cost of RBC locations in Case 7

RBCs (1)	Provinces (2)	Region (3)	No. of service provinces (4)	Fixed cost (Baht) (5)
01	Bangkok	Center	7	0
02	Lopburi	Center	6	0
03	Nakhonsawan	Center	3	0
04	Phitsanulok	Center	8	0
05	Saraburi	Center	1	0
06	Chonburi	East	5	0
07	Ratchaburi	West	5	0
08	Nakhonratchasima	Northeast	4	0
09	Khonkaen	Northeast	11	0
10	Ubonratchathani	Northeast	5	0
11	Chiang Mai	North	7	0
12	Nakhonsithammarat	South	6	0
13	Songkhla	South	5	0
14	Phuket	South	3	0
Total fixed cost ($\sum f_j X_j$: Baht)				0

Table L.2 Results from solving the Capacitated Fixed Charge Facility Location model of case 7

RBC	Allocation_Location ($i - j$) (2)	Delivery cost: C_{ij} (Baht/unit) (3)	Demand: h_i (units/year) (4)	Fraction of demand at demand point $i : Y_{ij}$ (5)	The demand point - weighted distance (Baht) (6)	Distance (km.) (7)
(1)						
01	Bangkok_Bangkok	0	370,594	1.0000	0	0
	Nonthaburi_Bangkok	4.22	12,092	1.0000	51,028	50.17
	Pathumthani_Bangkok	7.72	21,197	1.0000	163,641	47.45
	Prachiburi_Bangkok	8.77	11,078	1.0000	97,154	192.70
	Samutprakan_Bangkok	7.18	17,634	1.0000	126,612	30.15
	Samutsongkhram_Bangkok	13.64	4,375	1.0000	59,675	122.56
	Samutsakhon_Bangkok	7.99	10,073	1.0000	80,483	92.36
	Kalasin_Khonkaen	6.53	11,740	1.0000	76,662	143.37
	Khonkaen_Khonkaen	0	59,208	1.0000	0	0
02	Chaiyaphum_Khonkaen	5.52	14,346	1.0000	79,190	129.25
	Nakhonphanom_Khonkaen	11.85	6,678	1.0000	79,134	294.92
	Mahasarakham_Khonkaen	4.15	10,886	1.0000	45,177	104.83
	Roi Et_Khonkaen	4.85	18,030	1.0000	87,446	160.58
	Loei_Khonkaen	7.07	9,711	1.0000	68,657	190.07
	Sakonnakhon_Khonkaen	8.29	12,813	1.0000	106,220	239.07
	Nongkhai_Khonkaen	7.73	9,840	1.0000	76,063	255.70

Table L.2 Results from solving the Capacitated Fixed Charge Facility Location model of case 7(cont.)

RBC	Allocation_Location ($i - j$) (2)	Delivery cost: C_{ij} (Baht/unit) (3)	Demand: h_i (units/year) (4)	Fraction of demand at demand point $i : Y_{ij}$ (5)	The demand point - weighted distance (Baht) (6)	Distance (km.) (7)
(1)						
03	Nongbualamphu_ Khonkaen	5	4,151	1.0000	20,755	129.08
	Udonthani_ Khonkaen	4.63	27,219	1.0000	126,024	158.57
	Chanthaburi_ Chonburi	9.77	25,989	1.0000	253,913	148.82
	Chachoengsao_ Chonburi	9.52	14,656	1.0000	139,525	71.96
	Chonburi_ Chonburi	0	53,923	1.0000	0	0
	Trat_ Chonburi	13.3	3,668	1.0000	48,784	215.33
04	Rayong_ Chonburi	6.06	16,399	1.0000	99,378	67.14
	Chiang Rai_ Chiang Mai	6.36	31,213	1.0000	198,515	235.82
	Chiang Mai_ Chiang Mai	0	64,631	1.0000	0	0
	Nan_ Chiang Mai	12.13	9,619	1.0000	116,678	348.63
	Phayao_ Chiang Mai	5.12	11,488	1.0000	58,819	248.99
	Mae Hong Son_ Chiang Mai	9.13	3,599	1.0000	32,859	230.71
05	Lampang_ Chiang Mai	4.72	21,583	1.0000	101,872	145.35
	Lamphun_ Chiang Mai	2.53	12,122	1.0000	30,669	131.53
	Nakhonratchasima_					
	Nakhonratchasima	0	57,304	1.0000	0	0

Table L.2 Results from solving the Capacitated Fixed Charge Facility Location model of case 7 (cont.)

RBC	Allocation_Location ($i - j$) (2)	Delivery cost: C_{ij} (Baht/unit) (3)	Demand: h_i (units/year) (4)	Fraction of demand at demand point $i : Y_{ij}$ (5)	The demand point - weighted distance (Baht) (6)	Distance (km.) (7)
(1)						
	Buriram_Nakhonratchasima	5.72	20,402	1.0000	116,699	129.99
	Sakaeo_Nakhonratchasima	7.87	6,628	1.0000	52,162	231.04
	Surin_Nakhonratchasima	6.49	16,108	1.0000	104,541	190.72
06	Krabi_Nakhonsithammarat	5.47	5,395	1.0000	29,511	110.51
	Chumphon_					
	Nakhonsithammarat	10.41	17,575	1.0000	182,956	282.99
	Trang_Nakhonsithammarat	3.13	7,893	1.0000	24,705	125.38
	Nakhonsithammarat_					
	Nakhonsithammarat	0	20,252	1.0000	0	0
	Phatthalung_					
	Nakhonsithammarat	5.77	7,578	1.0000	43,725	115.08
	Suratthani_					
	Nakhonsithammarat	5.66	17,978	1.0000	101,755	141.04
07	Chai Nat_Nakhonsawan	4.25	6,143	1.0000	26,108	80.48
	Nakhonsawan_Nakhonsawan	0	23,153	1.0000	0	0
	Uthaithani_Nakhonsawan	2.32	5,982	1.0000	13,878	99.40

Table L.2 Results from solving the Capacitated Fixed Charge Facility Location model of case 7 (cont.)

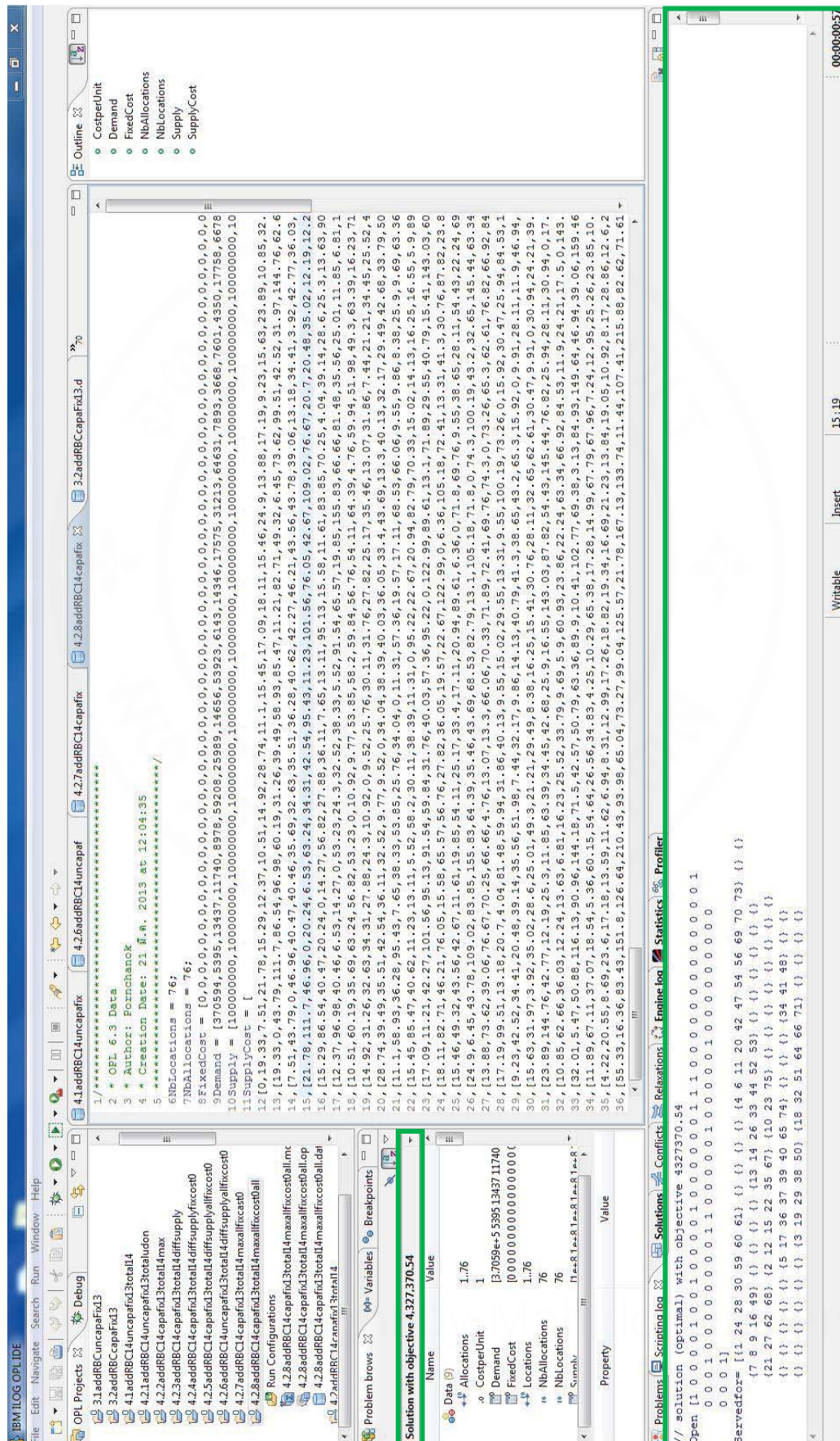
RBC (1)	Allocation_Location ($i - j$) (2)	Delivery cost: C_{ij} (Baht/unit) (3)	Demand: h_i (units/year) (4)	Fraction of demand at demand point $i : Y_{ij}$ (5)	The demand point - weighted distance (Baht) (6)	Distance (km.) (7)
08	Kamphaengphet_ Phitsanulok	4.66	8,978	1.0000	41,837	171.05
	Tak Phitsanulok	5.38	7,601	1.0000	40,893	241.13
	Phichit Phitsanulok	3.51	8,100	1.0000	28,431	125.32
	Phitsanulok Phitsanulok	0	22,832	1.0000	0	0
	Phetchabun Phitsanulok	6.56	18,423	1.0000	120,855	148.93
	Phare Phitsanulok	8.11	11,491	1.0000	93,192	199.81
	Sukhothai Phitsanulok	3.45	9,219	1.0000	31,806	147.03
09	Uttaradit Phitsanulok	6.74	13,490	1.0000	90,923	143.05
	Phangnga_ Phuket	13.02	4,160	1.0000	54,163	107.89
	Phuket_ Phuket	0	11,390	1.0000	0	0
	Ranong_ Phuket	11.18	3,747	1.0000	41,891	348.49
10	Kanchanaburi_ Ratchaburi	3.08	13,437	1.0000	41,386	199.00
	Nakhonpathom_ Ratchaburi	2.87	17,758	1.0000	50,965	93.22
	Phetchaburi_ Ratchaburi	8.26	9,087	1.0000	75,059	236.47
	Ratchaburi_ Ratchaburi	2.25	7,592	1.0000	17,082	112.58
	Phetchaburi_ Ratchaburi	0	23,593	1.0000	0	0

Table L.2 Results from solving the Capacitated Fixed Charge Facility Location model of case 7 (cont.)

RBC (1)	Allocation_Location (i_j) (2)	Delivery cost: C_{ij} (Baht/unit) (3)	Demand: h_i (units/year) (4)	Fraction of demand at demand point $i : Y_{ij}$ (5)	The demand point - weighted distance (Baht) (6)	Distance (km.) (7)
11	Nakhonnayok_Lopburi	8.83	4,350	1.0000	38,411	207.88
	Ayuthaya_Lopburi	3.43	19,594	1.0000	67,207	151.50
	Lopburi_Lopburi	0	23,368	1.0000	0	0
	Singburi_Lopburi	1.82	6,575	1.0000	11,967	80.37
	Suphanburi_Lopburi	4.96	8,241	1.0000	40,875	149.99
	Anghong_Lopburi	2.40	4,837	1.0000	11,609	100.69
12	Narathiwat_Songkhla	2.4	4,837	1.0000	11,609	210.50
	Pattani_Songkhla	7.25	7,261	1.0000	52,642	106.12
	Yala_Songkhla	3.93	5,510	1.0000	21,654	128.00
	Songkhla_Songkhla	5.22	9,144	1.0000	47,732	0
	Satun_Songkhla	0	25,701	1.0000	0	107.83
	Saraburi_Saraburi	4.64	2,302	1.0000	10,681	0
14	Mukdahan_Ubonratchathani	0	20,748	1.0000	0	222.83
	Yasothon_Ubonratchathani	8.02	5,843	1.0000	46,861	157.77
	Sisaket_Ubonratchathani	5.58	7,049	1.0000	39,333	109.54

Table L.2 Results from solving the Capacitated Fixed Charge Facility Location model of case 7 (cont.)

RBC (1)	Allocation_Location ($i - j$) (2)	Delivery cost: C_{ij} (Baht/unit) (3)	Demand: h_i (units/year) (4)	Fraction of demand at demand point $i : Y_{ij}$ (5)	The demand point - weighted distance (Baht) (6)	Distance (km.) (7)
	Amnatcharoen_					
	Ubonratchathani	4.86	15,275	1.0000	74,237	123.42
	Ubonratchathani_					
	Ubonratchathani	4.44	3,312	1.0000	14,705	0
The total demand point – weighted distance ($\sum \sum C_{ij} h_i Y_{ij} : \text{Baht}$)					4,327,370	



APPENDIX M

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การประชุมวิชาการวิศวกรรมอุตสาหกรรมแห่งชาติ 2010
เพื่อเฉลิมพระเกียรติพระบาทสมเด็จพระเจ้าอยู่หัวฯ เนื่องในวโรกาสทรงพระชนมายุ 84 พรรษา

การกระจายโลหิตระดับชาติ: วิธีการปัจจุบัน ประเด็นปัญหาและแนวคิดในการปรับปรุงประสิทธิภาพ Nationwide Blood Distribution: Current Practice, Issues and Concept for Efficiency Improvement

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บทคัดย่อ : ระบบโลจิสติกส์การกระจายโลหิตไปให้คนไข้ในภูมิภาคต่างๆ ของประเทศไทย อาศัยเครือข่ายในลักษณะ Hub-and-Spoke กล่าวคือ เรามีศูนย์กลางการกระจายอยู่ที่ศูนย์บริการโลหิตแห่งชาติ สภากาชาดไทย ในกรุงเทพมหานครให้บริการโลหิตกับโรงพยาบาลในเขตพื้นที่กรุงเทพฯ และจังหวัดโดยรอบ ในระดับภูมิภาคเรามีภาคบริการโลหิตอีก 13 แห่งกระจายอยู่ทั่วประเทศทำหน้าที่ให้บริการกับจังหวัดต่างๆ โดยรอบ สถานการณ์ที่เป็นอยู่คือ ศูนย์บริการโลหิตแห่งชาติจำเป็นต้องจัดส่งโลหิตราว 40% ของปริมาณที่จัดหาได้ไปสนับสนุนภาคบริการโลหิตต่างๆ ทุกปี เนื่องจากโลหิตที่ภาคบริการโลหิต ได้รับบริจาคไม่เพียงพอกับความต้องการใช้โลหิต แต่ละวันจึงต้องมีการขนส่งโลหิตเป็นระยะทางไกล โดยที่การควบคุมคุณภาพของโลหิตระหว่างการขนส่งเป็นไปด้วยความยากลำบากมาก บทความนี้รายงานผลการศึกษาโลจิสติกส์การกระจายโลหิตจากส่วนกลางไปยังภูมิภาคต่างๆ ทั่วประเทศไทยทั้งจากมุมมองเชิงปริมาณและคุณภาพ ทำการสำรวจรวบรวมข้อมูลภายในเดือนสิงหาคม 2553 และพบว่าการกระจายโลหิตไปยังภูมิภาคเป็นแบบ Door-to-Station ไม่ว่าจะเป็นสถานีขนส่งผู้โดยสารหรือสนามบิน ปริมาณการขนส่งมีจำนวนมากและกระจายไปทั่วทุกภูมิภาค ซึ่งบทความได้แสดงผลการวิเคราะห์ค่าใช้จ่ายการกระจายโลหิตนี้และเสนอแนะแนวทางในการลดต้นทุน เพื่อปรับปรุงประสิทธิภาพให้ดียิ่งขึ้น โดยที่ยังคงรักษามาตรฐานการให้บริการโลหิตในระดับสากลได้

ABSTRACT: Blood distribution system in Thailand is in the form of hub-and-spoke network. The center is at the National Blood Center (NBC), Thai Red Cross Society in Bangkok that provides blood and blood products to the hospitals in Bangkok Metropolitan area and its vicinity. At the national level, there are 13 regional blood centers (RBC) around the country serving patients in the provincial hospitals. Presently, the NBC has to transport about 40% of donated blood to support RBCs due to their insufficient blood supply. Blood therefore has to be distributed over a very long distance and quality control become even more difficult. This research paper discussed the distribution process of blood from NBC to RBCs and hospitals throughout the country from both quantitative and qualitative perspectives. The data were surveyed in August 2010. It is found out that the distribution system is of the door-to-station type, regardless by land or air transportation. The total distribution cost was also estimated. Some guidelines are suggested in order to reduce cost and improve the efficiency of the distribution system without compromising the international medical standard.

KEYWORDS: Blood; Transportation; National Blood Center; Distribution; Location/Allocation

1. ที่มาและความสำคัญของปัญหา

ในปัจจุบันนี้ความก้าวหน้าทางวิทยาศาสตร์ มีความรู้เรื่องดีเอ็นเอ (DNA) และยีน (Gene) เป็นอย่างดี สามารถสร้างโปรตีนชนิดต่างๆ ภายนอกร่างกายได้ แต่ยังไม่สามารถสร้างเม็ดโลหิตนอกร่างกายได้ ต้องอาศัยเม็ดโลหิตที่สร้างโดยร่างกายมนุษย์เท่านั้น ดังนั้นการบริจาคโลหิตจึงมีความสำคัญในการรักษาผู้ป่วย [1] ในแต่ละปีศูนย์บริการโลหิตแห่งชาติต้องจัดหาโลหิตเป็นจำนวนมากและกระจายให้กับผู้ป่วยตามโรงพยาบาลต่างๆ ในปีงบประมาณ 2549 พบว่าศูนย์บริการโลหิตแห่งชาติ จัดหาโลหิตในกรุงเทพฯ ได้ร้อยละ 10.2 ซึ่งร้อยละ 57 ใช้กับผู้ป่วยในกรุงเทพฯ และร้อยละ 43 ใช้กับผู้ป่วยในต่างจังหวัด ซึ่งศูนย์บริการโลหิตแห่งชาติ ต้องส่งโลหิตไปสนับสนุนผู้ป่วยในต่างจังหวัดทั้งที่ความตั้งใจจริงของการตั้งภาคบริการโลหิต เพื่อสามารถดำเนินงานในการให้บริการโลหิตได้ด้วยตนเอง โดยใช้ขั้นตอนและวิธีการเดียวกับศูนย์บริการโลหิตแห่งชาติ นั่นคือ ทำหน้าที่จัดหา คัดกรอง จัดเก็บและกระจายโลหิตให้กับโรงพยาบาลศูนย์และโรงพยาบาลชุมชนที่ต้องการ แต่ในปัจจุบันภาคบริการโลหิตไม่สามารถรับผิดชอบการจัดหาโลหิตในส่วนภูมิภาคทั่วประเทศได้เพียงพอกับการใช้ของผู้ป่วย ซึ่งศูนย์บริการโลหิตแห่งชาติจำเป็นต้องจัดส่งโลหิตให้กับภาคบริการโลหิตต่างๆ และพบว่ายากที่ควบคุมคุณภาพของโลหิตระหว่างการขนส่ง เนื่องจากโลหิตเป็นผลิตภัณฑ์ที่ต้องควบคุมอุณหภูมิตามที่กำหนดไว้ตลอดเวลา และไม่อาจทราบสภาพแวดล้อมขณะขนส่งโลหิตนั้น มีผลกระทบต่ออุณหภูมิโลหิตมากน้อยเพียงใดในทางเดียวกันนั้นถ้ามีการขนส่งในระยะทางไกลภายใต้สภาวะแวดล้อมที่ไม่คงที่เป็นเวลานานจะเกิดความเสถียรต่อคุณภาพโลหิตได้ ซึ่งจะเป็นผลเสียต่อผู้ป่วยเมื่อได้รับโลหิตที่คุณภาพไม่ได้มาตรฐาน และการกระจายโลหิตนี้ยังทำให้ศูนย์บริการโลหิตแห่งชาติเกิดค่าใช้จ่ายที่เพิ่มขึ้น

2. ทบทวนงานวิจัยที่เกี่ยวข้อง

งานวิจัยนี้เป็นการศึกษากระบวนการกระจายโลหิตจากส่วนกลางสู่ภูมิภาค ไปยังภาคบริการโลหิตและโรงพยาบาลต่างจังหวัด เพื่อทำความเข้าใจวิธีการและขั้นตอนส่งโลหิตไปสนับสนุนภาคบริการโลหิต โดยเน้นการควบคุมคุณภาพโลหิตเป็นสำคัญ

2.1 สภาพทั่วไปของการกระจายโลหิต

ห่วงโซ่อุปทานของโลหิตเป็นการไหลจากผู้บริจาคโลหิตไปถึงผู้ป่วย เริ่มจากการบริจาค คัดกรอง การตรวจสอบ แยกส่วนประกอบ เก็บ การกระจายให้กับโรงพยาบาลต่างๆ และสุดท้ายที่คนไข้ได้รับโลหิต ตลอดห่วงโซ่อุปทานโลหิตจำเป็นต้องมีการตรวจสอบคุณภาพ เพราะโลหิตที่ไม่ได้คุณภาพจะทำให้เกิดอันตรายต่อผู้รับได้ ซึ่งการจำลองสถานการณ์จะช่วยเพิ่มประสิทธิภาพในการจัดหาโลหิต และตอบสนองการกระจายในห่วงโซ่อุปทานโลหิต [2] โดยวิเคราะห์จำนวนผู้ป่วย จำนวนโรงพยาบาล จำนวนโลหิตที่ต้องเก็บ ความผิดพลาดในการนำโลหิตไปใช้ การควบคุมคุณภาพระหว่างการกระจายโลหิต [3] ในการกระจายโลหิตให้กับโรงพยาบาลนั้นจำเป็นต้องมีการควบคุมอุณหภูมิตลอดเพื่อเป็นรักษาคุณภาพโลหิตไว้ มีการใช้เซ็นเซอร์ (Sensor), Radio-Frequency Identification (RFID), Personal Digital Assistant (PDA), Short Message Service (SMS), Global System for Mobile Communications (GSM) เพื่อช่วยในการติดตามรายงานอุณหภูมิ มีการแจ้งเตือนอัตโนมัติเมื่อมีความผิดปกติของอุณหภูมิเกิดขึ้นที่ถุงโลหิต เพื่อป้องกันการเสื่อมคุณภาพของโลหิตระหว่างการกระจายไปยังโรงพยาบาล [4 - 5] ใช้บาร์โค้ด (Barcode) เพื่ออัปเดตโดยอัตโนมัติในการจัดเก็บ การเบิกจ่าย และการทำฐานข้อมูล [6] ตลอดห่วงโซ่จะช่วยป้องกันการเกิดความผิดพลาดที่จะเกิดขึ้นได้ขณะกระจายโลหิต ขณะที่ศูนย์บริการโลหิตแห่งชาติในประเทศไทย มีการตรวจสอบคุณภาพโดยการสุ่มตรวจระดับอุณหภูมิของกล่องโลหิตที่กระจายไปยังภาคบริการโลหิต โดยใช้ดาต้าล็อกเกอร์ (Data Logger) ในการบันทึกอุณหภูมิขณะเคลื่อนย้าย เพื่อนำอุณหภูมิที่ได้มาปรับปรุงการกระจายโลหิตให้ดีขึ้นทั้งทางด้านปริมาณและคุณภาพ

2.2 ภาคบริการโลหิตในประเทศไทย

ในแต่ละวันศูนย์บริการโลหิตแห่งชาติมีการจัดส่งโลหิตให้โรงพยาบาลต่างๆ ซึ่งบางครั้งไม่พอเพียงสำหรับความต้องการที่จะกระจายให้โรงพยาบาลทั่วประเทศได้ ดังนั้นกระทรวงสาธารณสุขจึงมอบหมายให้ศูนย์บริการโลหิตแห่งชาติรับผิดชอบงานด้านบริการโลหิตทั้งหมดของประเทศ เพื่อให้การดำเนินงานการบริการโลหิตเป็นมาตรฐานเดียวกันทั่วประเทศ และมีนโยบายจัดตั้งภาคบริการโลหิตแห่งชาติ กระจายไปตามภูมิภาค จำนวน 12 ภาค และภาคบริการโลหิตแห่งชาติพิเศษที่

ภูเก็ทเพื่อให้เป็นศูนย์กลางของการดำเนินงานในการให้บริการโลหิตโดยใช้ขั้นตอนและวิธีการเดียวกันกับศูนย์บริการโลหิตแห่งชาติทุกประการ [7] โดยภาคบริการโลหิตแห่งชาติแต่ละภาคมีท่าเลที่ตั้งดังต่อไปนี้

ภาคบริการโลหิต	ภาค 2	ตั้งอยู่ที่ จังหวัดลพบุรี
ภาคบริการโลหิต	ภาค 3	ตั้งอยู่ที่ จังหวัดชลบุรี
ภาคบริการโลหิต	ภาค 4	ตั้งอยู่ที่ จังหวัดราชบุรี
ภาคบริการโลหิต	ภาค 5	ตั้งอยู่ที่ จังหวัดนครราชสีมา
ภาคบริการโลหิต	ภาค 6	ตั้งอยู่ที่ จังหวัดขอนแก่น
ภาคบริการโลหิต	ภาค 7	ตั้งอยู่ที่ จังหวัดอุบลราชธานี
ภาคบริการโลหิต	ภาค 8	ตั้งอยู่ที่ จังหวัดนครสวรรค์
ภาคบริการโลหิต	ภาค 9	ตั้งอยู่ที่ จังหวัดพิษณุโลก
ภาคบริการโลหิต	ภาค 10	ตั้งอยู่ที่ จังหวัดเชียงใหม่
ภาคบริการโลหิต	ภาค 11	ตั้งอยู่ที่ จังหวัดนครศรีธรรมราช
ภาคบริการโลหิต	ภาค 12	ตั้งอยู่ที่ จังหวัดสงขลา
ภาคบริการโลหิตพิเศษ		ตั้งอยู่ที่ จังหวัดภูเก็ต

3. ระเบียบวิธีวิจัย

3.1 ขอบเขตการศึกษา

ศึกษาสภาพทั่วไปของการกระจายโลหิตจากส่วนกลางสู่ภูมิภาค ไปยังภาคบริการโลหิตและโรงพยาบาลในต่างจังหวัด

3.2 ข้อมูลที่ใช้ในการวิจัย

ข้อมูลที่ใช้ในการวิจัยการกระจายโลหิตสู่ภูมิภาคในประเทศไทย แบ่งเป็น 2 ประเภท ได้แก่

- 1) ข้อมูลปฐมภูมิ รวมถึง ขั้นตอนการทำงานในการกระจายโลหิตของศูนย์บริการโลหิตแห่งชาติ, พฤติกรรมการขนส่งโลหิตและ ราคาในการขนส่งโลหิตแต่ละประเภทการขนส่ง
- 2) ข้อมูลทุติยภูมิ รวมถึง ผลงานวิจัย/การประชุมเชิงปฏิบัติการงานบริการโลหิตระดับชาติ เรื่องการขนส่งโลหิตของศูนย์บริการโลหิตแห่งชาติ/ภาคบริการโลหิตที่ผ่านมา, จำนวนภาคบริการโลหิตและ โรงพยาบาลที่กระจายโลหิตให้, ปริมาณความต้องการโลหิตที่จัดส่งในแต่ละวัน, ขนาดของคลังโลหิต และ ประเภท/ท่าเลที่ตั้งของสถานที่กระจายโลหิต

3.3 การเก็บรวบรวมข้อมูล

การเก็บรวบรวมข้อมูล โดยการสังเกตและสัมภาษณ์พนักงานของศูนย์บริการโลหิตแห่งชาติ เริ่มตั้งแต่ผู้รับคำขอใช้โลหิต ผู้เบิกจ่าย ผู้บรรจุ ผู้ขนส่งโลหิต สํารวจประเภทและขนาดคลังบรรจุโลหิต นับจำนวนคลังโลหิต ที่จัดส่งใน 7 วัน คือวันที่ 8, 10, 14, 19, 20, 24 และ 28 สิงหาคม 2553 สํารวจเส้นทางและสถานที่กระจายคลังโลหิต โดยนํ้าไปกับรถตู้ส่งคลังโลหิตของศูนย์บริการโลหิตแห่งชาติพร้อมทั้งบันทึกภาพสถานที่กระจายโลหิต สังเกตสภาพแวดล้อมรวมทั้งขั้นตอนการจัดส่งโลหิตในแต่ละที่โดยละเอียด ศึกษาวิธีการจัดส่งคลังโลหิตแต่ละขนาด และแต่ละประเภทการจัดส่งตั้งแต่ต้นน้ำจนถึงปลายน้ำ เพื่อนํามาวเคราะห์ถึงค่าใช้จ่ายในการกระจายโลหิตสู่ภูมิภาค

3.4 การวิเคราะห์ข้อมูล

หลังจากเก็บรวบรวมข้อมูลเรียบร้อยแล้ว การดำเนินงานวิจัยในขั้นต่อไป คือ การประเมินค่าใช้จ่ายเพื่อปรับปรุงประสิทธิภาพในการกระจายโลหิตสู่ภูมิภาค ทั้งในเชิงปริมาณและคุณภาพที่เหมาะสม ดังนี้

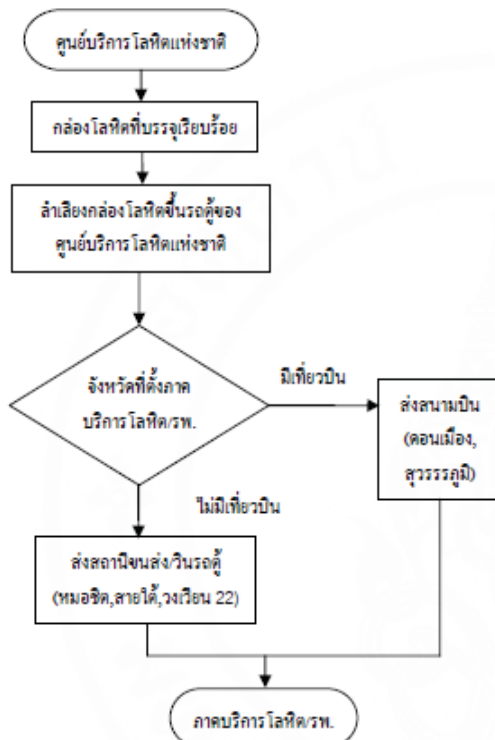
- 1) วิเคราะห์สภาพโดยทั่วไปของการกระจายโลหิตของศูนย์บริการโลหิตแห่งชาติในปัจจุบัน จะได้ทราบประเด็นปัญหาที่เกิดขึ้น
- 2) คำนวณระยะทางในการขนส่งโลหิตตั้งแต่ศูนย์บริการโลหิตแห่งชาติถึงภาคบริการโลหิต/โรงพยาบาล จากโปรแกรม ArcMap 9.3 เพื่อเป็นแนวทางในการหาค่าน้ำมันเชื้อเพลิงในค่าใช้จ่ายในการใช้รถเพื่อการขนส่ง
- 3) คำนวณราคาขนส่งคลังโลหิตตามประเภทการขนส่งและขนาดของคลังโลหิต เพื่อหาค่าใช้จ่ายในการขนส่งใน 7 วัน ตั้งแต่วันที่ 8, 10, 14, 19, 20, 24 และ 28 สิงหาคม 2553
- 4) ประเมินต้นทุนในการกระจายโลหิตสู่ภูมิภาคในแต่ละการขนส่งแต่ละประเภทตั้งแต่ต้นน้ำจนถึงปลายน้ำ
- 5) วิเคราะห์และเสนอแนะแนวทางในการลดค่าใช้จ่ายปรับปรุงการกระจายโลหิตสู่ภูมิภาคให้มีประสิทธิภาพมากขึ้น โดยมีมาตรฐานที่ยอมรับในระดับสากล

4. ผลการวิจัย

4.1 การกระจายโลหิตสู่ภูมิภาคในปัจจุบัน

พิจารณาการกระจายโลหิตของศูนย์บริการโลหิตแห่งชาติ เป็นการกระจายแบบ Door-to-Station เริ่มต้นจากศูนย์บริการโลหิต

แห่งชาติ ลำเลียงกล่องโลหิตที่บรรจุตามใบเบิกเลือดในแต่ละวัน ขึ้นรถตู้แล้วนำไปส่งที่สนามบินสุวรรณภูมิ สนามบินดอนเมือง ท่ารถตู้ที่วงเวียน 22 สถานีขนส่งหมอชิต และสถานีสายใต้ ฯลฯ ดังภาพที่ 1



ภาพที่ 1 ขั้นตอนการพิจารณากระจายโลหิตสู่ภูมิภาค

ซึ่งการกระจายโลหิตไปสู่ภูมิภาคของศูนย์บริการโลหิตแห่งชาติแบ่งเป็น 2 ส่วนหลักๆ คือ ทางอากาศและทางบกซึ่งศูนย์บริการโลหิตแห่งชาติจะพิจารณาวิธีการส่งโลหิตให้กับภาคบริการโลหิตและโรงพยาบาล โดยใช้ระยะเวลาการขนส่งที่น้อยที่สุดเป็นปัจจัยในการพิจารณาจากจังหวัดที่มีสนามบินเป็นหลัก ส่วนภาคบริการโลหิตและโรงพยาบาลอื่นๆ ที่ไม่มีสนามบิน ศูนย์บริการโลหิตแห่งชาติจะจัดส่งให้ทางรถทัวร์และรถตู้ตามที่ภาคบริการโลหิตและโรงพยาบาลสะดวกที่มารับกล่องโลหิต โดยภาคบริการโลหิตและโรงพยาบาลจะแจ้งศูนย์บริการโลหิตแห่งชาติล่วงหน้าว่าให้ส่งทางรถทัวร์หรือรถตู้กับบริษัทขนส่งอะไร เพื่อความสะดวกในการรับกล่องโลหิต

4.2 ราคาการขนส่งกล่องโลหิต

จากการศึกษาการกระจายโลหิตจากศูนย์บริการโลหิตแห่งชาติ ถึงภาคบริการโลหิตและโรงพยาบาลในต่างจังหวัด ทำ

การเก็บรวบรวมข้อมูลการขนส่งโลหิตจำนวน 7 วัน คือ วันที่ 8, 10, 14, 19, 20, 24 และ 28 สิงหาคม 2553 พบว่าจำนวนกล่องโลหิตที่ศูนย์บริการโลหิตแห่งชาติจัดส่งให้ภาคบริการโลหิตและโรงพยาบาลในแต่ละวัน ดังตารางที่ 1

ตารางที่ 1 จำนวนกล่องโลหิตที่ศูนย์บริการโลหิตแห่งชาติจัดส่งในแต่ละวัน

จังหวัดที่จัดส่ง, ขนาดกล่อง (เล็ก/กลาง/ใหญ่)	จำนวนที่จัดส่งเดือนสิงหาคม(กล่อง/วัน)							รวม
	8	10	14	19	20	24	28	
ขอนแก่น (0/1/8)	1	2	2	1	-	1	2	9
ชลบุรี (8/2/3)	1	2	2	2	2	2	2	13
ชัยภูมิ (4/1/0)	1	1	-	1	2	-	-	5
เชียงราย (8/5/0)	1	3	2	2	-	2	3	13
เชียงใหม่ (30/10/14)	9	10	8	6	5	6	10	54
นครราชสีมา (2/2/13)	3	2	4	3	2	2	1	17
นครสวรรค์ (3/1/7)	2	1	1	1	2	2	2	11
นครศรีธรรมราช (4/2/10)	1	2	3	2	3	4	1	16
บึงกาฬ (3/1/0)	-	1	-	1	2	-	-	4
บุรีรัมย์ (1/1/1)	-	1	-	-	1	1	-	3
ประจวบคีรีขันธ์ (1/0/0)	-	-	1	-	-	-	-	1
พะเยา (1/1/0)	-	-	-	-	-	2	-	2
พังงา (2/1/0)	-	1	-	1	-	1	-	3
พิษณุโลก (3/2/7)	2	2	1	4	1	1	1	12
ภูเก็ต (2/0/0)	1	-	1	-	-	-	-	2
แม่ฮ่องสอน (5/1/0)	1	1	-	2	-	1	1	6
ราชบุรี (6/7/15)	7	4	2	4	2	4	5	28
ลพบุรี (6/2/18)	3	2	6	4	3	5	3	26
สกลนคร (0/3/1)	1	-	-	1	1	1	-	4
สงขลา (7/1/7)	-	2	1	2	2	5	3	15
สุราษฎร์ธานี (12/1/0)	2	2	2	2	1	2	2	13
สุรินทร์ (0/1/0)	1	-	-	-	-	-	-	1
หนองคาย (1/1/0)	-	-	-	2	-	-	-	2
หนองบัวลำภู (4/0/0)	-	-	1	-	2	-	1	4
อุดรธานี (11/8/6)	2	6	4	1	7	3	2	25
อุบลราชธานี (4/0/5)	1	-	2	1	2	1	2	9
รวม	40	45	43	43	40	46	41	298

แต่ละวันภาคบริการโลหิตและโรงพยาบาล มีปริมาณความต้องการโลหิตแตกต่างกันไป ดังนั้นกล่องโลหิตที่ศูนย์บริการโลหิตแห่งชาติจัดส่งให้จึงมีขนาดบรรจุ 3 ขนาด คือ เล็ก กลาง และใหญ่ ซึ่งขนาดของกล่องโลหิตมีผลต่อค่าใช้จ่ายในการขนส่ง ซึ่งการขนส่งทางบก แบ่งเป็นรถทัวร์และรถตู้ มีการคิดค่าขนส่ง

ตามขนาดกล่องหรือน้ำหนักของกล่องโลหิต แต่การขนส่งทางอากาศ ศูนย์บริการโลหิตแห่งชาติ ได้รับการยกเว้นค่าจัดส่งกล่องโลหิต สำหรับราคาจัดส่งกล่องโลหิตผ่านบริษัทขนส่งแต่ละแห่ง (ซึ่งใช้นามสมมุติขนส่ง 1 ถึงขนส่ง 10) แสดงไว้ในตารางที่ 2

ตารางที่ 2 ราคาค่าขนส่งกล่องโลหิตตามบริษัทและขนาดกล่อง

ชื่อบริษัท	จังหวัดที่จัดส่ง	ราคาขนาด (บาท/กล่อง)		
		เล็ก	กลาง	ใหญ่
การบินไทย จำกัด	จังหวัด ¹	-	-	-
สายการบินนกแอร์ จำกัด	จังหวัด ²	-	-	-
ขนส่ง 1	ลพบุรี	50	70	70
ขนส่ง 2	ชลบุรี	140	140	160
ขนส่ง 3	ราชบุรี	60	60	60
ขนส่ง 4	นครราชสีมา	60	60	60
ขนส่ง 5	นครสวรรค์	150	150	200
ขนส่ง 6	แม่ฮ่องสอน	250	250	250
ขนส่ง 7	สกลนคร	150	200	300
ขนส่ง 7	กาฬสินธุ์	150	200	300
ขนส่ง 8	หนองคาย	200	200	250
	อุดรธานี	200	200	250
ขนส่ง 9	บุรีรัมย์	250	250	250
	สุรินทร์	250	250	250
	ศรีสะเกษ	300	300	300
ขนส่ง 10	ชัยภูมิ	60	80	100

¹ ขอนแก่น, อุดรธานี, เชียงใหม่, เชียงราย, สงขลา, สุราษฎร์ธานี,ภูเก็ต

² อุบลราชธานี, พิษณุโลก, นครศรีธรรมราช

จากการเก็บรวบรวมข้อมูลการกระจายโลหิตสู่ภูมิภาคทั่วประเทศ ทั้งเรื่องวิธีการกระจายโลหิต จำนวนกล่องโลหิตและราคาค่าขนส่งในการขนส่ง ฯลฯ สามารถนำไปคำนวณค่าใช้จ่ายในการกระจายโลหิต แล้วเสนอแนะแนวทางปรับปรุงประสิทธิภาพการกระจายโลหิตที่เหมาะสมในประเทศไทย โดยมีเครือข่ายในลักษณะ Hub-and-Spoke ที่ยังคงรักษามาตรฐานการให้บริการโลหิตในระดับสากลได้

4.3 การประเมินค่าใช้จ่ายในการกระจายโลหิต

ค่าใช้จ่ายในการกระจายโลหิตสู่ภูมิภาคในแต่ละวันของศูนย์บริการโลหิตแห่งชาติ เป็นค่าใช้จ่ายที่เพิ่มขึ้นของศูนย์บริการโลหิตแห่งชาติ เพราะการจัดส่งโลหิตให้ภาคบริการโลหิตไม่ใช่น้ำหนักหลักของศูนย์บริการโลหิตแห่งชาติ ภาคบริการโลหิตควรต้องสามารถจัดหา คัดกรอง จัดเก็บและกระจายโลหิตให้กับโรงพยาบาลศูนย์ และโรงพยาบาลชุมชนที่ต้องการใช้โลหิตได้

ด้วยตนเอง แต่ปัญหาที่เกิดขึ้นคือภาคบริการโลหิตในส่วนภูมิภาคยังไม่สามารถจัดหาโลหิตได้เพียงพอต่อความต้องการใช้ในพื้นที่ จึงเกิดค่าใช้จ่ายในการกระจายโลหิตเพิ่มขึ้น ซึ่งประกอบไปด้วยค่าน้ำมันเชื้อเพลิง ค่าผ่านทาง ค่าระวาง ค่าจ้างพนักงาน ค่าซ่อมบำรุง ค่าใช้จ่ายอื่นๆ ฯลฯ โดยสรุปค่าใช้จ่ายเหล่านี้สามารถแบ่งได้ 2 ส่วน คือ

1) ค่าใช้จ่ายในการใช้รถ ได้แก่ ค่าใช้จ่ายคงที่ อาจสามารถคำนวณได้จากต้นทุนราคารถซึ่งเป็นรถตู้โตโยต้า (TOYOTA) ค่าจ้างพนักงานขับรถ ค่าใช้จ่ายการดำเนินงานต่างๆ ตลอดจนการกระจายโลหิต และค่าใช้จ่ายผันแปร ได้จากการคำนวณระยะทางการขนส่ง โดยใช้โปรแกรม ArcMap 9.3 ผลลัพธ์ที่ได้จากการคำนวณจะได้ระยะทางการขนส่งในแต่ละวัน ซึ่งนำไปหาค่าน้ำมันเชื้อเพลิง ค่าซ่อมบำรุงรักษา และค่าเสียโอกาสในการใช้รถเพื่อการกระจายโลหิตสู่ภูมิภาค

สมการ ที่ได้ คือ ค่าใช้จ่ายในการใช้รถ = ค่าใช้จ่ายในการใช้รถ¹ + ค่าจ้างพนักงาน + ค่าค่าน้ำมัน² + ค่าน้ำมัน³ + ค่าเสียโอกาส⁴

เมื่อ ¹ (ราคารถ - มูลค่าซากของรถ)/อายุการใช้งาน

² สรุปรอบประมาณวันที่ 12 พฤศจิกายน 2552

³ ราคาน้ำมัน 27.99 บาท/ลิตร (ณ วันที่ 5 สิงหาคม 2553)

⁴ ค่าใช้รถออกหน่วยเคลื่อนที่

2) ค่าใช้จ่ายในการขนส่งกล่องโลหิต ประกอบไปด้วย ค่าใช้ทางยกระดับ ได้แก่ ค่าทางด่วน 45 บาท, ค่าผ่านทาง 25 บาท, ค่าผ่านทางโทลเวย์วิภาวดี-รังสิต 60 บาท และค่าระวางในการขนส่งกล่องโลหิตไปสู่ปลายทางในแต่ละแห่ง สมการ ที่ได้ คือ ค่าใช้จ่ายในการขนส่งกล่องโลหิต = ค่าทางยกระดับ + ค่าระวางกล่องโลหิต

จากการประเมินค่าใช้จ่ายที่เกิดขึ้นเนื่องมาจากการกระจายโลหิตจากส่วนกลางไปยังภูมิภาค ทั้งส่วนของค่าใช้จ่ายในการใช้รถ และค่าใช้จ่ายในการขนส่งกล่องโลหิต สามารถสรุปได้ดังตารางที่ 3

ตารางที่ 3 ผลรวมค่าใช้จ่ายในการกระจายโลหิตสู่ภูมิภาค

ประเภทค่าใช้จ่าย	ผลรวมค่าใช้จ่าย		
	บาท/ปี	บาท/เดือน	บาท/วัน
ค่าใช้จ่ายในการใช้รถ	6,503,400	541,950	18,065
ค่าใช้จ่ายในการขนส่งกล่องโลหิต	775,800	64,650	2,155
รวม (บาท)	7,279,200	606,600	20,220

จากตารางที่ 3 พบว่า ผลรวมค่าใช้จ่ายในการกระจายโลหิตสู่ภูมิภาคประมาณ 20,220 บาท/วัน ซึ่งถ้าคิดเป็นปีจะเป็นจำนวนเงินที่มหาศาล คือ ประมาณ 7,279,200 บาท/ปี เพราะศูนย์บริการโลหิตแห่งชาติส่งโลหิตไปสนับสนุน เมื่อภาคบริการโลหิตมีโลหิตไม่เพียงพอเป็นการเพิ่มงานของศูนย์บริการโลหิตแห่งชาติ นั่นคือค่าใช้จ่ายที่เพิ่มขึ้นในแต่ละปี

5. สรุปผลและข้อเสนอแนะ

การสำรวจรวบรวมข้อมูล 7 วัน ภายในเดือนสิงหาคม 2553 จากการสังเกตพบว่าการกระจายโลหิตไปยังภูมิภาคเป็นแบบ Door-to-Station ไม่ว่าจะเป็นสถานีขนส่งผู้โดยสารหรือสนามบิน ซึ่งปริมาณการขนส่งมีจำนวนมากและกระจายไปทั่วทุกภูมิภาค จากงานวิจัยนี้แสดงผลการประเมินค่าใช้จ่ายส่วนนี้ ซึ่งเป็นค่าใช้จ่ายเพิ่มขึ้น ดังนั้นเพื่อปรับปรุงประสิทธิภาพการกระจายโลหิตในปัจจุบันให้ดีขึ้น มีข้อเสนอแนะแนวทางเกี่ยวกับงานวิจัยที่จะทำในอนาคตได้แบ่งออกเป็น 2 ประเด็นคือ

1) การศึกษานี้เป็นไปได้ว่าที่ตั้งของภาคบริการโลหิต อาจไม่เหมาะสมต่อความต้องการโลหิตในพื้นที่จังหวัดที่รับผิดชอบ จึงทำให้เกิดความขาดแคลนโลหิต จนต้องขอความสนับสนุนจากศูนย์บริการโลหิตแห่งชาติ ดังนั้นควรศึกษาวิเคราะห์การเลือกทำเลที่ตั้งของศูนย์บริการโลหิตแห่งชาติหรือภาคบริการโลหิตที่เหมาะสมที่จะช่วยให้การกระจายโลหิตจากส่วนกลางไปยังภูมิภาคต่างๆ ของประเทศ และในส่วนของภูมิภาคเอง มีความประหยัด ลดต้นทุนค่าใช้จ่ายในการขนส่งโลหิต และยังสามารถควบคุมคุณภาพได้มากขึ้น

2) การที่ภาคบริการโลหิตไม่สามารถจัดหาโลหิตให้เพียงพอต่อความต้องการโลหิตของโรงพยาบาลในจังหวัดที่ภาคบริการโลหิตรับผิดชอบได้ อาจเป็นไปได้ว่า ประชากรในพื้นที่นั้นไม่เห็นความสำคัญของการบริจาคโลหิต หรือการประชาสัมพันธ์เพื่อเชิญชวนผู้บริจาคให้มาบริจาคโลหิตอาจไม่ทั่วถึง จึงทำให้คนมาบริจาคโลหิตน้อยกว่าในกรุงเทพฯ ดังนั้นจึงควรทำแผนการประชาสัมพันธ์ที่เข้าถึงผู้บริจาคอย่างใกล้ชิด และผู้ที่เคยบริจาคโลหิตแล้ว ก็ติดตามมาบริจาคโลหิตเป็นประจำอย่างต่อเนื่อง ให้เคยชินเป็นนิสัย อาจจะทำให้ปริมาณโลหิตในภาคบริการโลหิตเพิ่มมากขึ้น ลดความจำเป็นในการกระจายโลหิตจากส่วนกลางลงได้มาก

6. กิตติกรรมประกาศ

งานวิจัยนี้ได้รับทุนอุดหนุนการวิจัยจากกองทุนเพื่อส่งเสริมการอนุรักษ์พลังงาน ขอขอบพระคุณผู้บริหารของศูนย์บริการโลหิตแห่งชาติ สภากาชาดไทย สำหรับความเอื้อเฟื้อด้านข้อมูลและสถานที่ รวมถึงเจ้าหน้าที่ของศูนย์ฯ ทุกท่านที่กรุณาเสียสละเวลาให้ข้อมูลในการทำวิจัย

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APPENDIX N

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การประชุมวิชาการงานวิจัยนวัตกรรมสุขภาพการ บมจ. 2554
20-21 ตุลาคม 2554



การวิเคราะห์รูปแบบและต้นทุนการกระจายโลหิตในประเทศไทย Distribution of blood in Thailand: modes and associated cost

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ภาควิชาวิศวกรรมโยธาและสิ่งแวดล้อม คณะวิศวกรรมศาสตร์ มหาวิทยาลัยมหิดล

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บทคัดย่อ

รูปแบบการกระจายโลหิตของประเทศไทยในปัจจุบันเป็นแบบกระจายจากศูนย์กลาง (Decentralized blood services model) คือ มีศูนย์บริการโลหิตแห่งชาติ สภากาชาดไทยและภาคบริการโลหิตแห่งชาติ 13 แห่ง เป็นศูนย์กลางในการจัดหาโลหิตให้เพียงพอต่อความต้องการของโรงพยาบาลในกรุงเทพมหานครและปริมณฑล และโรงพยาบาลในภูมิภาคตามลำดับ อย่างไรก็ตาม ทุกปีศูนย์บริการโลหิตแห่งชาติจำเป็นต้องจัดส่งโลหิตราว 40% ของปริมาณที่จัดหาได้ไปสนับสนุนภาคบริการโลหิตต่างๆ เนื่องจากโลหิตที่ภาคบริการโลหิตมีนั้นไม่เพียงพอต่อความต้องการ ซึ่งนับเป็นต้นทุนที่เพิ่มขึ้นของระบบการกระจายโลหิต งานวิจัยนี้ศึกษาความเข้าใจกระบวนการกระจายโลหิตในระดับภูมิภาคของประเทศไทย ศึกษากระบวนการขนส่ง (Modes) และต้นทุนที่เกิดขึ้นของแต่ละรูปแบบ จากการสำรวจข้อมูลในเดือนสิงหาคม พ.ศ. 2553 พบว่าโลหิตที่ถูกจัดส่งให้ภูมิภาคใช้รูปแบบการจัดส่งที่หลากหลาย ทั้งทางรถตู้ รถทัวร์ รถรับจ้างและทางเครื่องบิน ซึ่งแต่ละประเภทการจัดส่งมีค่าใช้จ่ายที่แตกต่างกันไป บทความนี้เสนอผลการวิเคราะห์ค่าใช้จ่ายในการกระจายของโลหิตที่แท้จริงตามรูปแบบการจัดส่งเพื่อประเมินต้นทุนที่เพิ่มขึ้นในการกระจายโลหิตสู่ภูมิภาคของศูนย์บริการโลหิตแห่งชาติ พร้อมทั้งเสนอแนะแนวทางในการปรับปรุงประสิทธิภาพเพื่อกระตุ้นคุณภาพชีวิตผู้ป่วยที่ใช้โลหิตในประเทศไทยให้ดียิ่งขึ้น คำหลัก โลหิต, ภาคบริการโลหิต, การกระจายโลหิต, โลจิสติกส์ของโลหิต

1. ที่มาและความสำคัญของปัญหา

ระบบจัดหาโลหิตของประเทศไทยมีศูนย์กลางอยู่ที่ศูนย์บริการโลหิตแห่งชาติ สภากาชาดไทย (National Blood Center, Thai Red Cross Society) ซึ่งเป็นองค์กรอิสระที่ไม่หวังผลกำไรในการดำเนินงาน มีหน้าที่ให้บริการโลหิตและผลิตภัณฑ์โลหิตที่มีความปลอดภัยได้มาตรฐานเดียวกันในระดับประเทศและระดับภูมิภาคให้เพียงพอต่อความต้องการของผู้ป่วย ในปี พ.ศ. 2549 ศูนย์บริการโลหิตแห่งชาติ สามารถจัดหาโลหิตได้ถึง 465,448 หน่วย จากผู้บริจาคโลหิตทั้งปี 295,187 คน [1] ซึ่งเป็นแนวโน้มที่เพิ่มขึ้นจากปีที่ผ่านมา การกระจายโลหิตของประเทศไทยใน

ปัจจุบัน แบ่งได้ 2 ส่วนใหญ่ ส่วนแรกกระจายโลหิตให้กับโรงพยาบาลในกรุงเทพฯและปริมณฑล โดยโรงพยาบาลจะจัดส่งรถมารับโลหิตเอง ส่วนที่สองกระจายโลหิตให้กับโรงพยาบาลในภูมิภาคทั่วประเทศ โดยจัดส่งโลหิตผ่านทางภาคบริการโลหิตแห่งชาติทั้ง 12 แห่งและภาคบริการโลหิตพิเศษที่จังหวัดภูเก็ต ซึ่งจัดส่งผ่านทาง รถทัวร์ รถตู้ รถรับจ้างและทางเครื่องบิน การกระจายโลหิตสู่ภูมิภาคนั้น ไม่ใช่เจตนารมณ์ดั้งเดิมของศูนย์บริการโลหิตแห่งชาติ เพราะความตั้งใจจริงของการจัดตั้งภาคบริการโลหิตเพื่อสามารถดำเนินการในการให้บริการโลหิตได้ด้วยตนเอง นั่นคือทำหน้าที่จัดหา คัดกรอง จัดเก็บและกระจายโลหิตให้กับโรงพยาบาลในพื้นที่บริการให้เพียงพอ ซึ่งการจัดส่งโลหิตสู่ภูมิภาคเป็นการจัดส่งที่มีระยะทางไกลและยากที่ควบคุมคุณภาพของโลหิตระหว่างการขนส่ง เพราะโลหิตที่ไม่ได้คุณภาพอาจเกิดอันตรายแก่ชีวิตของผู้ป่วยได้ และสิ่งสำคัญในการกระจายโลหิตสู่ภูมิภาค ทำให้ศูนย์บริการโลหิตแห่งชาติมีค่าใช้จ่ายที่เพิ่มขึ้นอีกด้วย

2. งานวิจัยที่เกี่ยวข้อง

งานวิจัยนี้เป็นการศึกษาการกระจายโลหิตของประเทศไทยและประเทศต่างๆ ทั้งวิเคราะห์เส้นทางการกระจาย ตารางเวลาในการจัดส่งโลหิต และคำนวณภาพในการจัดส่งที่มีการวิจัยไว้แล้ว

2.1 การกระจายโลหิตที่เกิดขึ้นในปัจจุบัน

ห่วงโซ่อุปทานของโลหิตเป็นการไหลจากศูนย์บริจาคโลหิตไปถึงผู้ป่วยเริ่มจากการบริจาค คัดกรอง การตรวจทดสอบ แยกส่วนประกอบ การจัดเก็บ การกระจายให้กับโรงพยาบาลต่างๆ และสุดท้ายที่คนไข้รับโลหิต [2] ตลอดทั้งห่วงโซ่นี้จำเป็นต้องมีการควบคุมคุณภาพ ซึ่งจะประกอบไปด้วยการตรวจหาเชื้อโรค การตรวจเชื้อที่ติดต่อทางโลหิต ได้แก่ โรคซิฟิลิส, ไวรัสเอชไอวีและโรคไวรัสตับอักเสบบีและซี ด้วยวิธีชีวโมเลกุล (Nucleic acid Amplification Testing: NAT) [1] การกระจายโลหิตให้กับโรงพยาบาลนั้นจำเป็นต้องมีการควบคุมอุณหภูมิตลอดเพื่อรักษาคุณภาพโลหิตไว้ ขณะที่ศูนย์บริการโลหิตแห่งชาติ สภากาชาดไทย มีการสุ่มตรวจระดับอุณหภูมิของกล่องโลหิตที่กระจายไปยังภาคบริการโลหิตแห่งชาติทั่วประเทศ โดยใช้ตัวนำล็อกเกอร์ (Data



Logger) ในการบันทึกอุณหภูมิขณะเคลื่อนย้าย เพื่อนำอุณหภูมิที่ได้มาปรับปรุงการกระจายโลหิต [3] ขณะที่สภาพอากาศของประเทศออสเตรเลียมีการวิเคราะห์การขนส่ง โดยใช้การจำลองสถานการณ์ในการจัดการตารางเวลาของรถฉุกเฉิน [4] โดยใช้ความเร็วในการตรวจจับ แต่การควบคุมอุณหภูมิของโลหิตจะมีประสิทธิภาพเพิ่มขึ้น ถ้าโลหิตใช้เวลาในการขนส่งในระยะเวลาสั้น ดังนั้นสภาพอากาศอเมริกา จึงมีการปรับปรุงตารางเวลา/สถานที่การเจาะและเส้นทางการกระจายโลหิต ในบริเวณแอตแลนติก (The Mid-Atlantic) คือ รัฐเวอร์จิเนีย และนอร์ทแคโรไลนาให้เหมาะสมที่สุด [5] ซึ่งการกระจายโลหิตจากศูนย์กลางสู่ภูมิภาคในประเทศไทยให้สามารถฐานสากล ช่วยยกระดับคุณภาพชีวิตผู้ป่วยที่ใช้โลหิตให้ดียิ่งขึ้นได้

2.2 ภาคบริการโลหิตของประเทศไทยในปัจจุบัน

ในแต่ละวันศูนย์บริการโลหิตแห่งชาติมีการจัดส่งโลหิตให้โรงพยาบาลต่างๆ ซึ่งบางครั้งไม่พอเพียงสำหรับความต้องการที่จะกระจายให้โรงพยาบาลทั่วประเทศได้ ดังนั้นกระทรวงสาธารณสุข จึงมีนโยบายจัดตั้งภาคบริการโลหิตแห่งชาติ กระจายไปตามภูมิภาค จำนวน 12 ภาค และภาคบริการโลหิตแห่งชาติพิเศษที่ภูเก็ตเพื่อให้เป็นศูนย์กลางของการดำเนินงานในการให้บริการโลหิตโดยใช้ขั้นตอนและวิธีการเดียวกันกับศูนย์บริการโลหิตแห่งชาติทุกประการ [6] โดยภาคบริการโลหิตแห่งชาติแต่ละภาคมีทำเลที่ตั้งดังต่อไปนี้

ภาคบริการโลหิต ภาค 1 ตั้งอยู่ที่ จังหวัดพระนครศรีอยุธยา
ภาคบริการโลหิต ภาค 2 ตั้งอยู่ที่ จังหวัดลพบุรี
ภาคบริการโลหิต ภาค 3 ตั้งอยู่ที่ จังหวัดชลบุรี
ภาคบริการโลหิต ภาค 4 ตั้งอยู่ที่ จังหวัดราชบุรี
ภาคบริการโลหิต ภาค 5 ตั้งอยู่ที่ จังหวัดนครราชสีมา
ภาคบริการโลหิต ภาค 6 ตั้งอยู่ที่ จังหวัดขอนแก่น
ภาคบริการโลหิต ภาค 7 ตั้งอยู่ที่ จังหวัดอุบลราชธานี
ภาคบริการโลหิต ภาค 8 ตั้งอยู่ที่ จังหวัดนครสวรรค์
ภาคบริการโลหิต ภาค 9 ตั้งอยู่ที่ จังหวัดพิษณุโลก
ภาคบริการโลหิต ภาค 10 ตั้งอยู่ที่ จังหวัดเชียงใหม่
ภาคบริการโลหิต ภาค 11 ตั้งอยู่ที่ จังหวัดนครศรีธรรมราช
ภาคบริการโลหิต ภาค 12 ตั้งอยู่ที่ จังหวัดสงขลา
ภาคบริการโลหิต พิเศษ ตั้งอยู่ที่ จังหวัดภูเก็ต

อย่างไรก็ตาม ภาคบริการโลหิต ภาค 1 ซึ่งมีแนวคิดว่าจะจัดตั้งที่จังหวัดพระนครศรีอยุธยานั้น กระทั่งปัจจุบันยังไม่มีการจัดตั้งขึ้นแต่อย่างใด

3. ระเบียบวิธีวิจัย

ในส่วนนี้เป็นการกล่าวถึงรายละเอียดและขั้นตอนการวิจัยที่เหมาะสม ชัดเจน ซึ่งประกอบไปด้วย 4 ส่วนหลักๆ คือ การอธิบายถึงขอบเขตการศึกษา ข้อมูลที่นำมาใช้ในการวิจัย วิธีการเก็บรวบรวมข้อมูล และขั้นตอนการวิเคราะห์ข้อมูลค่าใช้จ่ายในการ

กระจายโลหิต ซึ่งมีรายละเอียดดังต่อไปนี้

3.1 ขอบเขตการศึกษา

ศึกษาค่าใช้จ่ายของการกระจายโลหิตจากส่วนกลางสู่ภูมิภาคไปยังภาคบริการโลหิตและโรงพยาบาลในต่างจังหวัด สำหรับรูปแบบการจัดส่งแต่ละประเภท

3.2 ข้อมูลที่ใช้ในการวิจัย

การวิเคราะห์ค่าใช้จ่ายในการกระจายโลหิตตามรูปแบบการจัดส่ง (Mode) ต้องอาศัยข้อมูลดังต่อไปนี้

- 1) ขั้นตอนการทำงานในการกระจายโลหิตสู่ภูมิภาคของศูนย์บริการโลหิตแห่งชาติ
- 2) ค่าใช้จ่ายในการขนส่งส่งโลหิตแต่ละขนาดและประเภทของการขนส่ง ทั้งรถทัวร์ รถรับจ้างและเครื่องบิน
- 3) รายชื่อภาคบริการโลหิตและโรงพยาบาลที่กระจายโลหิตให้
- 4) ทำเลที่ตั้งภาคบริการโลหิตและโรงพยาบาลที่รับโลหิตจากศูนย์บริการโลหิตแห่งชาติ
- 5) ปริมาณความต้องการโลหิต (Demand) ที่จัดส่งในแต่ละวัน

3.3 การเก็บรวบรวมข้อมูล

ข้อมูลที่นำมาวิเคราะห์ค่าใช้จ่ายการกระจายโลหิต บางครั้งเป็นข้อมูลที่ไม่มีการเก็บรวบรวมไว้ ดังนั้นผู้วิจัยจึงจำเป็นต้องเก็บรวบรวมเองให้สมบูรณ์ โดยมีขั้นตอนดังนี้

- 1) เก็บรวบรวมข้อมูลการกระจายโลหิตสู่ภูมิภาค ที่ศูนย์บริการโลหิตแห่งชาติ สภากาชาดไทย ภายใน 7 วัน คือวันที่ 8, 10, 14, 19, 20, 24 และ 28 สิงหาคม 2553 (โดยบันทึกข้อมูลครบถ้วนได้ 6 วัน เพราะวันที่ 8 เป็นการสังเกตการณ์โดยบันทึกข้อมูลได้ไม่ครบถ้วน)
- 2) สังเกตและสัมภาษณ์พนักงาน เริ่มตั้งแต่ผู้รับสายขอใช้โลหิต ผู้เบิก-จ่าย ผู้บรรจุ ผู้ขนส่งโลหิต
- 3) สสำรวจประเภท/ขนาดกล่องบรรจุโลหิตและจำนวนกล่องโลหิตที่จัดส่งในแต่ละวัน
- 4) สสำรวจเส้นทาง สถานีขนส่งและสนามบินในการกระจายส่งโลหิตไปยังจังหวัดต่างๆ โดยมุ่งไปที่รถตู้ส่งโลหิตของศูนย์บริการโลหิตแห่งชาติ และศึกษาขั้นตอนการจัดส่งโลหิตในแต่ละสถานีขนส่งและสนามบินโดยละเอียด พร้อมทั้งบันทึกภาพและสังเกตสภาพแวดล้อมทั่วไป
- 5) สอบถามราคาการจัดส่งกล่องโลหิตแต่ละขนาดและแต่ละจังหวัดที่จัดส่งโลหิต เพื่อนำมาวิเคราะห์ถึงค่าใช้จ่ายในการกระจายโลหิตสู่ภูมิภาค

3.4 การวิเคราะห์ข้อมูล

หลังจากเก็บรวบรวมข้อมูลครบถ้วนแล้ว งานถัดมา คือ การวิเคราะห์ต้นทุนกระจายโลหิตในประเทศไทย ซึ่งมี 5 ขั้นตอนที่สำคัญ ดังนี้



1) ศึกษาขั้นตอนการจัดส่งโลหิตจากศูนย์บริการโลหิตแห่งชาติ สภากาชาดไทย ให้กับภาคบริการโลหิตและโรงพยาบาลในต่างจังหวัดโดยละเอียด

2) คำนวณระยะทางในการขนส่งโลหิตโดยใช้โปรแกรม ArcMap 9.3 เพื่อเป็นแนวทางในการคำนวณค่าใช้จ่ายน้ำมันเชื้อเพลิง ค่าใช้จ่ายในการใช้รถเพื่อการขนส่ง ระยะทางต่างๆ ประกอบด้วย

- ระยะทางจากศูนย์บริการโลหิตแห่งชาติถึงสถานีขนส่ง (วงเวียน 22, หมอชิต) /สนามบิน (ดอนเมือง/สุวรรณภูมิ)

- ระยะทางระหว่างกรุงเทพมหานครถึงจังหวัดต่างๆ ที่ศูนย์บริการโลหิตแห่งชาติจัดส่งโลหิตให้

- ระยะทางระหว่างสถานีขนส่ง/สนามบินปลายทางถึงภาคบริการโลหิตและโรงพยาบาลในภูมิภาค

3) คำนวณราคาขนส่งโลหิตตามขนาดของกล่องโลหิตสำหรับแต่ละรูปแบบการขนส่ง เพื่อคำนวณราคาค่าใช้จ่ายในการขนส่งโลหิตโดยแต่ละรูปแบบการจัดส่ง

4) วิเคราะห์รูปแบบการกระจายโลหิตและประเมินค่าใช้จ่ายในการจัดส่งโลหิต

5) เสนอแนวคิดว่าวิธีการปรับปรุงการกระจายโลหิตสู่ภูมิภาคให้มีประสิทธิภาพมากขึ้น เพื่อยกระดับคุณภาพชีวิตของผู้ป่วยที่ใช้โลหิตในประเทศไทย

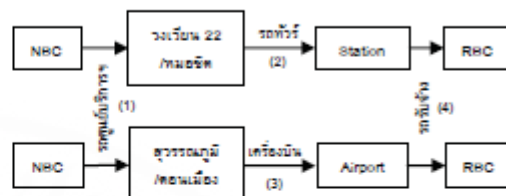
4. ผลการวิจัย

ข้อมูลสำคัญที่สำรวจได้ประกอบด้วยการกระจายโลหิตของศูนย์บริการโลหิตแห่งชาติ และจำนวนโลหิตที่ถูกจัดส่งในแต่ละจังหวัด ข้อมูลเหล่านี้ถูกนำมาใช้ในการวิเคราะห์ค่าใช้จ่ายการจัดส่งโลหิตให้กับภาคบริการโลหิตและโรงพยาบาลต่างจังหวัดจำแนกตามรูปแบบการจัดส่ง

4.1 รูปแบบการกระจายโลหิตในปัจจุบัน

จากการสำรวจข้อมูลการจัดส่งโลหิตจากศูนย์บริการโลหิตแห่งชาติ (National Blood Center: NBC) สภากาชาดไทย (Regional Blood Center: RBC) ภายใน 6 วัน พบว่าโลหิตถูกจัดส่งทั้งหมด 24 จังหวัด หรือประมาณ 18 จังหวัด/วัน ซึ่งในแต่ละจังหวัดมีสถานที่จัดส่งแตกต่างกัน 4 แห่ง คือ 1) วงเวียน 22 กรกฎาคม 2) สถานีขนส่งหมอชิต 3) สนามบินดอนเมือง และ 4) สนามบินสุวรรณภูมิ กล่าวโดยสรุปการจัดส่งโลหิตแบ่งออกเป็น 2 รูปแบบหลัก ได้แก่ ทางบก (Land) และทางอากาศ (Air) รูปที่ 1 แสดงผังการไหลของโลหิตสำหรับทั้งสองรูปแบบ

ความแตกต่างระหว่างสองรูปแบบหลักนี้อยู่ที่สถานีเปลี่ยนถ่ายโลหิตที่ต้นทางและปลายทางเท่านั้น กล่าวคือ หากเป็นการขนส่งทางบก สถานีเปลี่ยนถ่ายโลหิต คือ ท่ารถตู้หรือสถานีขนส่งผู้โดยสาร แต่ถ้าเป็นทางอากาศ สถานีเปลี่ยนถ่ายโลหิต คือ สนามบินนั่นเอง



รูปที่ 1 รูปแบบการจัดส่งโลหิตของศูนย์บริการโลหิตแห่งชาติ

4.2 จำนวนกล่องโลหิตที่จัดส่งในแต่ละจังหวัด

ปริมาณโลหิตที่จัดส่งให้กับจังหวัดต่างๆ มีปริมาณที่แตกต่างกัน ดังนั้นทางศูนย์บริการโลหิตแห่งชาติจึงแบ่งกล่องที่จัดส่งออกเป็น 3 ขนาด คือ ขนาดเล็ก (S: 8.5 x 12 x 8.5 นิ้ว) ขนาดกลาง (M: 10 x 14.5 x 12.5 นิ้ว) และขนาดใหญ่ (L: 14 x 19 x 14 นิ้ว) ซึ่งรายละเอียดของจำนวนและขนาดกล่องโลหิตที่ได้จากการเก็บข้อมูลการจัดส่งโลหิตภายใน 6 วัน รวมถึงสถานที่จัดส่งโลหิตในแต่ละจังหวัด แสดงดังตารางที่ 1

ตารางที่ 1 สถานที่จัดส่งโลหิตและปริมาณโลหิตที่ศูนย์บริการโลหิตแห่งชาติจัดส่งใน 6 วัน (กล่อง)

จังหวัดที่จัดส่ง	ที่	โลหิตจัดส่งเดือนสิงหาคม (กล่อง/วัน)						รวม (S/M/L)
		10	14	19	20	24	28	
ขอนแก่น ⁸	ธ	1	2	1	-	1	2	7(0/1/6)
ชลบุรี ³	ว	2	2	2	2	2	2	12(7/2/3)
ชัยภูมิ	ท	1	-	1	2	-	-	4(3/1/0)
เชียงใหม่	ธ	3	2	2	-	2	3	12(7/5/0)
เชียงใหม่ ¹⁰	ธ	10	8	6	5	6	7	42(24/8/10)
นครราชสีมา ⁶	ท	2	4	3	2	2	1	14(2/2/10)
นครราชสีมา ¹¹	ค	3	3	2	3	4	1	16(4/3/9)
นครสวรรค์ ⁶	ท	2	1	1	2	2	2	10(4/0/6)
บุรีรัมย์	ท	1	-	-	1	1	-	3(1/1/1)
ประจวบ	ท	-	1	-	-	-	-	1(1/0/0)
พิจิตร	ธ	-	-	-	-	2	-	2(2/0/0)
พิษณุโลก	ธ	1	-	1	-	1	-	3(2/1/0)
พิษณุโลก ⁹	ค	3	1	4	1	1	1	11(3/2/6)
ภูเก็ต ¹²	ธ	-	1	-	-	-	-	1(1/0/0)
แม่ฮ่องสอน	ท	1	-	2	-	1	1	5(4/1/0)
ราชบุรี ⁴	ท	5	2	4	2	4	5	22(6/5/11)
ธพบูรี ²	ท	2	6	4	3	5	3	23(6/1/16)
สกลนคร	ท	-	-	1	1	1	-	3(0/3/0)
สงขลา ¹²	ธ	2	1	2	2	5	3	15(7/1/7)
สุราษฎร์ธานี	ธ	2	2	1	1	1	2	9(8/1/0)
หนองคาย	ท	1	-	3	2	-	-	6(4/2/0)
หนองบัวลำภู	ธ	-	1	-	2	-	1	4(4/0/0)
อุดรธานี	ธ	6	4	1	7	3	2	23(9/8/6)
อุบลราชธานี ⁷	ค	-	1	1	2	1	2	7(3/0/4)
รวม		48	42	42	40	45	38	255

หมายเหตุ

¹ ลำดับภาคบริการโลหิต

² สถานที่จัดส่ง: ว = วงเวียน 22, ค = ดอนเมือง, ท = หมอชิต, ธ = สุวรรณภูมิ



4.3 ต้นทุนการกระจายโลหิตแต่ละรูปแบบการจัดส่ง (Mode)

จากรูปที่ 1 รูปแบบการจัดส่งโลหิตของศูนย์บริการโลหิตแห่งชาติ สามารถคำนวณค่าใช้จ่ายในการจัดส่งโลหิตในแต่ละวันได้ 4 ประเภทการจัดส่ง คือ

1) รถตู้ของศูนย์บริการโลหิตแห่งชาติ

การคิดต้นทุนค่าใช้จ่ายรถตู้ของศูนย์บริการโลหิตแห่งชาติ สามารถแบ่งได้เป็น 4 สถานีเปลี่ยนถ่ายโลหิต คือ วงเวียน 22, สนามบินดอนเมือง สถานีขนส่งหมอชิตและสนามบินสุวรรณภูมิ โดยการใช้โปรแกรม Arc Map 9.3 ผู้วิจัยสามารถคำนวณระยะทางการจัดส่งโลหิตได้ ต้นทุนการจัดส่งคิดจาก 2 ส่วน [7] ส่วนแรก คือ ต้นทุนคงที่ (Fixed Cost) ได้แก่ ประกันภัย, ภาษีรถยนต์, ค่าต่อพรบ., ค่าตรวจสภาพรถ, ค่าซ่อมบำรุง, ค่าจ้างพนักงานและค่าเสื่อมราคา และส่วนที่สอง คือ ต้นทุนแปรผัน (Variable Cost) ได้แก่ ค่าน้ำมันเชื้อเพลิง ค่ายาง ค่าน้ำมันเครื่อง เบรก แบตเตอรี่ และค่าผ่านทางพิเศษ ผลการวิเคราะห์ค่าใช้จ่ายทั้งหมด สรุปไว้ในตารางที่ 2 จะเห็นได้ว่าต้นทุนเฉลี่ยของการจัดส่งโลหิตในแต่ละวันมีค่าที่ใกล้เคียงกันในทุกรูปแบบ ระหว่าง 3.15 – 3.50 บาท/กม./เที่ยว ค่าเฉลี่ยต้นทุนของทั้งสี่สถานีมีค่าเท่ากับ 3.35 บาท/กม./เที่ยว

ตารางที่ 2 ค่าใช้จ่ายของรถตู้จากศูนย์บริการโลหิตแห่งชาติไปยังสถานีเปลี่ยนถ่ายโลหิต

สถานีเปลี่ยนถ่ายโลหิต	ระยะทาง (กม./เที่ยว)	ต้นทุน (บาท/เที่ยว)	รวมค่าใช้จ่าย (บาท/กม./เที่ยว)
วงเวียน 22	7.12	24.91	3.50
ดอนเมือง	49.26	155.33	3.15
หมอชิต	36.02	119.88	3.33
สุวรรณภูมิ	59.86	203.44	3.40

ระยะทางทั้งไปและกลับ, ต้นทุนคงที่และต้นทุนแปรผัน

2) รถทัวร์

ศูนย์บริการโลหิตแห่งชาติ จัดส่งโลหิตกับบริษัทขนส่งต่างๆ ที่สถานีขนส่งหมอชิต ซึ่งการประเมินค่าใช้จ่ายในการจัดส่งโลหิตของรถทัวร์ใน 6 วันที่เก็บข้อมูลในเดือนสิงหาคม พ.ศ. 2553 คัดจากการเฉลี่ยน้ำหนัก (Weight Average) ตามราคาของขนาดกล่องโลหิต จากที่แสดงไว้ในตารางที่ 3 กับปริมาณกล่องโลหิตที่จัดส่งไปจังหวัดปลายทางในแต่ละวัน ตามตารางที่ 1 วิเคราะห์ได้ว่าต้นทุนการกระจายโลหิตโดยรถทัวร์จากสถานีต้นทางไปยังสถานีปลายทางมีค่า 0.45 บาท/กม./กล่อง

ตารางที่ 3 ราคาการจัดส่งกล่องโลหิตตามขนาดกล่อง

สถานีจังหวัดปลายทาง	ระยะทาง (กม.)	ราคาคาขนขนาด (บาท/กล่อง)		
		เล็ก	กลาง	ใหญ่
ชลบุรี	128.60	140	140	160
ชัยภูมิ	384.08	60	80	100

นครสวรรค์	282.06	150	150	200
บุรีรัมย์	383.37	250	250	250
ประจวบคีรีขันธ์	275.86	150	150	150
แม่ฮ่องสอน	911.39	250	250	250
ราชบุรี	107.66	60	60	60
ลพบุรี	155.49	50	70	70
สกลนคร	642.60	150	200	300
หนองคาย	615.91	200	200	250

คำนวณระยะทางระหว่างจังหวัดจากโปรแกรม Arc Map 9.3

3) เครื่องบิน

ในปัจจุบันการจัดส่งโลหิตทางเครื่องบินได้รับการ ยกเว้นค่าใช้จ่ายในการจัดส่งโลหิตจาก 2 บริษัท คือ บริษัท การบินไทย จำกัด (มหาชน) และสายการบินนกแอร์ จำกัด ทำให้ศูนย์บริการโลหิตแห่งชาติเลือกที่จัดส่งโลหิตทางเครื่องบินมากกว่าทางรถทัวร์ สำหรับภาคบริการโลหิตที่อยู่ห่างไกลจากศูนย์ฯ มากๆ เนื่องจากระยะเวลาในการจัดส่งรวดเร็ว และสามารถควบคุมอุณหภูมิได้ดีกว่า แต่ในงานวิจัยชิ้นนี้ จะวิเคราะห์ค่าใช้จ่ายทางเครื่องบินเมื่อไว้ในอนาคต ถ้าหากสายการบินใดยกเลิกการละเว้นค่าจัดส่งโลหิต ซึ่งรายละเอียดการประเมินค่าใช้จ่ายในการจัดส่งโลหิตทางเครื่องบิน แบ่งได้ 2 บริษัท ดังนี้

• บริษัท การบินไทย จำกัด(มหาชน)

จัดส่งให้กับสนามบินขอนแก่น, เชียงราย, เชียงใหม่, ภูเก็ต, สงขลา, สุราษฎร์ธานีและอุดรธานี ค่าใช้จ่าย ประกอบด้วย ค่าธรรมเนียมคลังสินค้า ราคาในการจัดส่ง (ค่าระวาง) คิดเป็นบาท/กิโลกรัม โดยการกำหนดราคาในการจัดส่งแตกต่างกันสำหรับแต่ละสนามบิน ดังแสดงไว้ในตารางที่ 4

• สายการบินนกแอร์ จำกัด

จัดส่งให้กับสนามบินนครศรีธรรมราช, อุบลราชธานีและพิษณุโลก ประกอบไปด้วยค่าใช้จ่าย 2 ส่วน คือ ราคาในการจัดส่ง 150 บาท/กล่อง และ ค่าใช้จ่ายอื่นๆ 100 บาท/รายการ

ตารางที่ 4 อัตราค่าขนส่งสินค้าทางอากาศของบริษัท การบินไทย จำกัด (มหาชน)

สนามบินต้นทาง (Origin)	สนามบินปลายทาง (Destination)	ระยะทาง (กม.)	ราคา (บาท/กก.)
สุวรรณภูมิ	ขอนแก่น	387	13
สุวรรณภูมิ	เชียงราย	678	22
สุวรรณภูมิ	เชียงใหม่	566	18
สุวรรณภูมิ	ภูเก็ต	696	22
สุวรรณภูมิ	หาดใหญ่	770	24
สุวรรณภูมิ	สุราษฎร์ธานี	552	20
สุวรรณภูมิ	อุดรธานี	457	16

ระยะทางการบิน



จากข้อมูลค่าใช้จ่ายและปริมาณโลหิตที่จัดส่งทางเครื่องบินในแต่ละวันโดยบริษัท การบินไทย จำกัด (มหาชน) และสายการบินนกแอร์ จำกัด ตามตารางที่ 1 วิเคราะห์ได้ว่าค่าใช้จ่ายในการจัดส่งโลหิตทางอากาศมีค่าเท่ากับ 0.48 บาท/กม./เที่ยว และ 0.53 บาท/กม./เที่ยว โดยบริษัท การบินไทย จำกัด (มหาชน) และสายการบินนกแอร์ ตามลำดับ ซึ่งเป็นราคาที่ใกล้เคียงกัน จึงหาค่าเฉลี่ยต้นทุนในการจัดส่งโลหิตทางเครื่องบินได้เท่ากับ 0.51 บาท/กม./เที่ยว

4) กรอบข้างในภูมิภาค

กล่องโลหิตที่ถูกจัดส่งจากศูนย์บริการโลหิตแห่งชาติ ไม่ว่าจะเป็นทางรถทัวร์หรือทางเครื่องบินจะถูกนำมาส่งไว้ที่สถานี/สนามบินปลายทาง เพื่อรอให้ทางภาคบริการโลหิต/โรงพยาบาล ในต่างจังหวัดมารับ โดยมีวิธีต่างๆ เช่น ให้รถของทางภาคบริการโลหิต/โรงพยาบาลมารับเอง หรือจ้างรถรับจ้างมารับกล่องโลหิต ซึ่งมีวิธีคิดค่าขนส่งที่แตกต่างกันไป เช่น คิดค่าจ้างแบบเป็นรายเดือน, คิดเป็นเที่ยวหรือคิดเป็นจำนวนกล่องในการขนส่ง ซึ่งในงานวิจัยครั้งนี้ เลือกตัวอย่างการจัดส่ง 9 สถาน (Sample) จากสถานที่จัดส่งทั้งหมด 48 สถาน (Population) เพื่อคิดค่าใช้จ่ายของรถรับจ้างในภูมิภาค ตารางที่ 5 แสดงผลการวิเคราะห์ค่าใช้จ่ายในการจัดส่งโลหิตของในส่วนของการรับจ้าง ค่าใช้จ่ายเฉลี่ยทั้ง 9 สถาน ที่เท่ากับ 6.24 บาท/กม./เที่ยว

ตารางที่ 5 ค่าใช้จ่ายการจัดส่งโลหิตของรถรับจ้าง

ภาคบริการโลหิต/โรงพยาบาล	ระยะทาง (กม.)	ราคาจ้าง (บาท/เที่ยว)	ค่าใช้จ่ายทั้งหมด (บาท/กม./เที่ยว)
ภาคบริการ 5	6.58	40	6.08
ภาคบริการ 6	17.52	70	4.00
ภาคบริการ 7	6.24	40	6.41
ภาคบริการ 8	10.44	100	9.58
ภาคบริการ 9	16.50	133	8.06
ภาคบริการ 10	12.82	74	5.77
ภาคบริการ 11	133.18	600	4.51
ภาคบริการ 12	13.97	75	5.37
พ.อุตรธานี	7.46	48	6.43

คำนวณระยะทางระหว่างสถานีขนส่ง/สนามบินกับภาคบริการโลหิต/โรงพยาบาลจากโปรแกรม Arc Map 9.3 (ระยะทางไป-กลับ)

4.4 ต้นทุนการกระจายโลหิต

เมื่อได้ประเมินต้นทุนในการจัดส่งกล่องโลหิตตามรูปแบบการจัดส่งทั้ง 4 ประเภท คือ 1) ต้นทุนของรถตู้จากศูนย์บริการฯ 2) รถทัวร์ 3) เครื่องบินและ 4) รถรับจ้าง ดังผลลัพธ์ที่ได้ คือ 3.35, 0.45, 0.5 และ 6.24 บาท/กม./เที่ยว ตามลำดับนำมาคำนวณต้นทุนรวมในการกระจายโลหิตจากศูนย์บริการโลหิตแห่งชาติสู่จังหวัดปลายทางโดยพิจารณาระยะทางในการจัดส่งในแต่ละวัน ซึ่งงานวิจัยนี้ศึกษาประเด็นเรื่องการหาต้นทุนรวมการจัดส่งโลหิตที่

เกิดขึ้นในปัจจุบันและต้นทุนที่แท้จริงของศูนย์บริการโลหิตแห่งชาติ เนื่องจากต้นทุนในการกระจายโลหิตในปัจจุบันได้รับการ ยกเว้น ค่าจัดส่งทางเครื่องบิน แต่ความเป็นจริงแล้วถ้าในอนาคตทางสายการบินคิดราคาในการจัดส่งโลหิต ทางศูนย์ฯจะต้องเสียค่าใช้จ่ายโลหิตที่แท้จริงเป็นจำนวนเท่าไร หากจำเป็นต้องจัดส่งโลหิตไปสนับสนุนภาคบริการโลหิต/โรงพยาบาลในภูมิภาคต่อไป

การวิเคราะห์ต้นทุนจะประเมินต้นทุนการกระจายโลหิตจากทั้ง 6 วัน ที่เก็บข้อมูล คือ วันที่ 10, 14, 19, 20, 24 และ 28 สิงหาคม พ.ศ. 2553 โดยเฉลี่ยระยะทางกับจำนวนวันในการจัดส่งโลหิตในแต่ละจังหวัดตามตารางที่ 1 เพื่อประเมินค่าใช้จ่ายในการจัดส่งโลหิตในปัจจุบันและค่าใช้จ่าย การวิเคราะห์ค่าใช้จ่ายแบ่งออกเป็น 2 ส่วน คือ ส่วนที่ 1) ค่าใช้จ่ายของศูนย์บริการฯ ประกอบไปด้วยค่าใช้จ่ายของรถส่งโลหิต, รถทัวร์และทางเครื่องบิน กับส่วนที่ 2) ค่าใช้จ่ายส่วนของภูมิภาค คือ ค่าจ้างรถรับจ้างเพื่อมารับโลหิตไปส่งสถานที่ปลายทาง ผลลัพธ์แสดงไว้ในตารางที่ 6

ตารางที่ 6 ต้นทุนค่าใช้จ่ายในการกระจายโลหิตสู่ภูมิภาค

หน่วย		ค่าใช้จ่ายการกระจายโลหิตของ		
		ศูนย์ฯ	ภูมิภาค	รวม
บาท/วัน	ปัจจุบัน	1,800	2,400	4,000
	จริง	4,000	2,400	6,400
บาท/เดือน	ปัจจุบัน	48,000	72,000	120,000
	จริง	120,000	72,000	2,280,000
บาท/ปี	ปัจจุบัน	584,000	876,000	1,460,000
	จริง	1,460,000	876,000	2,336,000

จากตารางที่ 6 พบว่าการกระจายโลหิตจากศูนย์บริการโลหิตไปสู่ปลายทางในภูมิภาค ต้องเสียค่าใช้จ่ายประมาณ 4,000 บาท/วัน หรือราว 1,460,000 บาท/ปี คิดเป็นค่าใช้จ่ายของศูนย์บริการฯ ถึง 40% ในการกระจายโลหิตในปัจจุบันทั้งหมด ซึ่งค่าใช้จ่ายนี้เป็นค่าใช้จ่ายที่ได้รับการ ยกเว้น การจัดส่งทางเครื่องบินแล้ว แต่ค่าใช้จ่ายที่แท้จริงแล้วถ้าทางสายการบินคิดค่าขนส่งของศูนย์บริการโลหิตแห่งชาติ จะมีค่าที่เพิ่มขึ้นอีกประมาณ 2,400 บาท/วัน เลยทีเดียว แต่ค่าใช้จ่ายในการกระจายโลหิตรวมทั้งหมด ไม่ว่าจะเป็นค่าใช้จ่ายในปัจจุบันหรือค่าใช้จ่ายที่แท้จริงก็นับเป็นค่าใช้จ่ายที่เพิ่มขึ้นในแต่ละปีของศูนย์บริการฯ ซึ่งเป็นค่าใช้จ่ายที่ศูนย์บริการฯ ไม่สมควรจะเสีย เพียงแต่ว่าภาคบริการโลหิตหรือโรงพยาบาลในภูมิภาคสามารถจัดหาโลหิตได้อย่างเพียงพอ

5. สรุปผลและข้อเสนอแนะ

จากการสำรวจรวบรวมข้อมูล 6 วัน ภายในเดือนสิงหาคม 2553 พบว่าการกระจายโลหิตจากศูนย์บริการโลหิตแห่งชาติไปยังภูมิภาค แบ่งเป็น 2 รูปแบบใหญ่ๆ คือ ทางบก (Land) และทางอากาศ (Air) ซึ่งปริมาณการขนส่งโลหิตมีจำนวนประมาณ 43 กล่อง/วัน จากงานวิจัยนี้แสดงผลการประเมินค่าใช้จ่ายในการกระจายโลหิตในแต่ละรูปแบบการจัดส่ง (Mode) ดังนั้นเพื่อ



ปรับปรุงประสิทธิภาพการกระจายโลหิตให้ดีขึ้น มีข้อเสนอแนะแนวทางเกี่ยวกับงานวิจัยที่จะทำในอนาคตในหลายประเด็นดังต่อไปนี้

1) ความขาดแคลนโลหิตของโรงพยาบาลในความดูแลของภาคบริการโลหิต อาจมีสาเหตุมาจากการจัดพื้นที่ความรับผิดชอบไม่เหมาะสม ปริมาณโลหิตที่จัดหาได้ (Supply) อาจไม่เพียงพอต่อความต้องการ (Demand) ใช้โลหิตของผู้ป่วยในโรงพยาบาลในพื้นที่ที่ให้บริการนั้นๆ ซึ่งการวิเคราะห์พื้นที่การให้บริการที่เหมาะสม (Service Areas) อาจทำให้ลดค่าใช้จ่ายในการกระจายโลหิตของศูนย์บริการโลหิตแห่งชาติและภาคบริการโลหิตได้

2) การที่ต้องจัดส่งโลหิตจากศูนย์กลางไปสู่ภูมิภาคเป็นระยะทางไกลๆ ดังเช่นในปัจจุบัน เป็นไปได้ว่า ท่าเลที่ตั้ง/จำนวนอาจไม่เหมาะสมต่อความต้องการโลหิตในพื้นที่จังหวัดที่รับผิดชอบ จึงทำให้เกิดความขาดแคลนโลหิต จึงต้องขอความสนับสนุนจากศูนย์บริการโลหิตแห่งชาติ อยู่ทุกๆวัน ดังนั้นการวิเคราะห์การเลือกท่าเลที่ตั้งของศูนย์บริการโลหิตแห่งชาติหรือภาคบริการโลหิตที่เหมาะสม เพื่อลดการกระจายโลหิตของประเทศ อาจทำให้เกิดมีความประหยัด ลดต้นทุนค่าใช้จ่ายในการขนส่งโลหิต และยังสามารถควบคุมคุณภาพของโลหิตได้มากขึ้น

3) บางครั้งการแก้ปัญหาอย่างยั่งยืน อาจเป็นการแก้เป็นหน้าที่พูดง่ายแต่ทำได้ยากนั่นคือ การเพิ่มปริมาณโลหิต นั้นได้จากผู้บริจาคโลหิตนั่นเอง บางที่การที่โลหิตในภูมิภาคมีปริมาณไม่เพียงพอ อาจเพราะประชากรในพื้นที่นั้นมองไม่เห็นความสำคัญของการบริจาคโลหิต หรือการประชาสัมพันธ์เพื่อเชิญชวนผู้บริจาคให้มาบริจาคโลหิตไม่ทั่วถึง จึงทำให้ผู้บริจาคโลหิตมีจำนวนน้อย ดังนั้นจึงควรประชาสัมพันธ์เพื่อเข้าถึงผู้บริจาคอย่างใกล้ชิด และผู้ที่เคยบริจาคโลหิตแล้ว ก็ควรที่รักษาให้มาบริจาคโลหิตเป็นประจำอย่างต่อเนื่อง ให้เคยชินเป็นนิสัย ซึ่งอาจจะทำให้ปริมาณโลหิตในภูมิภาคเพิ่มมากขึ้น และนี่อาจเป็นวิธีการแก้ปัญหาที่เกิดขึ้นได้อย่างยั่งยืนที่สุดก็เป็นได้

6. กิตติกรรมประกาศ

งานวิจัยนี้ได้รับความร่วมมือเป็นอย่างดีเยี่ยมจากผู้บริหารระดับสูงของศูนย์บริการโลหิตแห่งชาติ สภากาชาดไทย และขอขอบพระคุณเจ้าหน้าที่ของศูนย์ฯ ทุกท่านที่กรุณาเสียสละเวลาให้ข้อมูลในการทำการวิจัย ขอขอบคุณวิจัยแก่นักศึกษาระดับอุดมศึกษา ปีงบประมาณ 2553 จากกองทุนเพื่อส่งเสริมการอนุรักษ์พลังงาน (แผนเพิ่มประสิทธิภาพการใช้พลังงาน) สถานที่ Hardware และ Software ในการทำงานวิจัยได้รับความอนุเคราะห์จากศูนย์ผู้เชี่ยวชาญด้านระบบขนส่ง การจราจรและโลจิสติกส์ (T-LEX Center) ภาควิชาวิศวกรรมโยธาและสิ่งแวดล้อม คณะวิศวกรรมศาสตร์ มหาวิทยาลัยมหิดล

7. เอกสารอ้างอิง

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APPENDIX O

A PUBLICATION IN THE 8th NATIONAL TRANSPORT CONFERENCE

การประชุมวิชาการ การขนส่งแห่งชาติ ครั้งที่ 8
พัฒนาการขนส่งภายใต้ความเป็นเลิศทางเศรษฐกิจระดับโลก



(NTCS-046)

การวิเคราะห์หาพื้นที่การให้บริการที่เหมาะสมของภาคบริการโลหิตในประเทศไทย Optimal Service Area of Regional Blood Centers in Thailand

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บทคัดย่อ:

โครงสร้างเครือข่ายการให้บริการโลหิตในประเทศไทยเป็นแบบการกระจายจากศูนย์กลาง (Centralized blood service model) ซึ่งประกอบไปด้วย ศูนย์บริการโลหิตแห่งชาติ มีหน้าที่ให้บริการโลหิตแก่โรงพยาบาลในกรุงเทพมหานครและปริมณฑล และภาคบริการโลหิตทั้ง 12 แห่งทั่วประเทศ มีหน้าที่ให้บริการโลหิตแก่โรงพยาบาลในจังหวัดใกล้เคียง แต่สถานการณ์ปัจจุบันที่เกิดขึ้น ภาคบริการโลหิตบางแห่งไม่สามารถให้บริการโลหิตในโรงพยาบาลของพื้นที่ที่รับผิดชอบได้อย่างเพียงพอ เนื่องจากโลหิตขาดแคลน ทางโรงพยาบาลจึงจำเป็นต้องรับโลหิตจากภาคบริการโลหิตใกล้เคียง ซึ่งเป็นการเพิ่มค่าใช้จ่าย เพราะมีระยะทางการขนส่งที่เพิ่มขึ้น บทความเสนอผลการศึกษาวิเคราะห์ขอบเขตพื้นที่การให้บริการที่เหมาะสมสำหรับศูนย์บริการฯ และภาคบริการฯ ที่มีอยู่ในปัจจุบัน โดยการใช้ตัวแบบจำลองคณิตศาสตร์เป็นเครื่องมือ ผลลัพธ์รูปแบบและต้นทุนค่าขนส่งที่ได้แสดงให้เห็นว่าการจัดหาโลหิตให้พอเพียงเป็นปัจจัยสำคัญที่ช่วยลดต้นทุนการกระจายโลหิตได้อย่างมาก และที่สำคัญไม่น้อยกว่านั้น คือ การลดระยะเวลาการขนส่ง ซึ่งเป็นการควบคุมคุณภาพของโลหิตให้สอดคล้องกับมาตรฐานสากล

คำสำคัญ: โลหิต, ศูนย์บริการโลหิตแห่งชาติ, ภาคบริการโลหิตแห่งชาติ, พื้นที่การให้บริการ, โมเดลทางคณิตศาสตร์





1. บทนำ

โครงสร้างการให้บริการทางโลหิตในประเทศไทย ประกอบไปด้วย ศูนย์บริการโลหิตแห่งชาติ สภากาชาดไทย เป็นศูนย์กลาง และมีเครือข่าย คือ ภาควิชาการโลหิตแห่งชาติทั่วประเทศทั้ง 12 แห่งและสำนักงานเขตประจำจังหวัดต่างๆ มีหน้าที่จัดหาโลหิตให้เพียงพอต่อความต้องการของผู้ป่วย ซึ่งการกระจายโลหิต แบ่งได้ 2 ส่วนใหญ่ๆ ส่วนแรกกระจายโลหิตให้กับโรงพยาบาลในกรุงเทพฯและปริมณฑลผ่านทางศูนย์บริการโลหิตแห่งชาติ โดยโรงพยาบาลจะจัดรถมารับโลหิตเอง ส่วนที่สองกระจายโลหิตให้กับโรงพยาบาลในภูมิภาคทั่วประเทศ ผ่านทางภาควิชาการโลหิตทั้ง 12 แห่งและภาควิชาการโลหิตพิเศษที่จังหวัดภูเก็ต ในปีงบประมาณ 2549 [1] ปริมาณโลหิตที่ศูนย์บริการโลหิตแห่งชาติจัดหาได้ ร้อยละ 67 ใช้กับผู้ป่วยในกรุงเทพฯ และร้อยละ 33 ส่งไปสนับสนุนภาควิชาการโลหิตและโรงพยาบาลทั่วประเทศ เนื่องจากภาควิชาการโลหิตไม่สามารถจัดหาโลหิตได้เพียงพอกับการใช้ของผู้ป่วยในโรงพยาบาลที่รับผิดชอบได้ จึงจำเป็นต้องรับการสนับสนุนโลหิตจากศูนย์บริการโลหิตแห่งชาติหรือภาควิชาการโลหิตใกล้เคียง ซึ่งเป็นการเพิ่มต้นทุนการขนส่งโลหิต ซึ่งลักษณะปัญหาที่เกิดขึ้นนี้อาจมีสาเหตุมาจากการจัดพื้นที่บริการโลหิตที่ไม่เหมาะสมต่อความสามารถของการจัดหาโลหิตของภาควิชาการโลหิตนั้นๆ เพราะพื้นที่ให้บริการของภาควิชาการโลหิตมีการกำหนดไว้ล่วงหน้าโดยไม่ได้มีการวิเคราะห์ตามหลักวิชาการ ดังนั้นหากมีการศึกษาพื้นที่การให้บริการโลหิตที่เหมาะสมแล้ว อาจช่วยลดต้นทุนในการจัดส่งโลหิตและยังสามารถรักษาคุณภาพโลหิตให้ได้มาตรฐาน เพื่อผู้ป่วยที่ใช้โลหิตทุกรายอีกด้วย

2. งานวิจัยที่เกี่ยวข้อง

2.1 ใชู้ปทานของโลหิต

จุดเริ่มต้นของโลหิต คือจากผู้ป่วยบริจาคโลหิต ถ้าไม่มีผู้บริจาค ก็จะไม่เกิดผลิตภัณฑ์โลหิตต่างๆให้กับผู้ป่วย เพราะโลหิตไม่สามารถทดแทนจากส่วนอื่นได้ [2] ดังนั้นจึงต้องสร้างรักษาผู้บริจาคเอาไว้ (Retention) และให้รางวัลกับผู้บริจาค (Reward) เพื่อสร้างแรงจูงใจในการบริจาคโลหิต [3] แต่บางครั้งผู้บริจาคโลหิตมีจำนวนลดลง เพราะมีความเชื่อที่ผิดๆในการบริจาคและถ่ายโลหิต [4] ส่งผลให้โลหิตไม่เพียงพอจึงต้องมีการนำเข้าโลหิตเพิ่มเติม เช่น ในประเทศอิตาลี ประเทศสกอตแลนด์ และแอฟริกาใต้ เป็นต้น [5] เมื่อได้โลหิตแล้วมีการตรวจโลหิต จัดเก็บตามอุณหภูมิที่เหมาะสม และกระจายให้กับโรงพยาบาลเพื่อนำไปใช้กับผู้ป่วย การกระจายในประเทศไทยใช้ขนส่งสาธารณะ เช่น รถทัวร์ รถตู้และเครื่องบิน ซึ่งในประเทศไทยการศึกษาเรื่องการกระจายโลหิตยังมีน้อย แต่ในต่างประเทศมีงานวิจัยบ้างแล้ว เช่น สภากาชาดอเมริกา มีการปรับปรุงตารางเวลา/สถานที่การเจาะและศึกษาเส้นทางการกระจายโลหิต ในบริเวณมิดแอตแลนด์ติกให้เหมาะสมที่สุด [6] ซึ่งการจัดการกระจายโลหิตในประเทศไทยที่เหมาะสมจะช่วยควบคุมคุณภาพโลหิตได้ และยังสามารถยกระดับคุณภาพชีวิตผู้ป่วยที่ใช้โลหิตให้ดียิ่งขึ้น

2.2 ภาควิชาการโลหิตและพื้นที่ในการให้บริการ

กระทรวงสาธารณสุขมีนโยบายจัดตั้งภาควิชาการโลหิตกระจายไปตามภูมิภาค ตั้งแต่ปีงบประมาณ 2539 จำนวน 12 ภาคและภาควิชาการพิเศษที่ จ.ภูเก็ต ซึ่งปัจจุบันดำเนินการจัดตั้งเรียบร้อยแล้ว ยกเว้นภาควิชาการที่ 1 ยังไม่มีแนวโน้มที่จะจัดตั้งแต่อย่างใด ทำหน้าที่เป็นศูนย์กลางของการดำเนินงานในการให้บริการโลหิตโดยใช้ขั้นตอนและวิธีการเดียวกันกับศูนย์บริการโลหิตแห่งชาติ [1] โดยตำแหน่งที่ตั้งภาควิชาการและพื้นที่บริการ ดังตารางที่ 1

การประชุมวิชาการ การขนส่งแห่งชาติ ครั้งที่ 8

พัฒนาการขนส่งหลายรูปแบบสู่ความเป็นเลิศทางเศรษฐกิจระดับโลก



ตารางที่ 1 ตำแหน่งและพื้นที่รับผิดชอบของภาคบริการโลหิต

ภาคบริการฯ	จังหวัดรับผิดชอบในการบริการโลหิต
ภาค 1	พระนครศรีอยุธยา, นนทบุรี, ปทุมธานี, สมุทรปราการ, อ่างทอง
ภาค 2	สระบุรี, ชัยนาท, นครนายก, ลพบุรี, สิงห์บุรี, สุพรรณบุรี
ภาค 3	ชลบุรี, ฉะเชิงเทรา, ระยอง, จันทบุรี, ตราด, ปราจีนบุรี, สระแก้ว
ภาค 4	นครปฐม, สมุทรสาคร, สมุทรสงคราม, ราชบุรี, เพชรบุรี, กาญจนบุรี, ประจวบคีรีขันธ์
ภาค 5	นครราชสีมา, บุรีรัมย์, สุรินทร์, ชัยภูมิ, มหาสารคาม, ศรีสะเกษ
ภาค 6	อุดรธานี, ขอนแก่น, สกลนคร, หนองคาย, หนองบัวลำภู, เลย
ภาค 7	นครพนม, อุบลราชธานี, มุกดาหาร, ร้อยเอ็ด, ยโสธร, อำนาจเจริญ, กาฬสินธุ์
ภาค 8	กำแพงเพชร, นครสวรรค์, อุทัยธานี, สุโขทัย, ตาก
ภาค 9	พิษณุโลก, พิจิตร, เพชรบูรณ์, อุตรดิตถ์,แพร่, น่าน
ภาค 10	เชียงใหม่, ลำพูน, ลำปาง, พะเยา, เชียงราย, แม่ฮ่องสอน
ภาค 11	ชุมพร, สุราษฎร์ธานี, ระนอง, นครศรีธรรมราช, พังงา, ภูเก็ต, กระบี่
ภาค 12	สงขลา, สตูล, พัทลุง, ตรัง, ปัตตานี, ยะลา, นราธิวาส

ที่มา: รายงานประจำปี 2548 ศูนย์บริการโลหิตแห่งชาติ สภากาชาดไทย
'ยังไม่มีบริการตั้งภาคบริการโลหิต, "จังหวัดที่มีภาคบริการโลหิตตั้งอยู่'

3. เปรียบเทียบวิธีวิจัย

3.1 ตัวแบบจำลองคณิตศาสตร์

งานวิจัยนี้วิเคราะห์รูปแบบการจัดส่งโลหิตจากภาคบริการฯ สู่จังหวัดให้เหมาะสม โดยพิจารณาต้นทุนค่าใช้จ่ายที่ต่ำที่สุดของระบบ จากปัญหาที่เกิดขึ้นโดยรวม เห็นว่าโมเดลทางคณิตศาสตร์ขนส่งเหมาะที่จะใช้แก้ปัญหาที่เกิดขึ้น [7] ซึ่งมีรายละเอียดของแบบจำลองดังนี้

Parameter

S_i = ปริมาณโลหิตที่จัดหาได้ที่ภาคบริการโลหิต i (หน่วย)

D_j = ปริมาณความต้องการโลหิตที่จังหวัด j (หน่วย)

C_{ij} = ต้นทุนการจัดส่งโลหิตจากภาคบริการโลหิต i ไปจังหวัด j ที่รับบริการโลหิต วัดแทนด้วยระยะทาง(กิโลเมตร)

Decision Variables

X_{ij} = ปริมาณโลหิตที่ทำการขนส่งจากภาคบริการโลหิต i ไปยังจังหวัดที่รับบริการโลหิต j (หน่วย)

Mathematical Formulation

Minimize
$$\sum_i \sum_j C_{ij} X_{ij} \quad (1)$$

Constraints
$$\sum_j X_{ij} \leq S_i \quad ; \forall_i \quad (2)$$

$$\sum_i X_{ij} \geq D_j \quad ; \forall_j \quad (3)$$

$$X_{ij} \geq 0 \quad ; \forall_{i,j} \quad (4)$$

ฟังก์ชันวัตถุประสงค์ (1) ต้องการให้รูปแบบการขนส่งจากภาคบริการฯ ไปยังจังหวัดที่รับบริการโลหิต มีต้นทุนค่าขนส่งรวมทั้งระบบที่ต่ำที่สุด เงื่อนไข (2) กำหนดให้ปริมาณโลหิตที่ถูกจัดส่งของภาคบริการฯ ใดๆ ต้องไม่เกินปริมาณโลหิตที่จัดหาได้ เงื่อนไข (3) กำหนดให้ทุกจังหวัดที่รับบริการ ต้องได้รับปริมาณโลหิตเพียงพอกับปริมาณความต้องการ เงื่อนไข (4) คือปริมาณโลหิตที่จัดส่งจากภาคบริการโลหิตไปยังจังหวัดที่รับบริการต้องไม่ติดลบ

ซึ่งงานวิจัยนี้ได้เพิ่ม Dummy Location ที่จังหวัดที่รับบริการเพื่อให้เกิดความสมดุล เนื่องจากปริมาณโลหิตที่ภาคบริการโลหิตจัดหาได้ (S_i : Supply) มีมากกว่าปริมาณความต้องการโลหิตของแต่ละจังหวัดที่รับบริการ (D_j : Demand) ดังนั้นเพื่อให้แบบจำลองสามารถหาคำตอบได้เสมอจึงได้เพิ่ม Dummy Location ไว้ในโมเดลด้วย



3.2 สมมุติฐาน

เนื่องจากงานวิจัยนี้ต้องการวิเคราะห์พื้นที่ที่รับผิดชอบของภาคบริการโลหิตในแต่ละแห่งให้เหมาะสมโดยสันนิษฐานว่าการจัดหาโลหิตให้พอเพียงเป็นปัจจัยสำคัญที่ช่วยลดต้นทุนการกระจายโลหิตได้อย่างมาก ดังนั้นจึงกำหนดให้ภาคบริการโลหิตทั้งหมดมีความสามารถในการบริการในระดับที่เท่ากัน และมีความสามารถในการจัดหาโลหิตได้อย่างไม่จำกัด (Supply)

3.3 ข้อมูล

งานวิจัยนี้ได้ใช้ข้อมูลจากรายงานประจำปีงบประมาณ 2548 ของศูนย์บริการโลหิตแห่งชาติ [1] เป็นข้อมูลตัวอย่างในการวิเคราะห์รูปแบบการกระจายโลหิต ซึ่งประกอบไปด้วย

- 1) ข้อมูลการเบิก-จ่ายโลหิต ของศูนย์บริการโลหิตฯ ภาคบริการโลหิตและโรงพยาบาลต่างๆ ในปีงบประมาณ 2548
- 2) ทำเลที่ตั้งศูนย์บริการฯ/ภาคบริการโลหิตทั้ง 11 แห่ง
- 3) พื้นที่ในการให้บริการโลหิตของภาคบริการโลหิต
- 4) ตำแหน่งจังหวัดที่รับบริการ ในที่นี้พบว่าบริเวณที่ใช้โลหิตเป็นจำนวนมากคือ รพ.ศูนย์หรือรพ.ประจำจังหวัด ซึ่งส่วนมาก ตั้งอยู่ในอำเภอเมือง ดังนั้นจึงสมมุติให้ตำแหน่งจังหวัดที่ต้องการรับบริการโลหิตอยู่บริเวณอำเภอเมืองของทุกจังหวัด

3.4 การรวบรวมข้อมูล

เพื่อแทนค่าพารามิเตอร์ของแบบจำลองคณิตศาสตร์ที่ใช้วิจัย ข้อมูลที่รวบรวมได้แบ่งออกเป็น 3 ส่วน ดังนี้

- 1) ปริมาณโลหิตที่ภาคบริการโลหิตจัดหาได้ (S_j)
จากสมมุติฐานที่ภาคบริการฯสามารถจัดหาโลหิตได้เพียงพอต่อความต้องการและไม่จำกัด ดังนั้นในงานวิจัยนี้จึงแทนปริมาณโลหิตที่ภาคบริการฯแต่ละแห่งที่สามารถจัดหาได้ เท่ากับ 1,000,000 หน่วย/ปี

2) ปริมาณการใช้โลหิตในจังหวัดที่รับบริการ (D_j)

ปริมาณความต้องการโลหิตได้จากรายงานประจำปีงบประมาณ 2548 [1] คือ ปริมาณโลหิตรวมทั้งใช้เองทั้งปี ประกอบไปด้วย ปริมาณโลหิตที่ใช้กับผู้ป่วยและปริมาณโลหิตที่ถูกจำหน่าย

3) ระยะทางการจัดส่งโลหิตจากภาคบริการโลหิตไปจังหวัดที่รับบริการ (C_{ij})

คำนวณระยะทางการจัดส่งโลหิตจากภาคบริการโลหิตไปจังหวัดที่รับบริการ โดยใช้โปรแกรม ArcMap 9.3 จากข้อมูลด้านเส้นทางคมนาคม (Transport Fundamental Geographic Data Set: Transport FGDS) [8]

เมื่อรวบรวมค่าพารามิเตอร์ต่างๆครบแล้ว ใช้โปรแกรม Visual Basic 2005 เขียนตัวแบบจำลองคณิตศาสตร์ หลังจากนั้น แก้ปัญหาตัวแบบด้วยโปรแกรม LINDO 6.01 เพื่อหาผลลัพธ์

3.5 การวิเคราะห์ข้อมูล

นำผลลัพธ์ที่ได้มาวิเคราะห์ความเปลี่ยนแปลงพื้นที่การให้บริการของภาคบริการโลหิตในแต่ละแห่ง ว่าเหมาะสมเพียงใด โดยพิจารณาความสัมพันธ์ระหว่างระยะทางการจัดส่งโลหิตจากภาคบริการฯถึงพื้นที่ที่รับผิดชอบ ซึ่งรูปแบบการกระจายโลหิต แสดงโดยโปรแกรม ArcMap 9.3 ในรูปแบบแผนที่ เพื่อแสดงพื้นที่การให้บริการของภาคบริการโลหิตแต่ละแห่ง

4. ผลลัพธ์

ผลลัพธ์ที่ได้จากการแก้ปัญหา พบว่ารูปแบบการจัดส่งโลหิตที่ต้นทุนรวมต่ำที่สุด แสดงดังภาพที่ 1 ซึ่งงานวิจัยนี้ได้พิจารณาพื้นที่รับผิดชอบในการจัดหาโลหิตและปริมาณโลหิตที่แต่ละภาคบริการฯ ควรจัดหาไว้อย่างน้อยที่สุด (Minimum Supply)



ภาพที่ 1 รูปแบบการจัดส่งโลหิตที่มีต้นทุนค่าขนส่งรวมต่ำที่สุด

จากผลลัพธ์ที่ได้ ส่งผลให้จำนวนพื้นที่การให้บริการโลหิตของแต่ละภาคบริการเปลี่ยนแปลงไปจากเดิม เช่น จากตารางที่ 1 ภาคบริการที่ 2 มีพื้นที่รับผิดชอบ 6 จังหวัด คือ สระบุรี, ชัยนาท, นครนายก, ลพบุรี, สิงห์บุรี และ สุพรรณบุรี แต่หลังจากวิเคราะห์ระยะทาง, ปริมาณความต้องการและปริมาณที่จัดหาได้ของโลหิต จากโมเดลทางคณิตศาสตร์แล้ว ภาคบริการที่ 2 ควรให้บริการเพียง 5 จังหวัดเท่านั้น คือ อุดรธานี, ลพบุรี, สิงห์บุรี, สุพรรณบุรี และ อ่างทอง ซึ่งเป็นจังหวัดที่อยู่ใกล้กันมีความเหมาะสม (Optimal Solution) กว่าแบบเดิม และเมื่อพิจารณาปริมาณโลหิต ในตารางที่ 2 พบว่าภาคบริการที่ 6 มีจำนวนจังหวัดในพื้นที่รับผิดชอบมากที่สุดถึง 10 จังหวัด มีความต้องการโลหิต 130,442 หน่วย/ปี เมื่อเปรียบเทียบกับศูนย์บริการโลหิต มีจำนวนจังหวัดในพื้นที่รับผิดชอบ 9 จังหวัด แต่มี

ความต้องการโลหิตถึง 525,360 หน่วย/ปี ซึ่งมีพื้นที่รับผิดชอบน้อยกว่าเพียง 1 จังหวัดแต่มีความต้องการโลหิตที่มากกว่าถึง 4 เท่า ดังนั้น ตารางที่ 2 อาจเป็นแนวทางในการกำหนดระยะทางและปริมาณโลหิตที่เหมาะสมสำหรับการกระจายโลหิตที่ต้นทุนการขนส่งต่ำที่สุดก็เป็นได้

ภาพรวมระยะทางการจัดส่งโลหิต แสดงดังตารางที่ 2 พบว่าระยะทางการจัดส่งโลหิตโดยเฉลี่ยมีค่าเท่ากับ 60.92 กม. ซึ่งระยะทางที่น้อยที่สุดในการจัดส่งอยู่ที่ศูนย์บริการฯ และระยะทางที่มากที่สุดอยู่ที่ภาคบริการที่ 11 ซึ่งมีค่า 9.01 และ 298.6 กม. ซึ่งเป็นค่าที่มีความแตกต่างค่อนข้างมาก เพราะเมื่อพิจารณาจากสภาพภูมิประเทศแล้วศูนย์บริการฯ ตั้งอยู่ที่กรุงเทพฯ ที่ตั้งของแต่ละจังหวัดจะไม่ไกลกันนัก โดยเฉลี่ยแล้วประมาณ 24.69 กม. ซึ่งแตกต่างจากภาคบริการที่ 11 ตั้งอยู่ที่ อ.ทุ่งสง จ.นครศรีฯ อยู่ไกลจากบริเวณพื้นที่ของรพ.ที่รับบริการ ซึ่งงานวิจัยนี้กำหนดให้ตั้งอยู่บริเวณอำเภอเมืองของทุกจังหวัด และเมื่อพิจารณาปัจจัยทางภูมิศาสตร์พบว่าภาคใต้มีลักษณะเป็นคาบสมุทร ทำให้จังหวัดต่างๆ ทางภาคใต้วางตัวยาว มีระยะทางที่มากขึ้น ซึ่งระยะทางโดยเฉลี่ยเท่ากับ 142.63 กม.

ที่ตั้งของภาคบริการฯ ส่วนมากจะตั้งอยู่บริเวณอำเภอเมือง ซึ่งเป็นส่วนมากเป็นบริเวณที่เจริญแล้ว จะมีรพ.ขนาดใหญ่ (รพ.ศูนย์หรือรพ.มหาราช) ซึ่งเป็นรพ.ที่มีกำลังในการรักษาผู้ป่วยได้เป็นจำนวนมากไว้คอยให้บริการประชาชน โดยรพ.เหล่านี้ต้องการโลหิตเป็นจำนวนมาก ดังนั้นจึงสังเกตได้ว่าภาคบริการฯ ที่มีส่วนใหญ่อะไรจะตั้งในแหล่งชุมชนเพื่อความสะดวกหลายๆ อย่าง เช่น มีระยะทางในการจัดส่งโลหิตให้กับทางรพ.ที่ใกล้ การเข้าถึงชุมชนเพื่อการจัดหาและการประชาสัมพันธ์โลหิต เป็นต้น จากตารางที่ 2 พบว่าระยะทางที่น้อยที่สุดของทุกภาคบริการจะมีค่าไม่แตกต่างกันมากนัก ยกเว้นภาคบริการที่ 11 และ 12 เนื่องจากมีที่ตั้งอยู่ใน อ.ทุ่งสงและ อ.หาดใหญ่ จึงทำให้มีระยะทางในการจัดส่งมากกว่าปกติ แตกต่างจากภาคบริการอื่นๆ



ตารางที่ 2 ระยะทางการจัดส่งโลหิตจากภาคบริการไป
จังหวัดที่รับบริการโลหิต

ศูนย์/ ภาค	พท. บริการ	จน.โลหิต (หน่วย/ ปี)	ระยะทาง (กิโลเมตร)			
			Min	Mean	Max	S.D.
ศูนย์	9	525,360	9.01	24.69	161.93	55.06
ภาค 2	5	56,281	7.81	42.23	86.71	30.18
ภาค 3	4	90,427	12.43	57.21	235.00	98.51
ภาค 4	6	74,433	5.35	58.68	215.21	74.11
ภาค 5	3	79,692	1.50	46.91	190.02	95.36
ภาค 6	10	130,442	8.35	100.37	207.69	60.35
ภาค 7	7	82,267	9.90	92.49	262.06	85.59
ภาค 8	3	36,180	6.05	20.96	62.01	28.03
ภาค 9	8	104,442	4.39	97.27	180.02	58.47
ภาค 10	7	145,547	3.69	94.94	290.15	105.53
ภาค 11	6	74,274	58.31	142.63	298.60	87.71
ภาค 12	5	60,479	24.32	69.69	197.52	62.06
ภาค พิเศษ	3	20,495	4.72	64.20	291.30	146.83
รวม	76	1,480,292	1.50	60.92	298.60	76.18

จำนวนจังหวัด

5. สรุปผลและข้อเสนอแนะ

จากการวิเคราะห์โครงข่ายการให้บริการโลหิตในประเทศไทยที่ผ่านมามีข้อปรับปรุงในการกระจายโลหิตให้ดีขึ้น โดยยกตัวอย่างตามข้อเสนอแนะต่อไปนี้

1) การที่ต้องจัดส่งโลหิตจากศูนย์กลางไปสู่ภูมิภาคเป็นระยะทางไกลๆ อาจเป็นไปได้ว่า ทำเลที่ตั้ง/จำนวนอาจไม่เหมาะสมต่อความต้องการโลหิตในพื้นที่จังหวัดที่รับผิดชอบ จึงทำให้เกิดความขาดแคลนโลหิต จนต้องขอความช่วยเหลือจากศูนย์บริการโลหิตแห่งชาติ อยู่ทุกๆ วัน ดังนั้นการวิเคราะห์การเลือกทำเลที่ตั้งของศูนย์บริการโลหิตแห่งชาติหรือภาคบริการโลหิตที่เหมาะสม เพื่อลดการกระจายโลหิตของประเทศ อาจทำให้เกิดมีความประหยัด ลดต้นทุนค่าใช้จ่ายในการขนส่งโลหิต และยังสามารถควบคุมคุณภาพของโลหิตได้มากขึ้น

2) บางครั้งการแก้ปัญหาอย่างยั่งยืน อาจเป็นการแก้เป็นหาที่พูดคุยแต่ทำได้ยากนั้นคือ การเพิ่มปริมาณโลหิตนั้นได้จากผู้บริจาคโลหิตนั่นเอง ในบางพื้นที่นั้นประชากรอาจมองไม่เห็นความสำคัญของการบริจาคโลหิต ดังนั้นการประชาสัมพันธ์เพื่อเชิญชวนผู้บริจาคให้มาบริจาค จะทำให้ผู้บริจาคโลหิตมีจำนวนเพิ่มมากขึ้น ดังนั้นจึงควรประชาสัมพันธ์เพื่อเข้าถึงผู้บริจาคอย่างใกล้ชิด และผู้ที่เคยบริจาคโลหิตแล้ว ก็ควรที่รักษาให้มาบริจาคโลหิตเป็นประจำอย่างต่อเนื่อง ให้เคยชินเป็นนิสัย ซึ่งอาจจะทำให้ปริมาณโลหิตในภูมิภาคเพิ่มมากขึ้น และนี่อาจเป็นวิธีการแก้ปัญหาที่เกิดขึ้นได้อย่างยั่งยืนที่สุดก็เป็นได้

กิตติกรรมประกาศ

งานวิจัยนี้ได้รับความร่วมมือเป็นอย่างดีเยี่ยมจากผู้บริหารระดับสูงและเจ้าหน้าที่ของศูนย์บริการโลหิตแห่งชาติ สภากาชาดไทย ทุกท่านที่กรุณาเสียสละเวลาให้ข้อมูลในการทำวิจัย โครงการวิจัยนี้ได้รับการสนับสนุนจากสำนักงานคณะกรรมการอุดมศึกษา (สกอ.) และมหาวิทยาลัยมหิดลภายใต้โครงการมหาวิทยาลัยวิจัยแห่งชาติ สถานที่และเครื่องมือในการทำงานวิจัยได้รับความอนุเคราะห์จากศูนย์ผู้เชี่ยวชาญด้านระบบขนส่ง การจราจร และโลจิสติกส์ (T - LEX Center) ภาควิชาวิศวกรรมโยธา และสิ่งแวดล้อม คณะวิศวกรรมศาสตร์ มหาวิทยาลัยมหิดล

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การประชุมวิชาการ การขนส่งแห่งชาติ ครั้งที่ 8

พัฒนาการขนส่งทางรูปแบบสู่ความเป็นเลิศทางเศรษฐกิจระดับโลก



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เกี่ยวกับผู้เขียน

	นางสาวพรชนก โพธิ์บัณฑิตย์ <u>ประวัติการศึกษา</u> ปริญญาตรี : สำเร็จการศึกษา สาขาเทคโนโลยีการจัดการอุตสาหกรรม คณะวิศวกรรมศาสตร์และเทคโนโลยีการจัดการอุตสาหกรรม มหาวิทยาลัยศิลปากร ปริญญาโท : กำลังศึกษา สาขาวิศวกรรมอุตสาหกรรม คณะวิศวกรรมศาสตร์ มหาวิทยาลัยมหิดล <u>งานวิจัยที่สนใจ</u> สนใจงานทางด้าน Logistics Supply Chain Management เน้นศึกษาเรื่องงานบริหารโลจิสติกส์

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APPENDIX P
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**Analyzing and re-designing the locations of regional blood centers
for better supply chain of blood in Thailand**

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Abstract

This research is aimed to study, analyze and re-design the logistics of blood distribution at the regional level in the Kingdom of Thailand. Presently, the distribution network consists of one national blood center (NBC) and twelve regional blood centers (RBCs). The network was initially designed such that the RBC would be self-sufficient source of blood supply for its responsible provinces. However, the number of donors fell short at most RBCs. The NBC now has to distribute about 40% of its collected blood to supply those RBCs and many regional hospitals. As a result, the distribution system is of the hub-and-spoke network where the NBC acts as the hub and the RBCs are the spokes distributing blood to their surrounding hospitals. However, such a long-distant and several-hour transportation causes problems and much concerns regarding the quality of blood and costs. This research then re-designs the locations of RBCs and their allocation patterns by using the location-and-allocation optimization-based model. The comparison of system cost performance between the current and re-designed configuration is reported. It shows that the re-designed network can significantly improve the efficiency of blood distribution, especially the ability to fulfill the blood demand at the more reasonable costs.

Keywords: Blood, Regional Blood Center, Location, Allocation, Mathematical model

1. Introduction

Location is a prime factor contributing to the success of the operation for both private and public sectors. The location of regional blood centers (RBCs) is no exception. Blood is a very special product for being a living thing and easily perishable product (Federgruen et al., 1985). Blood is very sensitive to the change of the surrounding temperature which can cause blood degrading. As the temperature control is not standardized for all kinds of blood products and the travel time is highly variable, usually longer than expected, the location of RBC has become even more crucial. Not only locating RBCs at the right place saves the operating cost, but also guarantees the quality of blood. In other words, it helps save lives too.

Analyses of the appropriate locations usually take into account several viewpoints. It may include inventory and transport cost cuts by finding proper locations for distribution centers (Nozick and Turnquist, 1998). To reinforce the strength of the location, it can be done by providing all necessary public utilities, hospitals, police stations, fire stations and public terminals, etc (Taniguchi et al., 1999). In this paper, we present the results from the analysis of optimal locations for RBCs in the Kingdom of Thailand. The paper also discusses about the blood service in Thailand, blood supply chain, RBC location and the distribution network as well as the relevant issues.

The rest of the paper is organized as follows. After this introduction section, in Section 2, the blood service system in Thailand and its logistics issues are briefly explained. Section 3 describes research methodology focusing on mathematical models, data description and case studies. Results and discussion on the regional blood distribution network are followed in Section 4. Finally, conclusions are drawn in Section 5.

2. Literature review

2.1 Description of blood service system in Thailand

Thailand is located in Southeast Asia, covering an area of 513,115 km² or about the size of Spain. The number of population is approximately 64 million, slightly more than the number of French population. Thailand is administered into 76 provinces. The capital city is Bangkok where the National Blood Center (NBC) is located. The NBC is a non-profit and non-governmental organization. The structure of blood service network in Thailand is a kind of decentralized (Britten, 1992) with the head

quarter at the NBC. The NBC established regional blood centers (RBCs) in 12 important provinces, as the distribution centers for provinces nearby. Note that the designated RBC 1 at Ayutthaya province has not been established. The NBC has a plan to establish it when the budget is made available. The RBC at Phuket is usually called the special one due to its designated full function similar to the NBC. It was established in 2009 with the financial support from the Finnish Red Cross (NBC, 2010) following the first-ever Tsunami disaster in Thailand on 26 December 2004 when a number of people were injured and killed. Coincidentally, some of the victims were Scandinavian tourists. Figure 1 shows the locations of all 12 RBCs together with their respective service provinces on the map of Thailand. Geographically speaking, the locations seem to spread rather well all over the country.

These current RBCs' locations are simply followed the administrative districts designated by the Ministry of Interior for the sake of easy budgeting and personnel management. It is also convenient for organizations in charge to operate RBCs accordingly. These reasons, however, are not very beneficial to blood service and, consequently, lead to several problems. Notably, the blood supply from these RBCs cannot fulfill the demand for blood in their own service provinces. This essentially results in unnecessarily long distance and too expensive for transporting blood from another RBC or NBC. Perhaps, the quality control of blood is an even bigger issue since blood is a highly sensitive product. Various types of blood products do require different temperature control. It is really hard to consistently keep the temperature at check over the long distance without incurring high cost. All these issues raise the questions of whether the current numbers and locations of RBCs are the best for Thai society.

2.2 Blood supply chain at the regional level

Fundamentally, each blood unit delivered to patients is supposed to be processed as follows. Firstly, blood donors are preliminarily triaged by measuring their blood pressure and density. Preliminary health check-up is also required. Then the donors are registered and the blood is collected. Afterwards, the blood is examined to see if there is any blood-transmitted disease in it and is processed as blood components, stored at the blood bank under controlled temperature suitable for each blood product and be ready for distribution. Blood is withdrawn when there is an inquiry approved by a doctor from the hospital. The inquiry must provide details of the patient, type, amount, date of use, and a sample of patient's blood to the respective blood bank in order to allow for blood cross-matching. This procedure is meant to

prevent any incompatibility between donor's and the patient's blood that could threaten the life of the patient (Prastacos, 1984; Sapountzis 1984; Rytla and Spens 2006; National Blood Center, 2007; Canadian Blood Service, 2007; Japanese Red Cross Society, 2007, Delen et al, 2009). Figure 2 illustrated blood supply chain.

Literally, blood supply chain in Thailand is classified into two tiers. First, it is the distribution to hospitals in Bangkok metropolitan region (BMR). This tier is essentially a pick-up service in the logistics sense. The hospital who requesting the blood needs to dispatch a vehicle to pick it up at the NBC. The NBC only charges the hospital for blood processing and operation costs, not the blood itself since it was donated voluntarily. Therefore, the transportation cost is wholly on the hospitals.

Second, it is the distribution in regional areas beyond the BMR, using RBCs as the distribution centers for hospitals in their respective service provinces. Initially, the RBCs were designed to provide comprehensive blood service for the hospitals in their respective provinces just like the NBC does in Bangkok. The RBC indeed should be able to perform blood donor recruitment, blood collection, infectious disease marker screening, component preparation, inventory maintenance and delivery of blood and blood components to hospitals. However, the recruitment of blood donors in the regions is not as effective as in the capital city. The blood supply at several RBCs fall short below the target very much. The NBC inevitably has to transport about 40% of its own collected blood to RBCs and hospitals around the country. Such blood delivery sometimes takes more than a day. The situation has been persistent until it has become the common practice till now. This causes excessive logistics cost to the NBC including extra staff hiring, cost of packaging, and transport service hiring. Furthermore, it creates major concerns regarding the quality of blood after very long distance and time on the public transport modes.

This paper covers only blood distribution at the regional level or the second tier. Previous studies suggest that blood distribution problems have been one of the concerns in many countries for decades. Blood distribution needs strictly controlled temperature in order to maintain the quality of blood. NBC randomly checks the temperature of blood bags in the blood boxes distributed to RBCs using data loggers to record the temperature during transport. They expected to use the temperature data to improve blood distribution system (Chiewsilp et al, 2007). However, the

devices used are not automatic like Radio-Frequency IDentification (RFID) sensory devices used in other countries. Those tools can send short message (or SMS) via global system for mobile (GSM) phone communications whenever there is something wrong with blood units. This is meant to prevent blood degrading during the transport (Kim et al, 2007; Lv et al, 2009). Austrian Red Cross used simulation system to analyze blood distribution and schedule emergency vans (Koch and Weigl, 2003). As expected, the results indicated that the shorter it takes in transport, the better is the quality of blood. Therefore, American Red Cross has reconsidered its schedule and location for blood collection, as well as transport routes in the Mid-Atlantic (Virginia and North Carolina) by using integer programming model (Jacobs et al, 1996). On the other hand, Turkey has studied the blood services considering the number of blood banks, with the lowest resources needed in both establishment and transport. Cetin and Sarul (2009) used set covering, center of gravity method and binary nonlinear goal programming to solve the mathematical problem. The overall blood services in Turkey are based on optimal location management of regional centers, RBCs, collection stations, and fleet of mobile units. It can be concluded that blood distribution problems are hierarchical in nature which can be solved by the pq-median location model, set covering model and integer programming model (Sahin et al, 2005).

As described earlier, the RBC locations in Thailand were not technically designed, but mainly located in the administrative zones designated by the Ministry of Interior. There are always questions whether the current distribution network is right from the perspective of both number, location and service area. It was thought that the inappropriate RBC locations perhaps contribute partly to the current problems. This research takes this question to study in depth, analyze the situation and re-design the distribution network by employing the quantitative methods.

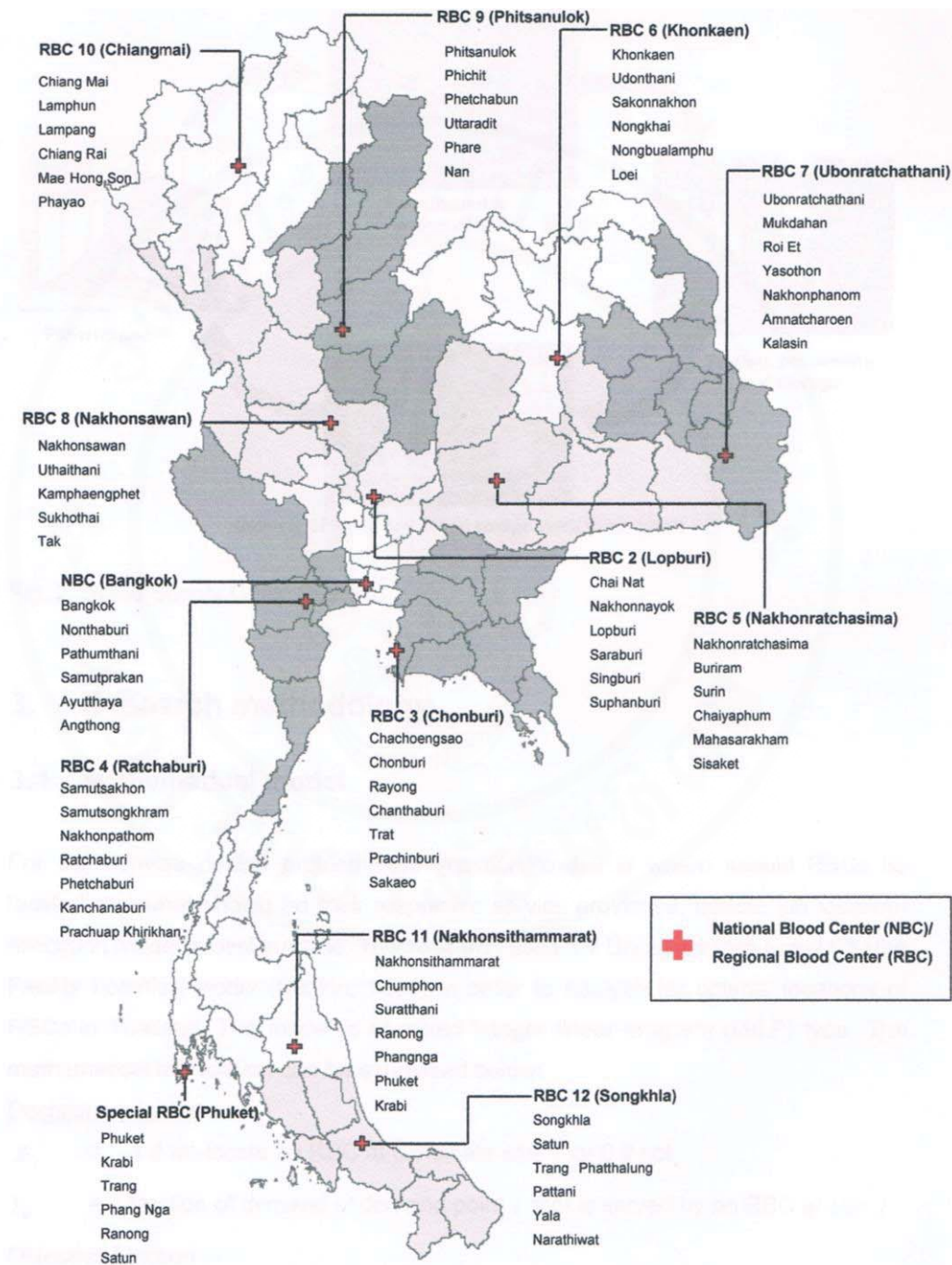


Fig. 1: Current blood centers and respective service areas in Thailand

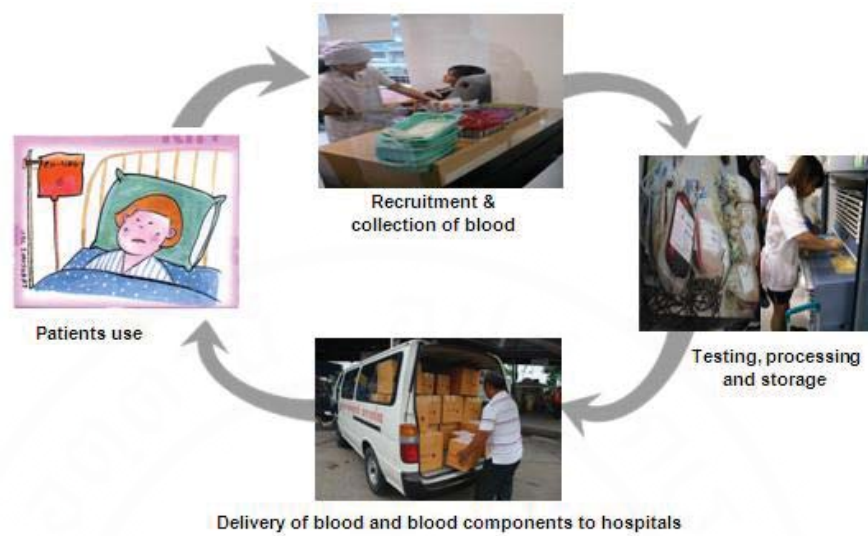


Fig. 2: Blood supply chain system

3. Research methodology

3.1 Mathematical model

For our network design problem, the question to ask is where should RBCs be located and what should be their respective service provinces; hence, the location-allocation model is best suitable. This research uses the Uncapacitated Fixed Charge Facility Location model (Daskin, 1995) in order to analyze for optimal locations of RBCs in Thailand. The model is of the mixed integer linear program (MILP) type. The mathematical formulation can be expressed below:

Decision variables

X_j = 1 if we locate an RBC at candidate site j or 0 if not

Y_{ij} = fraction of demand at demand point i that is served by an RBC at site j

Objective function

$$\text{Minimize} \quad \sum_j f_j X_j + \alpha \sum_i \sum_j h_i d_{ij} Y_{ij} \quad (1)$$

Subject to

$$\sum_j Y_{ij} = 1 \quad \forall i \quad (2)$$

$$Y_{ij} \leq X_j \quad \forall i, j \quad (3)$$

$$X_j = 0, 1 \quad \forall j \quad (4)$$

$$Y_{ij} \geq 0 \quad \forall i, j \quad (5)$$

The objective function in (1) is aimed to minimize the total system cost which is the summation of the two cost components. First, it is the total fixed costs for locating RBCs. Second, it is the total demand point-weighted distance multiplied by the cost per unit distance per unit blood demand. It is subject to the constraints (2) – (5).

Constraint (2) stipulates that each demand point i must be served. Constraint (3) says that demands at demand point i cannot be assigned to the RBC at candidate site j unless we locate an RBC at node j . Meanwhile, constraints (4) impose the integrality condition on the location variable X_j . Non-negativity is specified in constraint (5).

Implicitly, we have made an assumption that all RBCs can provide the same level of service as the NBC does. This is the NBC's intention although only five RBCs at the moment can actually do so. They are RBC 3 (at Chonburi province), RBC 7 (at Ubonratchathani province), RBC 10 (at Chiangmai province), RBC 12 (at Songkhla province) and Special RBC at Phuket. Another assumption is related to the selected mode of transport. In the case that there are alternative modes, the lowest-cost mode is chosen.

3.2 Analysis cases

This paper analyzes and reports results based on the following two cases.

Case 1: re-designing the locations of 12 RBCs

This case supposes that there was only the NBC from the beginning and the management was deciding where should another 12 RBCs be located in order to minimize the total system cost in objective function (1). In order to evaluate the performance of the re-designed distribution network, its optimal total cost will be compared to the estimated current cost. We can also compare the resulting optimal locations with the current locations. The results should inform us about how good is the current distribution network.

Case 2: locating an additional RBC to the current network

In most real-world cases, it is very unlikely to demolish the established infrastructure such as RBCs. Therefore, this case keeps the current configuration of 12 RBCs intact and think about where should the next RBC be located as the NBC has a plan to establish RBC 1 at Ayutthaya province. The analysis can provide the answer whether Ayutthaya province is still the best location choice in order to minimize the total system cost. In this case, we need to force location variables representing the current 12 RBCs to open by adding constraints (6), that is:

$$X_1, X_6, X_9, X_{14}, X_{21}, X_{22}, X_{23}, X_{37}, X_{41}, X_{50}, X_{51}, X_{57} = 1 \quad (6)$$

3.3 Data

Simply put, the minimum data requirement is equal to the number of parameters in the above mathematical model. These include:

1) Blood demand in each province (h_i - units), it comprises the amount of blood used among patients as well as the amount of disposed blood due to infection and expiration. We collected this data from the NBC's annual report (NBC, 2007). Remind that the model is of uncapacitated type, therefore the blood supply at any RBC is assumed to be unlimited. Although this is not a realistic assumption, it is still useful for determining the appropriate level of supply that the RBC needs to maintain by recruiting sufficient number of donors.

2) Fixed cost of locating RBCs (f_j - Baht), it is the overall establishment cost consisting of land cost, construction cost, equipment cost, and operation cost. We collected this information from historical data and updated by the current market prices.

3) Cost of blood transportation ($\alpha \times d_{ij}$ - Baht/unit), it is the unit transportation cost. We first collected the raw data by close observation of all processes during the actual blood distribution such as order taking, disbursement, packaging, and distribution. In short, there are five transportation modes involving along the supply chain of blood, i.e., NBC's van, public van, public bus, private car and air. The collected data can be used to estimate the unit transport cost by mode and distance.

4. Results and discussion

Table 1 reports results from solving the Uncapacitated Fixed Charged Facility Location model in case 1. The first column shows the list of NBC at Bangkok and 12 current RBCs. Meanwhile the second column reports the optimal locations of 12 RBCs. It can be seen that there are only seven RBCs in common, i.e., Lopburi, Chonburi, Ratchaburi, Nakhonratchsima, Ubonratchathani, Chiangmai and Nakornsimthammarat provinces. The model suggested five alternative RBC locations at Udonthani (in the northeast), Saraburi (in the central), Sukhothai (in the north), Pattani (in the south) and Chanthaburi (in the east) provinces.

Evidently, the current network configuration is somehow away from the ideal locations. That is why the current transportation distance (6.57 kilometers on average) at the bottom is relatively longer than the optimal re-design's (5.53 kilometers on average). The longest transportation distance is even longer, 24.11 as compared to 16.06 kilometers. Furthermore, from cost perspective, the current network incurred about 6.3 million Baht¹ annually or about 1.7 million Baht over the optimal total cost. Locating RBCs without proper analysis and design seems to cost the NBC a bit more every year, not to mention about the quality of blood that has to be transported further and longer every day.

The last three columns highlights the importance of donor recruitment. In column 3, the figures are the amount of blood that each ideal RBC must have in order to fulfill the demand. Meanwhile, the fourth column shows the actual amount of blood supply. It is obvious that only the NBC can serve the demand of its respective service provinces. This conforms to the actual current situation that RBCs cannot supply sufficient blood to patients. NBC, therefore, needs to reinforce them. All ideal RBCs will have a lot of work recruiting sufficient number of donors otherwise the estimated cost saving will never come true. This is the major challenge for the NBC and perhaps for other NBCs globally too.

Current RBCs (13 provinces)	Optimal RBCs case 1 (13 provinces)	Supply (units / year)		
		Model	Actual	differ
NBC: Bangkok	NBC: Bangkok	447,043	599,705	152,662
Lopburi	Lopburi	114,684	27,524	-87,160
Chonburi	Chonburi	68,579	59,517	-9,062
Ratchaburi	Ratchaburi	71,467	25,948	-45,519
Nakhonratchasima	Nakhonratchasima	114,788	65,839	-48,949
Khonkaen	Udonthani	152,246	31,415	-120,831
Ubonratchathani	Ubonratchathani	80,301	41,945	-38,356
Nakhonsawan	Saraburi	20,748	23,101	2,353
Phitsanulok	Sukhothai	87,693	9,935	-77,758
Chiangmai	Chiangmai	154,255	57,233	-97,022
Nakhonsrithammarat	Nakhonsrithammarat	95,968	26,419	-69,549
Songkhla	Pattani	49,918	4,289	-45,629
Phuket	Chanthaburi	46,056	25,828	-20,228
Distance (km.)	Minimum	Average	Maximum	
Current RBCs	1.82	6.57	24.11	
Optimal RBCs case 1	1.82	5.53	16.06	
Cost (Baht*)	Fixed cost	Transportation cost	Total cost	
Current RBCs	1,264,481,198	6,309,685	1,270,790,883	
Optimal RBCs case 1	1,179,094,425	4,624,469	1,183,718,894	

*39 Baht = 1 EUR

Tab.1: Results of optimal RBCs in case 1

Given that it is virtually impossible for the NBC to demolish the five uncommon RBCs and establish the new five RBCs according to results in case 1, we therefore proceed to case 2. In case 2, all current 12 RBCs are fixed as they are and then locate an additional RBC (or the missing RBC 1) which was planned by the NBC long time ago to be at Ayutthaya province.

Table 2 shows the results from solving the Uncapacitated Fixed Charged Facility Location model with additional constraints (6). The results turn out to locate the new RBC at Saraburi province, rather than Ayutthaya as planned by the NBC. Figure 3 shows optimal locations and distribution patterns. It can be seen that Saraburi is actually on the east of Ayutthaya. They share the same border. If the new RBC is located in Saraburi instead, the longest distance of blood distribution will decrease to 13.64 kilometers (or about 23 kilometers shorter), resulting in annual transportation cost of 4.29 million Baht (or about 2.3 million Baht cheaper)

Current RBCs (14 provinces)	Optimal RBCs of case 2 (14 provinces)	Supply (units/year)		
		Model	Actual	differ
NBC: Bangkok	NBC: Bangkok	447,043	599,705	152,662
Lopburi	Lopburi	87,713	27,524	-60,189
Chonburi	Chonburi	114,635	59,517	-55,118
Ratchaburi	Ratchaburi	71,467	25,948	-45,519
Nakhonratchasima	Nakhonratchasima	100,442	65,839	-34,603
Khonkaen	Khonkaen	184,662	67,289	-117,373
Ubonratchathani	Ubonratchathani	62,271	41,945	-20,326
Nakhonsawan	Nakhonsawan	52,449	25,282	-27,167
Phitsanulok	Phitsanulok	100,134	25,877	-74,257
Chiangmai	Chiangmai	154,255	57,233	-97,022
Nakhonsrithammarat	Nakhonsrithammarat	76,671	26,419	-50,252
Songkhla	Songkhla	49,918	36,996	-12,922
Phuket	Phuket	19,297	12,332	-6,965
Ayutthaya	Saraburi	20,748	23,101	2,353
Distance (km.)	Minimum	Average	Maximum	
Current RBCs	1.82	6.65	36.32	
Optimal RBCs case 2	1.82	5.50	13.64	
Cost (Baht*)	Fixed cost	Transportation cost	Total cost	
Current RBCs	1,286,718,387	6,811,332	1,293,529,719	
Optimal RBCs case 2	1,299,443,318	4,290,545	1,303,733,863	

*39 Baht = 1 EUR

The results show another major advantage of locating the new RBC at Saraburi province. In the last column, besides Bangkok NBC, there is also Saraburi RBC that has sufficient blood supply to service demand. There is still 2,353 blood units remained after fulfilled total demand of its respective service provinces. By taking a closer look at the blood demand in Saraburi province compared to other provinces under the responsibility of other RBCs, there is much greater demand for blood supply. While other RBCs can serve several provinces in their areas, the new Saraburi RBC will have to supply blood mainly for hospitals in Saraburi province. Saraburi, thus, may be an ideal location which will grant the new RBC maximum efficiency for blood service to hospitals in Saraburi.

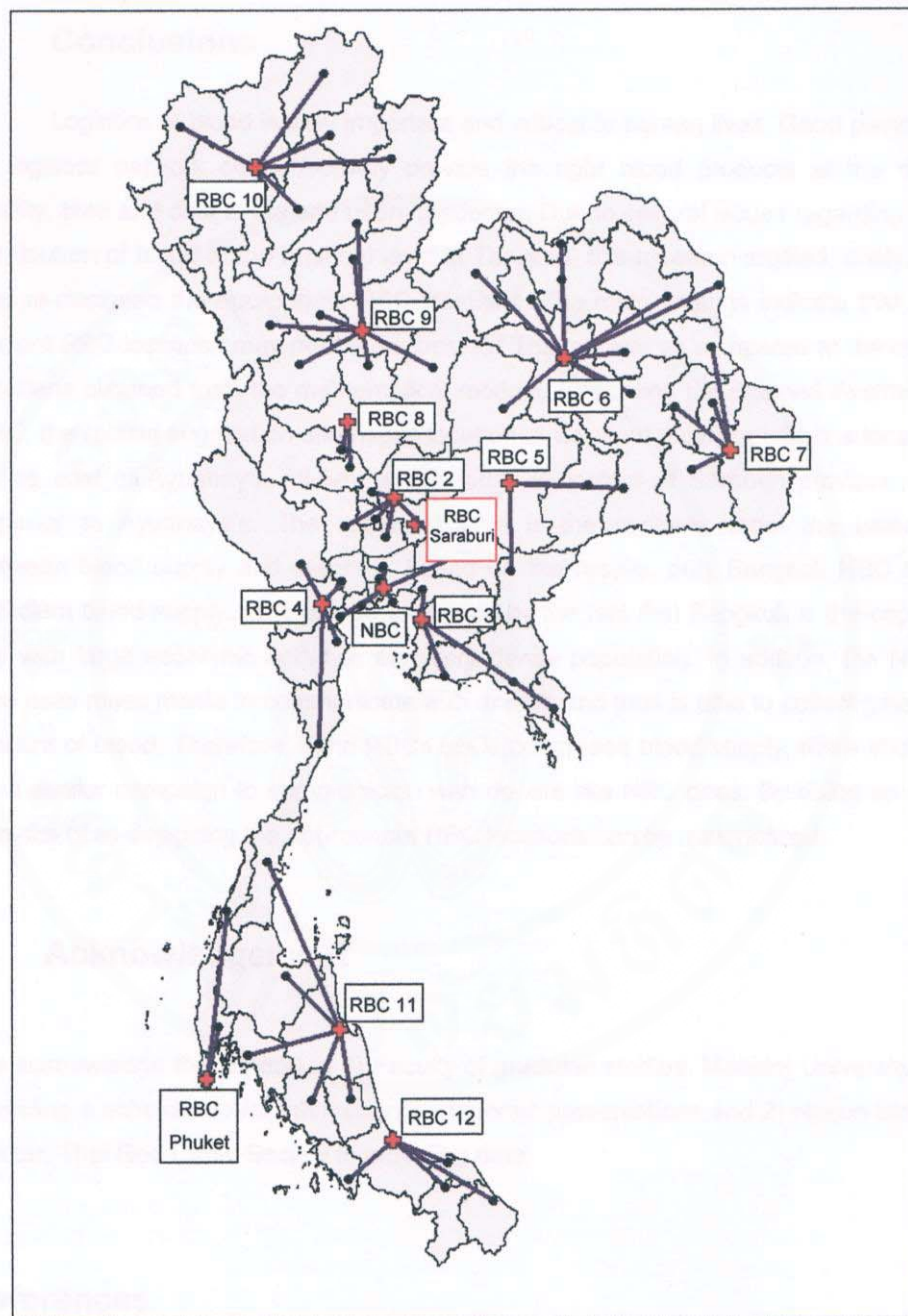


Fig. 3: Optimal blood distribution pattern case 2

5. Conclusions

Logistics of blood is very important and critical to human lives. Good planning of logistics network can effectively provide the right blood products at the right quality, time and cost to the end users (patients). Due to several issues regarding the distribution of blood at the regional level in Thailand, this research studied, analyzed and re-designed the appropriate RBC locations. The main findings indicate that the current RBC locations may not be the best for Thai society as compared to the ideal locations obtained from the mathematical models. Regarding the planned Ayutthaya RBC, the results suggest an alternative location at Saraburi province which is located to the east of Ayutthaya. All key performance indicators of Saraburi province are superior to Ayutthaya's. The important note is the concern about the balance between blood supply and demand. Based on the results, only Bangkok NBC has sufficient blood supply. This can be explained by the fact that Bangkok is the capital city with large economic activities and very dense population. In addition, the NBC also uses mass media to communicate with donors and thus is able to collect greater amount of blood. Therefore, if the RBCs seek to increase blood supply, there should be a similar campaign to communicate with donors like NBC does. By doing so the benefits of re-designing the appropriate RBC locations can be materialized.

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