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Blood Supply Chain and Logistics: a Case Study in Thailand

by

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ABSTRACT

FACULTY OF SOCIAL AND HUMAN SCIENCES

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Blood services and operations are key components of healthcare systems throughout the world. In this research, we introduce the current blood supply chain system of the Thai Red Cross Society (TRCS) as a case study in a developing country. Both location and routing problems are considered for improvements in the efficiency and service of the blood supply chain. The objectives of the research are, firstly, to consider locations of existing Regional Blood Centres (RBCs): allocation of provinces to RBCs, their relocation, and the number of RBCs needed to cover demand points. We present novel goal programming models which could be combined with methods such as the Analytical Hierarchy Process (AHP) to select optimal locations for RBCs.

Secondly, we present a strategic plan for determining either fixed donation stations to collect blood from donors or distribution sites to serve hospitals throughout the country within predefined health budgets. The novel integer linear programming model presented to select optimal locations for these two different types of low-cost facilities combines two criteria: maximisation of donors and minimisation of travelling distances in the supply chain network. The model is implemented using the CPLEX package for solving the problem.

Thirdly, novel fixed routing policies are developed for blood distribution and routing in a specific region used as a prototype for the blood supply and logistics in the other regions of the country. This problem is analysed under the current situation of insufficient blood supply. However, the study also addresses the desirable future situation when there is sufficient supply. Three fixed routing policies are proposed: (a) deliveries to each hospital once during the planning period, (b) deliveries on a reduced number of days, and also to hub hospitals only and (c) varying frequency distributions. We present two-phase heuristic algorithms to plan for blood distribution with multiple frequencies.

Finally, we consider variable routes to allow for variable insufficient blood supplies and present novel online algorithms for allocation of blood and routing once the actual amounts of donated blood become known daily. For this problem, we uniquely decompose the problem into fixed routes and variable routes in the region. Hospitals on fixed routes are determined by distance from the RBC: these distant hospitals are allocated the most reliable blood supplies on fixed delivery days. Hospitals closer to the RBC are assigned to variable routes which may be changed when the actual donated blood supply is known each day. An initial delivery plan for variable routes is rescheduled on a daily basis to satisfy the target blood supply to all hospitals, which have different priorities. Several different blood allocation and routing policies are proposed, with different transportation and inventory scheme and results compared. In view of the difficulty in solving the vehicle routing problem, which is NP-hard, heuristics have been employed for the purpose of looking for good solutions. Computational results of practical importance to a decision maker are reported and discussed.

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Declaration Of Authorship

I, Pornpimol Chaiwuttisak, declare that the thesis entitled Blood Supply Chain Systems and Logistics: a case study in Thailand and the work presented in the thesis are both my own, and have been generated by me as the result of my own original research. I confirm that:

- this work was done wholly or mainly while in candidature for a research degree at this University;
- where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
- where I have consulted the published work of others, this is always clearly attributed;
- where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
- I have acknowledged all main sources of help;
- where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;

Part of this work has been presented at:

1. CORMSIS Presentation 2011, "Location-Allocation-Routing Analysis for Blood Supply and Logistics in Thailand", at University of Southampton, United Kingdom, 19 May 2011;
2. CORMSIS Presentation 2012, "Location-Allocation Problem for Blood Service Facility in Thailand", at University of Southampton, United Kingdom, 1 May 2012;
3. Postgraduate Research Showcase 2012, "Location-Allocation Problem for Blood Service Facility in Thailand", at University of Southampton, United Kingdom, 3 May 2012;

4. ORAHS Poster Presentation 2012, "Location-Allocation Problem for Blood Service Facility in Thailand", at University of Twente, Netherlands,15 - 20 July 2012;
5. Postgraduate Research Showcase 2013, "Heuristics for Blood Distribution", at University of Southampton, United Kingdom, 2 May 2013;
6. 1st Young CORMSIS Conference 2013, "Location-Allocation and Scheduling Routing Problems for Blood Service in Thailand", at University of Southampton, United Kingdom,18 -19 June 2013;
7. 26th European on Operational Research (EURO) Conference 2013, "Location-Allocation Problem for Blood Service Facility in Thailand", at Sapienza University of Rome, Rome, Italy 1 - 4 July 2013;
8. 2nd Vehicle Routing and Logistics (VeRoLog) Conference 2013, "Periodic Vehicle Routing Problem for Blood Distribution", at University of Southampton, United Kingdom, 7 - 10 July 2013;
9. International Conference on OR for Development (ICORD 2014), "Online allocation and routing for blood delivery in conditions of variable and insufficient supply: a case study in Thailand", at University of Lleida, Catalonia, Spain, 10 - 11 July 2014;
10. 20th Conference of the International Federation of Operational Research Societies (IFOR 2014), "Online allocation and routing for blood delivery in conditions of variable and insufficient supply: a case study in Thailand", at Centre de Convencions Internacional de Barcelona, Spain, 13 - 18 July 2014;
11. 6th International Conference on Applied Operational Research (ICAOR 2014), "Blood Supply Chain with insufficient supply: a case study of location and routing in Thailand", at Vancouver, BC Canada, 29 - 31 July 2014.

Signed: ....

Date

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With the oversight of my main supervisor, editorial advice has been sought. No changes of intellectual content were made as a result of this advice. Moreover, I must also thank Mr. Stanley Engel for his patience in correcting the numerous English errors which I made in my writings.

Chapter 1

Introduction

This chapter of the thesis gives an overview of the blood supply chain and logistics. The first section presents the research background. The second section provides the objectives and scope of this study, including the expected outcomes of this project. The next section identifies the research methodologies used to achieve the research objectives. In the final section, the structure of the thesis is presented.

1.1 Blood, Blood centres, and Blood Supply Chain Management

Blood is a vital fluid that carries essential substances into cells within the body of human beings. It consists of two main components: approximately 55% of the total amount of blood is plasma and the rest is made up of cellular components. No chemical compound has been found to-date that can replace blood. Thus, transferring blood from one person to another is still required to save lives of persons in several life-threatening situations, such as those who have had surgery due to several causes: organ transplantations, childbirth, treatment for cancer, leukaemia, and anaemia, amongst others. Blood shortages are common in several countries throughout the world, including Thailand (Wiwanitkit, 2010). This results from increasingly unpredictable blood demand, with various influencing factors such as birth rate, disasters, epidemics, battle field injuries, political protests, and the lack of a strategic plan for national healthcare. Meanwhile the amount of blood collected is constant or increases only slowly, because of a lack of accurate knowledge about blood donation by non-donors. Moreover, the amount of blood available for transfusion may decrease due to increasing strictness of blood screening tests used to reduce the risk of infection.

Blood centres have been established for collecting donated blood, screening of blood, preparing blood and blood products, and transferring safe blood to patients in a timely manner. Blood centres also disseminate information about blood transfusion to local people. In Thailand a National Blood Centre and regional centres were established for these responsibilities, to perform all activities of a supply chain system involved in moving safe blood from donors to patients. Effective design and management coupled with efficient use of limited resources of the supply chain system is significant in meeting hospital blood demand within acceptable quality standards. Moreover, elimination of the risks associated with infections is a considerable performance issue for blood supply chain management. The World Health Organisation (WHO, 2000) declared that efficient management of blood services is an appropriate use of national budget, to ensure a safe and adequate blood supply.

A concept of regionalisation for blood service systems has been discussed in several countries, to reduce shortages, outdates and operating costs, while the quality of blood is sustained (Cohen et al., 1979). In principle, blood service facilities are structured hierarchically in a geographic region. Local coordination and cooperation with the other regions are key strategies to perform the following policies: (1) determining volunteer donor recruitment in the region (2) siting facilities to deliver blood to all hospitals in the region (3) providing total blood service within its area to schedule, in keeping with the requirements of the region (4) providing expert medical consultation on haemotherapy, compatibility problems and other blood-related problems (5) providing the quantity of blood and its components required in the region and (6) meeting appropriate inspection and accreditation standards in order to improve inventory management (Texas Medical Association, 2004).

Decision-making about the number of facilities and their location is of considerable importance in designing an effective regional supply chain network. Such decisions affect logistics, transportation costs and the ease with which both donors and hospitals can access facilities. Operational costs related to blood services including production costs, transportation costs, and distribution costs are of much concern to organisational administrators. Daskin and Dean (2004) posited that the incorrect number of facilities or poor locations can result in increasing expenses and reduced standards of customer service. In the healthcare arena, this may lead to increasing disease and death.

Apart from location problems, distribution is a key driver of overall costs for the system. Firstly, it is necessary to transport blood to hospitals for the treatment of patients, satisfying hospital demand while assuring blood quality. Moreover, whole blood and blood products are perishable items with differing shelf lives, namely 5 days for platelets, 28-35 days for red blood cells, and 1 year for plasma. These blood products are used for different functions. Plasma is used for burn patients, shock, and bleeding disorders. Red blood cells are mostly used in trauma, surgery, anaemia, blood disorders, and for any blood loss. Platelets are used in cancer treatment, organ transplants, and surgery. In this research, we focus on red blood cells due to the high frequency of usage of this blood product in medical treatment. For the remainder of this thesis, references to blood will imply red blood cells.

1.2 Motivation of research

The motivation of this study results from visits to the National Blood Centre (NBC) and the Regional Blood Centre (RBC) at Chiang Mai, including interviews with the deputy director of the NBC who has responsibility for providing the policies to manage blood supply and logistics of all RBCs throughout the country.

The NBC operated by the Thai Red Cross Society is responsible for blood services throughout the country, playing an important role in ensuring the safety of blood donation for both donors and recipients and. Moreover, Thailand has promoted itself to become the medical hub of Asia and blood requirements of hospitals are expected to increase in the future. The need for improved efficiency of the blood supply network and logistics has been proposed to the administrative board of the NBC. However, no people in the organisation have expertise and knowledge in Operational Research (OR) or Management Science (MS) that can be applied in the pursuit of improved decision-making and efficiency based on scientific analysis.

The blood supply chain is inherently different from other supply chains, due to the perishable nature of blood and difficulties in obtaining adequate supplies. The age of blood is a significant factor in treatment of patients in some cases. Evidence shows that transfusion of blood stored for more than fourteen days leads to complicated sepsis and death in trauma victims (Hassan et al., 2011). This research is expected to improve efficiency of the supply chain system for blood, in planning a delivery schedule and routes for blood distribution, which can reduce total costs and provide a fair allocation of blood to hospitals in face of an imbalance between supply and demand of blood.

The location problem of blood service facilities is a part of this study. The study of location can be viewed as strategic planning with long-term consequences. Many blood service centres have been built without sufficient location analysis. Consequently, it is difficult for many hospitals, particularly in remote parts, to access these centres. Investment in blood centres with full functions of collection, testing and distribution is difficult to implement for non-profit organisations in developing countries. Thus, setting up low-cost facilities to carry out some specific tasks (such as blood collection or blood distribution) is a viable alternative which can improve the efficiency of supply chain network. Low-cost extensions to the network of RBCs through donation rooms and distribution centres are presented in this research.

A future strategic plan is proposed for blood to be directly delivered to hospitals by the blood service centres. In the current situation, hospitals must collect blood at the blood service centres using various vehicles such as vans, cars, and motorcycles. Determining a regular schedule for blood distribution could help control quality of blood by using vehicles that can maintain a suitable temperature during transportation. Moreover, the total transportation costs of blood can be reduced in the network. Hospitals can also be helped to manage their own blood stocks and equitable allocation can be made of scarce blood resources, rather than simply responding to demands from individual hospitals.

The concept of vendor-managed distribution (Erera et al., 2009) has been demonstrated to manage supply chains efficiently. In the case of the blood supply chain, this policy can reduce the transportation costs of distribution in comparison with hospitals individually collecting blood. Planning of schedules and routes for blood distribution to hospitals is introduced in this thesis to support operations of RBCs under two possible scenarios: insufficient and sufficient supply.

An online system is proposed for handling blood allocation and routing in situations of variable amounts of donated blood. To reduce transportation costs, one weekly visit is proposed for hospitals distant from RBCs using fixed routes, while hospitals that are closest to the RBCs will be served using variable routes. Hospitals on such variable routes are visited more than once weekly, depending on the amount of donated blood available, their target supply, and their priority. Pre-planned schedules and routes are modified once the amount of blood available is known.

1.3 Thesis Aims and Scope

The main aims of the research can be described as follows:

1 To explore operational management of the supply chain systems for blood, focusing on the problems confronted in a case study of a developing country.

2 To review the relevant research into all aspects of a supply chain system related to blood, location theory, the Location-Allocation Problem (LAP), the Vehicle Routing Problem (VRP) and its variations, including solution methods.

3 To analyse the current locations of RBCs nationwide, recommending new locations to improve both supply and demand.

4 To recommend locations for low-cost extensions to the RBC network, with two types of service facility: collection-only rooms or collection-and-distribution centres.

5 To analyse in detail the current distribution of blood in one region of Thailand: the upper North region, and recommend supplier-managed delivery routes, considering situations of both sufficient and insufficient supply.

6 To develop the online daily schedule plan for blood distribution to hospitals with two different types of routes: fixed and variable routes. The different policies provide different trade-offs between transportation and holding costs of the blood service centre.

This research focuses on the supply and delivery of red blood cells, without consideration of different blood groups. The solution methods are applicable to collection and delivery of all blood products and blood groups. However, further research would be needed to consider combinations of products.

1.4 Research Methodology

The following methodologies are employed in three aspects of the research:

Firstly we propose location analysis depending on various criteria in the real world problem. Goal programming is used for nationwide location of new regional blood centres and for location of these centres combined with routing of blood to provinces. An integer linear model is proposed for nationwide location of two types of low-cost centres with components of both maximisation of supply with minimisation of travel costs.

Secondly, to design optimal fixed routes for blood delivery to hospitals, the Clarke and Wright (C&W) algorithm with Local Search (LS) and Greedy Randomized Adaptive Search Procedure (GRASP) are used as solution methods. Hospitals are clustered using the following techniques: K-Means clustering and Fuzzy C-Means clustering, under different policies to minimise the total transportation cost. A model related to the periodic vehicle routing problem is also presented. Because the problems are NP-hard, heuristic and meta-heuristic methods are used to deal with the problem, given the large data set. The algorithm can be divided into two phases: (1) assign hospitals to planning day (2) assign hospitals to routes in each day.

Finally, for the situation of variable and insufficient blood supplies, an online system is developed. Heuristic algorithms are used to construct an initial plan for blood delivery on variable routes and to reschedule the plan by different policies when the amount of blood available becomes known.

1.5 Research Contributions

This study represents the first application of OR/MS methods to the delivery of blood in a developing country like Thailand. Most research papers related to this study assume that there is a balance between demand and supply, but for many developing countries, in reality, there is an imbalance between the two elements. Thus, we are concerned with improvements in collection and equitable blood allocation. Moreover, this study focuses on a dynamically-changing supply side.

The existing RBCs for blood services are analysed. Goal programming (which could be combined with the Analytical Hierarchy Process (AHP)) is proposed for determining optimal locations for new RBCs. In addition to RBCs with full functions, this research concerns low-cost extensions to the RBC network for improving blood collection and supply. A novel binary integer programming model for location of donation rooms and distribution centres is presented.

Novel applicable policies are demonstrated for fixed and variable routes, suited to conditions of both sufficient and insufficient supply, to improve delivery through the efficient concept of vendor-managed distribution and equitable allocation. In economic terms, transportation costs increase as the number of visits increases. Moreover, varying situations of blood supply must be considered. With sufficient blood supply, one visit per week for hospitals is suitable. However, in situations of shortage, multiple frequency visit policies are proposed to solve the problem.

1.6 Thesis Structure

The thesis is structured in nine chapters as follows:

Chapter 1 provides the introduction to the thesis, the motivation for conducting the research, the research objectives and scope, and the research contribution.

Chapter 2 introduces the background and problems in greater detail.

Chapter 3 presents the basic theory and literature reviews of the Location-Allocation Problem (LAP) and the Vehicle Routing Problem (VRP), along with literature related to the supply chain system for blood.

Chapter 4 explains data used in the study, and data pre-processing, including the statistical analysis of data. The computer specification and software used are also described.

We can classify the blood supply chain problems addressed in this case study into two sections:

Location-Allocation Problem: The mathematical models to determine the locations for blood centres and low-cost blood service facilities are presented in Chapters 5 and 6.

Chapter 5 studies the location-allocation problem and the location-routing problem and proposes mathematical models with multi-objective functions to determine the number and location for blood service centres.

Chapter 6 defines the novel location-allocation model proposed to find optimal numbers and locations within budgetary constraints for two types of service facilities. An integer linear programming (ILP) model is proposed and the computational results and the theoretical and practical contributions are presented.

Distribution Problem: The plan proposed for daily allocation and distribution of blood supplies, both via fixed and variable routes, will be presented in Chapters 7 and 8.

Chapter 7 defines the mathematical models and proposes heuristic algorithms to determine fixed routes for the supply of hospitals: for sufficient supply, both (a) 6-day delivery, and (b) 3-day delivery to hub hospitals. Moreover, a distribution schedule for multi-frequency visits for hospitals is presented to deal with insufficient supply.

Chapter 8 presents the online algorithm, with fixed weekly routes employed for distant hospitals and variable daily routes for close-by hospitals, for which more than one visit per week may be needed to fulfil targets.

Chapter 9 concludes with a discussion of the theoretical and practical contributions along with directions for further research.

Chapter 2

Problem background: Thailand and its current blood supply chain and logistics

In this chapter, we describe the country profile, the structure of blood services, and the supply chain system for blood in Thailand, including both inbound and outbound logistics processes. The current situation of blood shortages is also discussed. The problems faced were assessed from in-depth interviews with the Assistant Director of the National Blood Centre, Thai Red Cross Society. The conclusion to this chapter highlights future policies of the National Blood Centre and directions taken in this research.

2.1 Thailand: country profile

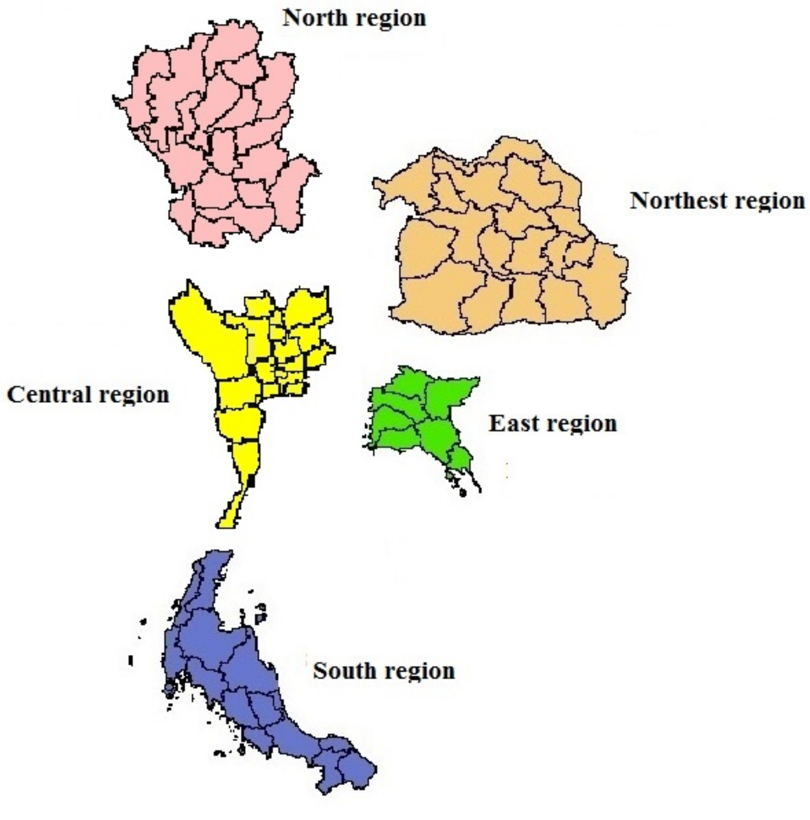
Thailand is one of the developing countries located in Southeast Asia. It is bordered to the north by Burma and Laos, to the northeast by Laos, to the east by Cambodia, and to the south by the Gulf of Thailand and Malaysia (see Figure 2.1). It has a total area of approximately 513,000 km^2 and a population of about 65 million inhabitants. Bangkok is the capital city of the country, with the largest population in the country. Thailand consists of 76 provinces (Changwat in the Thai language) which can be grouped by their locations in five administrative regions:

- North - 17 provinces
- Central - 18 provinces
- Northeast - 20 provinces
- East - 7 provinces

- South - 14 provinces

Each province is divided into districts (Khet for Bangkok and Amphoe for the others, in the Thai language) and sub-districts (Tambon in Thai). Amphoe Mueang is the capital district of every province. There are significant variations in area and population among the provinces, as shown in Appendix B.1.

(a) Geographical location of Thailand



(b) Five regions of Thailand

Figure 2.1: The profile and administrative divisions of Thailand

2.2 Blood Service Centres in Thailand: Hierarchical Structure and Responsibilities

In Thailand, blood service centres are run by the Thai Red Cross Society (TRCS) which is a non-profit healthcare organisation with the ultimate mission of ensuring sufficient safe blood supplies and the same quality standards across the country. The blood service centres can be classified by the geographic hierarchical structure of the country: namely, the National Blood Centre in Bangkok and Regional Blood Centres situated in the different regions of the country. Their locations can be seen in Figure 2.3.

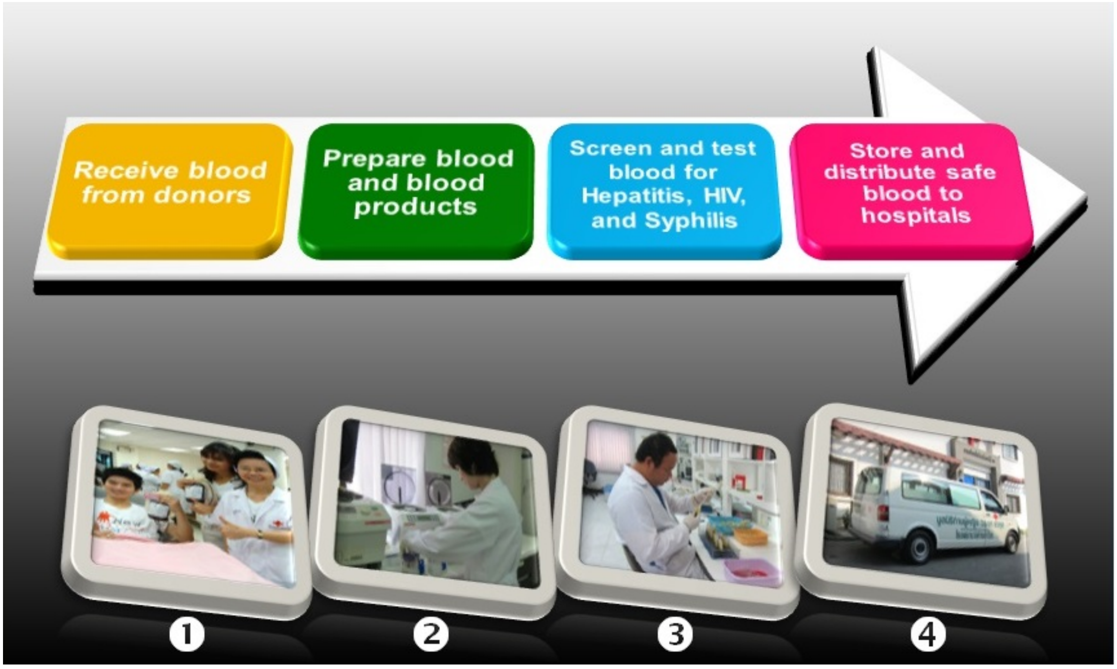


Figure 2.2: Functions of blood service centres

The main functions of the blood service centres can be summarised as blood collection, screening and testing, preparation, storage and distribution. Blood is collected from donors at fixed stations and in bloodmobiles. Blood screening and testing is carried out for ABO blood group, Rhesus blood group (Rh), Antibodies, Syphilis, Viral Hepatitis B, and Viral Hepatitis C. Tests performed also include Human Immunodeficiency Virus (HIV) tests with CMIA (Chemiluminescence Microparticle Immuno Assay) and NAT (Nucleic Acid Testing) methods. Blood and blood products are prepared in the form of Whole Blood (WB), Packed Red Blood Cells (PRBCs), Plasma, and Platelets. Finally, safe blood is stored for distribution to hospitals (as illustrated in Figure 2.2). In principle, blood collected through the processes performed by the National Blood Centre and

Regional Blood Centres is accepted to the standards laid down by the World Health Organization (WHO, 2000).

2.2.1 National Blood Centre and Regional Blood Centres

There is one National Blood Centre (NBC) located in Bangkok which was established in 1969 with assistance from the French government to develop blood services in Southeast Asia. In addition to performing the major blood processing functions specified above, it conducts research on blood transfusion and haematology, produces blood-testing chemicals and defines working procedures and policies for all blood services throughout the country. The NBC's goal is to be able to supply 1.6 million blood units per year (or 2 to 3 blood units per 100 head of population): this should be sufficient to supply the requirements of the whole country according to suggestions of the World Health Organization (WHO, 2000). Furthermore, the NBC has specified that blood should be obtained 100% from voluntary non-remunerated blood donation by 2015.

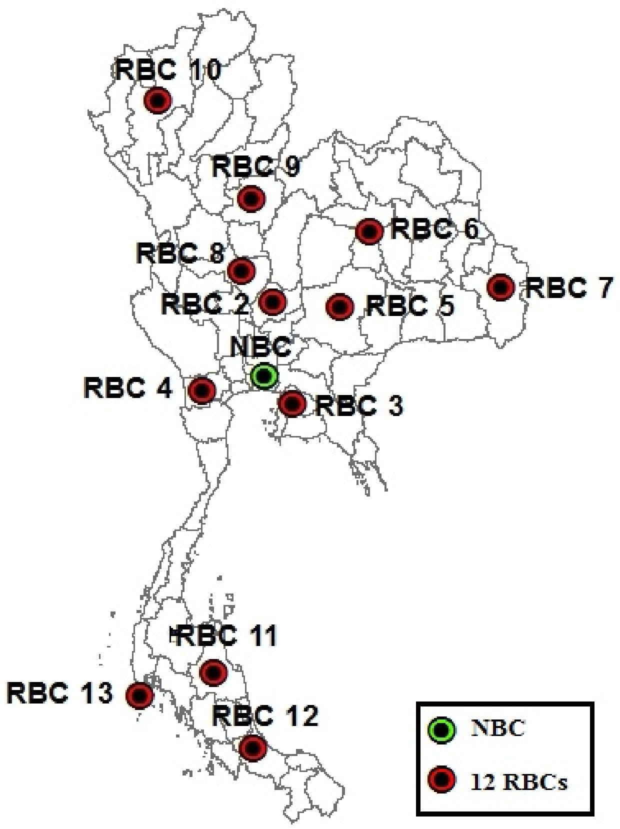


Figure 2.3: Site map of the NBC and 12 RBCs

There are twelve Regional Blood Centres (RBCs), which have been set up in the years since 1996 (see Appendix C). RBCs are equipped to perform some of functions that the NBC does. Blood is supplied to hospitals in the provinces by the RBCs, while the NBC provides blood mostly to hospitals in the capital city and its vicinity. RBCs are supported by the NBC with some blood supplies and RBCs also collaborate with the provincial Red Cross to launch campaigns for encouraging local people to donate blood. In 2010, a new RBC was opened at Phuket province through collaboration between the Finnish and Thai Red Cross Societies. At the present time, only two RBCs at Chiang Mai and Phuket province can perform all the major functions mentioned earlier in Section 2.2, while the other RBCs can do only blood testing. Each RBC must provide blood to hospitals in several provinces as determined by government administration.

2.3 Hospital types

Hospitals are viewed in the role of customers for the NBC and RBCs. A hospital requires blood for the medical treatment of patients. All hospitals in the country are operated under the supervision of the Ministry of Public Health. The total number of hospitals over the country is approximately 1,002 public hospitals and 316 private hospitals. The number of hospitals is different in each region: approximately 137 hospitals in Bangkok, 262 hospitals in the North region, 355 hospitals in the Northeast region, 79 hospitals in the Central region, 98 hospitals in the East region, and 206 hospitals in the South region. They can be classified into three main types as follows:

- Regional hospitals, which are situated in provincial capitals, have a capacity of at least 500 beds and have a comprehensive set of specialist staff.
- General hospitals are located in provincial capitals or major districts and have a capacity of 200 to 500 beds.
- Community hospitals are located at district level and further classified by size:
  - Large community hospitals have a capacity of 90 to 150 beds.
  - Medium community hospitals have a capacity of 60 beds.
  - Small community hospitals have a capacity of 10 to 30 beds.

2.4 Blood Supply Chain and Logistics

Both supply chain and logistics are key terms in analysis of any industrial sector: in this section we highlight characteristics of the blood supply chain. There is often confusion over the definitions of supply chains and logistics. 'Supply chain' focuses on a flow of information and physical products from suppliers through to customers, while 'logistics' covers all activities which involve management of storage, information, packaging, transportation of raw materials and delivery of finished products to the customers

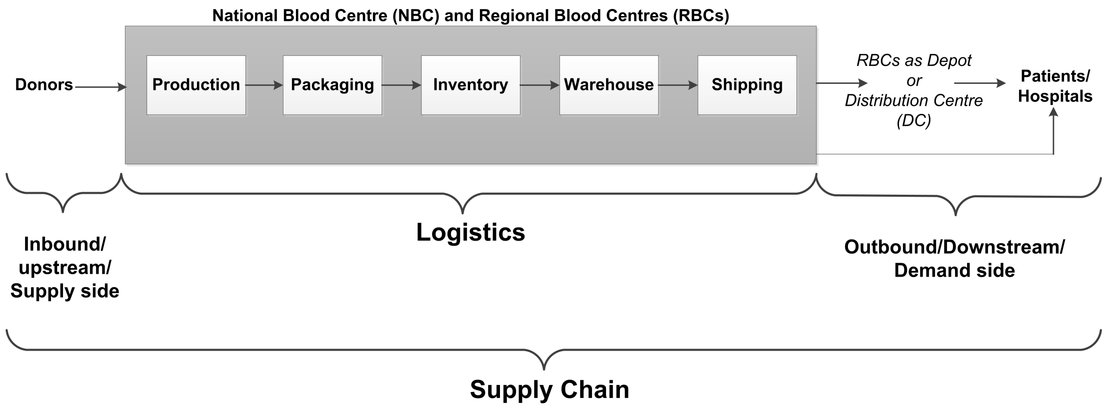


Figure 2.4: Relationship between supply chain and logistics

(Christopher, 2010). Both supply chain and logistics are crucial for the overall success of a business, and this is without doubt the case for blood services in a country. Figure 2.4 shows the flow between processes covered by the blood supply chain and logistics. It can be said that logistics is an intermediate component between suppliers and customers of the supply chain.

Blood is the physical product concerned in the supply chain and logistics for blood services. It is a perishable product, suffering from physical deterioration, with a specific, fixed shelf life. Although its value during the shelf life is constant, fresh blood is preferred for treatment. Moreover, the amount of blood that can be supplied is limited and dynamically changing. Additionally, it is hard to determine the quantity of blood likely to be obtained at any time from donation. This contrasts with supply chains for man-made products which can be produced in a timely manner to correspond to demands of customers.

A complex array of blood products is needed to perform transfusion of blood into patients. ABO and Rh blood groups of a recipient must be compatible with blood groups of a donor. Moreover a variety of different blood components and blood products can be obtained from whole blood: Packed Red Cells, Leukocyte-Poor Packed Red Cells, Fresh Frozen Plasma, Platelet Concentrates, Leukocyte-Poor Platelet Concentrates, Cryoprecipitate, Cryo-Removed Plasma, Fresh Dried Plasma, Dried Cryo-Removed Plasma, Heat Treated Freeze Dried Cryoprecipitate, Human Albumin Solution, Human Rabies Immunoglobulin, Hepatitis B Immunoglobulin, and Fibrin Glue. This research focuses on red blood cells because they are the major product needed for treatment in hospitals. Moreover, we do not differentiate between blood groups in our modelling, because of the high degree of complexity needed.

2.4.1 Donation, Production, and Inbound logistics

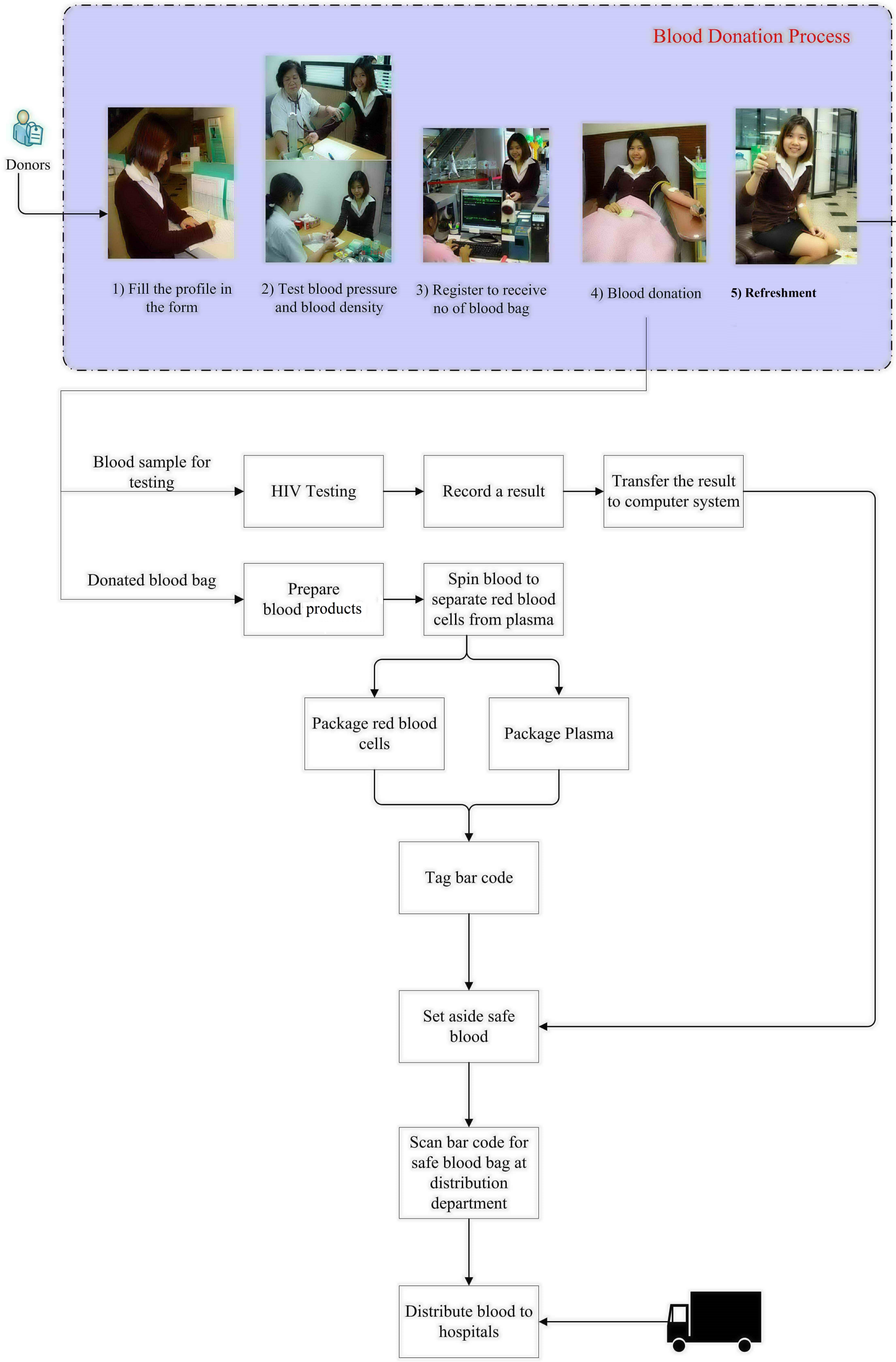
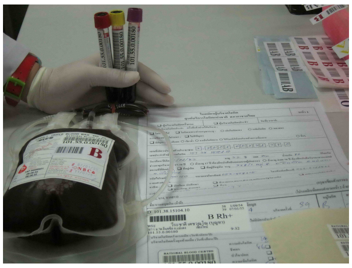


Figure 2.5: The inbound process of blood supply chain and logistics in Thailand

(a) Blood donation

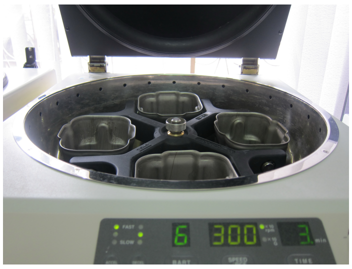


(b) Tubes for testing

(c) Serology test

(d) NAT test for HIV

(e) Key-in testing results



(f) Centrifuge for separating whole blood into components

Figure 2.6: Inbound logistics

In Thailand, blood can be collected from walk-in donors at a donation site at the NBC and RBCs, at branches in hospital-based blood banks or in bloodmobiles. Details of the inbound process of blood donation are shown in Figure 2.5. Firstly, donors must complete a donor registration form which contains name, address, and questions about past and present health history. Secondly, donors undergo a short examination concerning their weight, temperature, heart rate, and blood pressure, and also give a blood drop from their finger to measure haemoglobin level. After that, donors who have a normal result will receive a donor ID and proceed to a donor bed for blood transfusion by blood donation kits. Finally, donors will receive refreshment for a few minutes, with a snack and drink. The process of blood donation usually takes approximately 20 minutes per person. A blood bag thus collected is spun to separate red blood cells from plasma. Alongside this, a sample is sent to a laboratory in the NBC or an RBC for serology and Nucleic Acid Testing (NAT), which is the highest standard accepted in developed countries for enhanced blood safety. Safe blood is then tagged with a bar code and scanned, recorded in a computerised database system and frozen in storage at a temperature of less than $-20\,^{\circ}\mathrm{C}$ before it is distributed to hospitals. The total time taken for blood production is approximately 24 hours. The process of inbound logistics is shown in Figure 2.6. In Thailand, 63.6% of all donors are first-time donors, the rest being repeat donors (NBC, 2009).

2.4.2 Storing and Packaging blood

After blood is collected from donors, it must be transported to blood centres within six hours, at a temperature between +2 °C and +10 °C except blood used for the preparation of platelet concentrates. Moreover, fresh frozen plasma that is separated from whole blood should be at a temperature of −20 °C or lower, while platelet concentrates should be stored at a temperature between +20 °C to +24 °C. Storage and transportation conditions for blood and blood products are summarised in Table 2.1. Refrigerators and freezers are necessary for storing blood and blood products; staff personnel monitor and record the temperatures every morning and evening (Figure 2.7).

Table 2.1: Storage and transportation conditions for blood

Condition	Temperature range	Storage time
Transport of pre-processed blood	+20 °C to +24 °C	< 6 hours
Storage of pre-processed/processed blood	+2 °C to +6 °C	Approx. 35 days
Transport of processed blood	+2 °C to +10 °C	< 24 hours

(a) Storage for plasma (b) Refrigerator (c) Cold room

(d) Recording a temperature (e) Collecting blood from store room (f) Packing blood in a box

Figure 2.7: Packaging and inventory for blood supply chain and logistics

Figure 2.8: Three sizes of boxes used for containing bags of blood and blood products during transportation

Because the weather in Thailand is generally hot and humid throughout most of the year, special packaging for blood has been designed for deliveries of blood to provincial hospitals, in order to maintain quality of blood during transportation. A foam packing box, in small, medium, and large sizes (see Figure 2.8), is used as a container for blood and blood products, while packages of ice and wrapping sheets keep blood at a low temperature. In principle, one ice pack is used for small-size containers, two ice packs for the medium size, and three ice packs for the large size.

Table 2.2: Capacity of blood containers by size of box

Size	**Number of blood bags in box**
Small-sized box	1 - 8
Medium-sized box	9 - 16
Large-sized box	17 - 33

The weights of one pack of red blood cells of volume 350 ml and 450 ml are approximately 275 grams and 330 grams respectively, while one pack of Leuko Poor Red Cells weighs about 315 grams. The numbers of blood packs contained in each size of boxes are listed in Table 2.2. The dimensions of the commonly-used vehicle are 4.30 m $\times$ 2.79 m $\times$ 2.00 m, while the dimensions of a large-sized box are 1.20 m $\times$ 1.00 m $\times$ 0.60 m. Thus, the total number of boxes that can be carried in one vehicle is approximately 33 or 1,090 blood bags (one large size container can store 33 blood bags).

Whole blood and red blood cells that are distributed to RBCs or hospitals must be stored at a temperature between $+2\,^{\circ}$C to $+6\,^{\circ}$C during transportation. The oxygen-carrying ability of blood is decreased if the temperature is outside this range. Frozen components must be maintained at the temperature at which they were frozen. The transit time for blood and blood products should not exceed 24 hours. Usually, at 8.00am each day, staff start to wrap blood for dispatch according to orders of hospitals, finishing at 11.30am.

2.4.3 Distribution and Outbound logistics

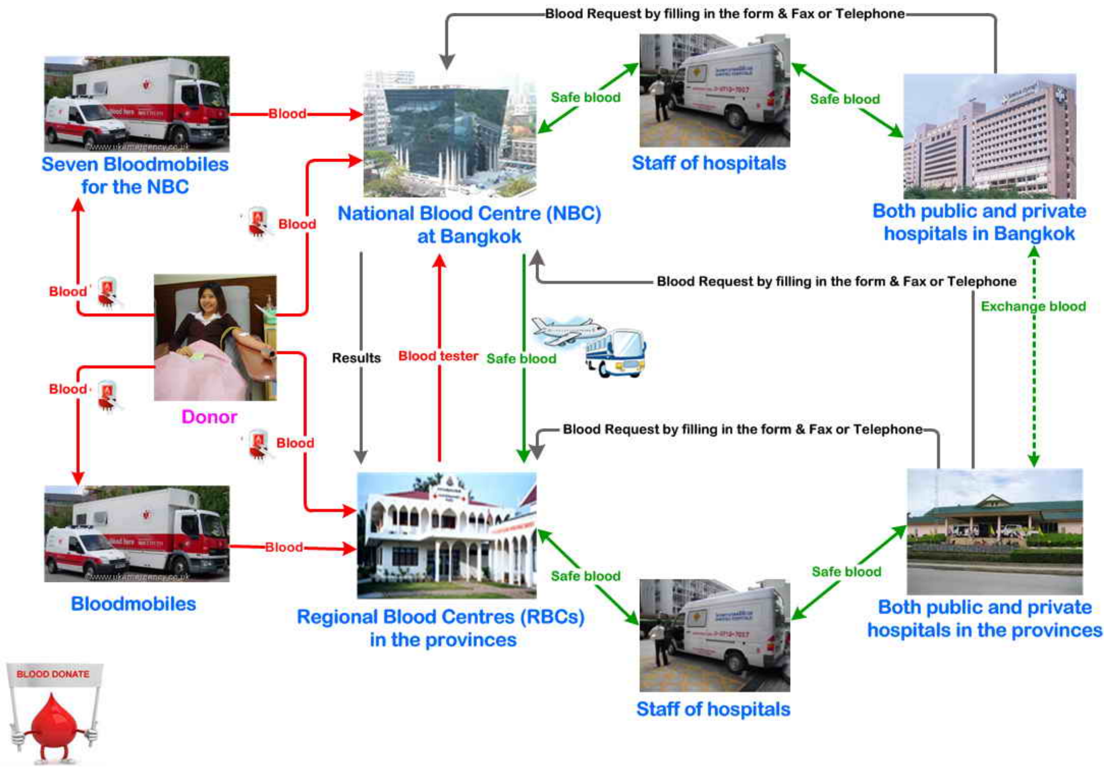


Figure 2.9: The outbound process of blood supply chain and logistics in Thailand

In the current situation, hospitals initiate the process of obtaining blood by sending a form directly to the NBC or an RBC by facsimile. Quantities of blood are allocated to hospitals according to a First-Come, First-Served (FCFS) sequence and according to reasons why blood is needed. Emergency needs are fulfilled immediately through telephone requests. Generally, hospitals in Bangkok or in the provinces must provide their own vehicles to drive to the NBC or an RBC and collect what blood has been allocated to them. Normally, hospitals can collect blood allocated to them about one day after placing an order by facsimile. However, currently, some hospitals may send vehicles to a blood centre only to find that there is no blood available for them. The outbound blood supply chain and logistics process is shown in Figure 2.9 and Figure 2.10.

(a) Direct distribution to hospitals in Bangkok

(b) Dispatch for RBCs

(c) Loading boxes

(d) Check-in at airport

(e) Arriving at cargo

(f) Unloading at cargo

Figure 2.10: Outbound logistics

Moreover, if amounts of blood collected at the NBC and the RBCs cannot satisfy the blood demand of hospitals, hospitals can exchange blood with other hospitals for different blood groups. Furthermore, hospitals can collect blood directly from donors, and then send samples to the NBC or RBCs for screening. The result is reported to the hospitals before blood is transfused to patients.

2.4.4 Modes of transportation for blood distribution between the NBC and RBCs

If the RBCs cannot support blood demand from provincial hospitals, a request is made to the NBC. Transportation modes for delivering blood from the NBC to the RBCs and hospitals in the provinces are shown in Figure 2.11. Blood requested is sent by two vans from the NBC to Suvarnabhumi International Airport or to public bus stations and thence transported directly to hospitals or to RBCs covering those hospitals. The mode of transport from there onward depends on the available transportation systems and geographical location of the province where an RBC is located. Air transport is used for RBCs in provinces with domestic airports, such as Chiang Mai, Khon Kaen, Ubon Ratchathani, Phitsanulok, Nakhon Si Thammarat, and Phuket, whereas blood is distributed to the other RBCs by public bus. Recently, a new service has been set up using Thailand Post to transport blood for 23 specific hospitals. Blood is taken to RBCs and picked up by these provincial hospitals on request. Furthermore, some empty containers from the RBCs are returned by rail.

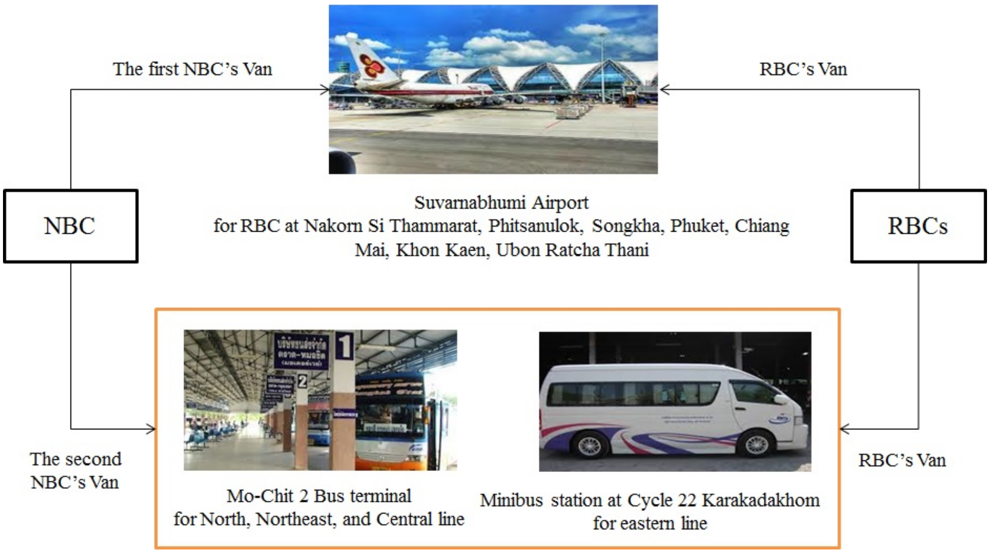


Figure 2.11: Transportation modes for blood distribution between the NBC and the RBCs

Table 2.3: Costs of shipping boxes by bus

Destinations	**Cost Per Box (Thai Baht/box)**		
	Small size	**Medium size**	**Large size**
Lopburi	50	70	70
Chonburii	140	140	160
Ratchaburi	60	60	60
Nakorn Ratchasima	60	60	60
Nakorn Sawan	150	200	250

Costs of transportation of blood to different RBCs vary with the transportation mode, but aeroplanes are considered the priority channel for blood distribution for reasons of speed. Two airline companies, Thai Airways and Nok Air offer transportation for blood. Thai Airways waives freight fees but charges a terminal fee. Blood transport is free of charge with Nok Air, which transports blood to the RBCs at Phitsanulok and at Nakhon Si Thammarat. Shipping costs by public bus vary according to the number of containers and the destination, as shown in Table 2.3.

2.5 The current situation of blood supply and demand in Thailand

A shortage of donated blood is the major problem in the blood supply chain in Thailand at the current time. It can be seen in Figure 2.12 that the amounts of blood requested by hospitals over the country over the period 1997-2009 were usually greater than the amount of safe blood available for supply (NBC, 2009).

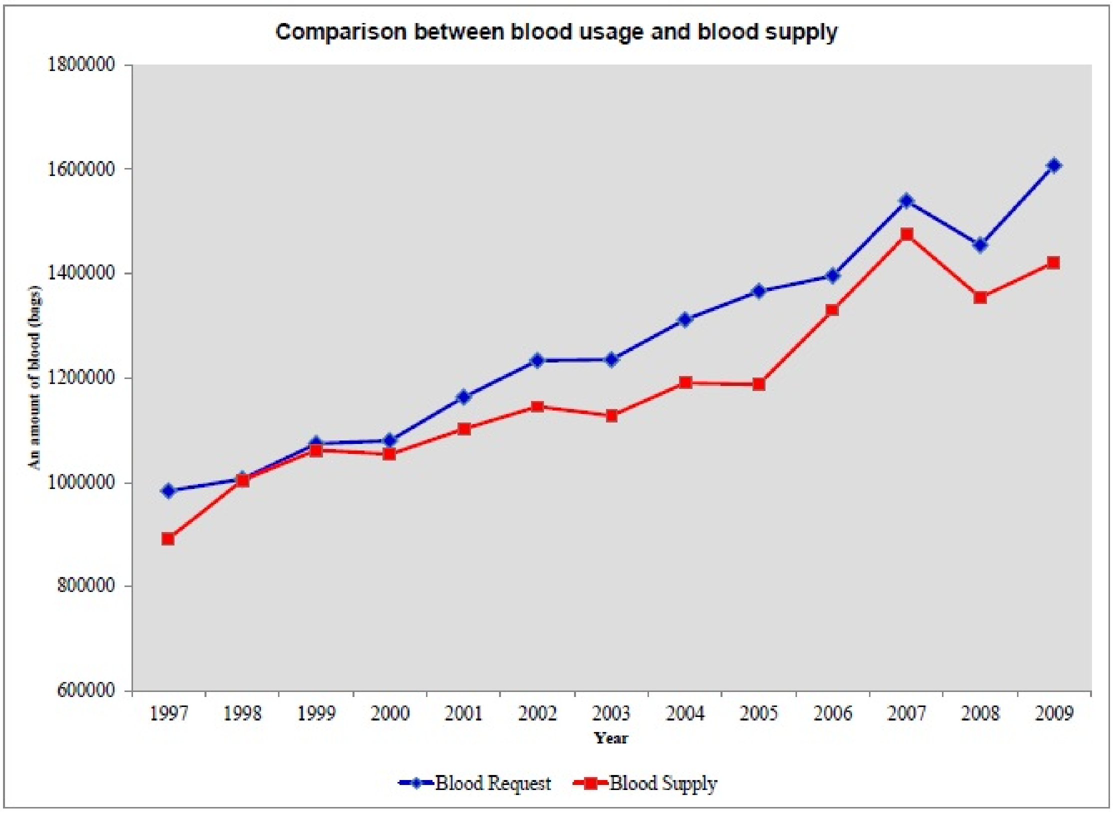


Figure 2.12: Comparison between red blood supply and blood requests (in bags) during 1997 - 2009

Table 2.4: Total blood collection in Thailand 2004-2009

NBC/RBCs	**Total blood bags collected**				
	2004-05	**2005-06**	**2006-07**	**2007-08**	**2008-09**
Bangkok	561,138	578,910	619,203	561,892	614,081
Provinces	957,853	1,091,687	1,182,165	1,127,730	1,051,049
Whole Country	1,518,991	1,670,597	1,801,368	1,689,622	1,665,130

The NBC has responsibility to distribute blood to Bangkok and to cities near the capital, but it also allocates blood to some RBCs because the quantity of donated blood at the RBCs is insufficient for provincial hospitals. The totals of blood collected in Bangkok and in the provinces (Sakuldamrongpanich, 2010*b*) can be seen in Table 2.4. The population in the provinces donated proportionately less blood than that from the Bangkok population. In 2007, about 43% of the total blood collected in Bangkok was delivered from the NBC to the regional hospitals. It is estimated that the sum of approximately 20,000 Thai Baht or 400 British Pound Sterling is spent daily on transporting blood from the NBC to RBCs throughout the country.

Moreover, blood shortages are experienced on a regional level, as shown in Tables 2.5 and 2.6, necessitating transportation of blood between the NBC and RBCs with a shortfall. In these tables, blood shortages (measured in bags) are calculated by subtracting the amount of blood usage from the amount of blood collected in each region (NBC, 2009). A negative number indicates that blood supply is greater than blood requests. It can be observed that most regions, except the Northeast region since 1998, have confronted situations of insufficient blood. In particular the North and Central regions have experienced the greatest shortages compared to the other regions. It can be noticed that blood shortage has arisen in Bangkok since the year 2003. Nevertheless, the NBC has continued to dispatch blood to RBCs in regions with a similar situation of shortage.

Table 2.5: Blood shortage (in bags) by different regions during 1997-2003

Region	**Year**						
	1997	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
North	26586	15408	15028	20532	31771	34012	51590
Northeast	2218	-24959	-20347	-13169	-11264	-6544	-8330
East	7179	-8514	-7422	-9938	-7913	292	-3893
Central	43878	31850	34755	36416	44956	54135	57752
Bangkok	-5351	-21187	-19904	-14277	-4521	-3480	4430
South	16876	9821	10046	6643	7850	10037	11529

(Negative amounts represent an excess of blood and positive amounts represent a shortage of blood)

Table 2.6: Blood shortage (in bags) by different regions during 2004-2009

Region	**Year**					
	2004	**2005**	**2006**	**2007**	**2008**	**2009**
North	66778	45994	35945	10315	57347	67347
Northeast	-19044	-3689	-31101	-23957	-22566	-4911
East	3483	13994	9137	9177	908	3130
Central	61766	57957	8288	34629	44696	96039
Bangkok	3525	20704	28290	19460	5494	7234
South	19602	22259	15826	14671	14482	16842

(Negative amounts represent an excess of blood and positive amounts represent a shortage of blood)

The different populations in the regions should be noted with regard to blood shortages. The Northeast region has the largest population, of approximately 18.9 million, while populations in the Central, North, South, Bangkok, and East regions are about 13.2, 11.6, 8.8, 8.3, and 4.9 million respectively (OSRS, 2009). Blood shortages in bags per 100 head of population, across the different regions, are compared in Figure 2.13 and also in Tables 2.7 and 2.8 (the latter show zeros for adequate supplies). It should be noted that in 2006, there was a severe blood shortage in Bangkok due to a protest against the government.

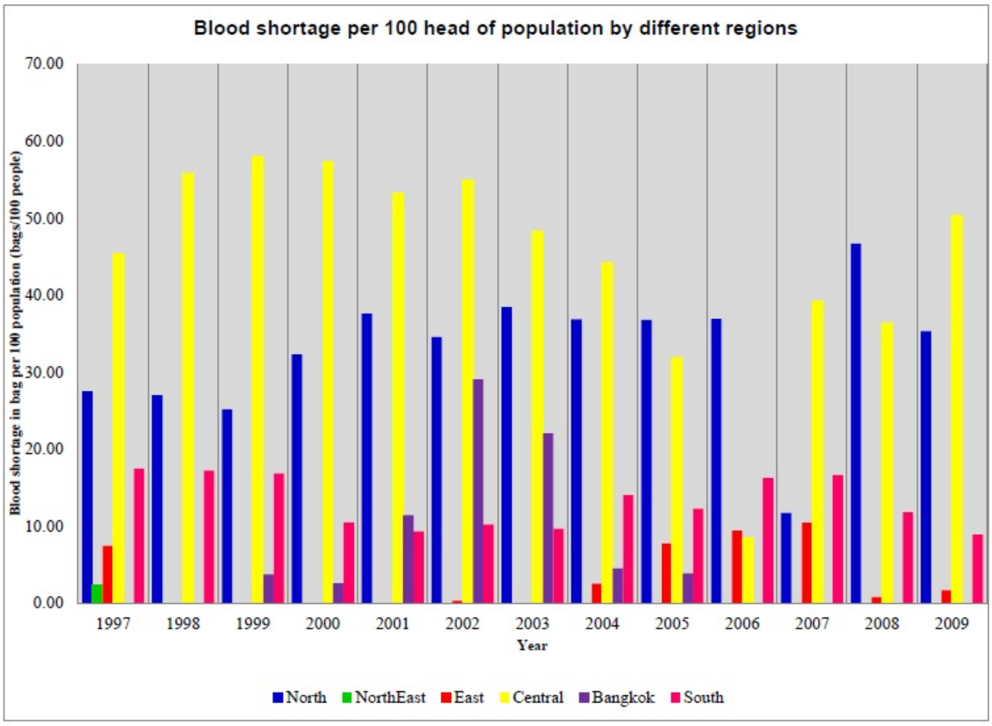


Figure 2.13: Blood shortage (in bag) per 100 head of population in different regions during 1997 - 2009

Table 2.7: Blood shortage (in bag) per 100 head of population in different regions during 1997-2003

Region	**Year**						
	1997	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
North	27.48	26.99	25.12	32.29	37.56	34.54	38.42
Northeast	2.29	0.00	0.00	0.00	0.00	0.00	0.00
East	7.42	0.00	0.00	0.00	0.00	0.30	0.00
Central	45.36	55.80	58.09	57.27	53.15	54.97	48.25
Bangkok	0.00	0.00	0.00	0.00	0.00	0.00	3.70
South	17.45	17.21	16.79	10.45	9.28	10.19	9.63

Table 2.8: Blood shortage (in bag) per 100 head of population in different regions during 2004-2009

Region	**Year**					
	2004	**2005**	**2006**	**2007**	**2008**	**2009**
North	36.86	36.75	36.87	11.69	46.65	35.34
Northeast	0.00	0.00	0.00	0.00	0.00	0.00
East	2.49	7.70	9.37	10.40	0.74	1.64
Central	44.13	31.90	8.50	39.24	36.36	50.39
Bangkok	2.52	11.40	29.02	22.05	4.47	3.80
South	14.00	12.25	16.23	16.62	11.78	8.84

The NBC plans to improve self-sufficiency of blood supplies in the different regions. To achieve this objective, the NBC plans that RBCs should perform full functions in the whole supply chain, including both collection, testing and distribution. However, one difficulty for new donor recruitment in rural areas of the country is that people with different educational background and culture lack understanding of the benefits of blood donation. RBCs were originally introduced as testing sites, without planning for other activities such as education. There has been short-term planning to extend capabilities of RBCs with new buildings in the following provinces (1) Phitsanulok (2) Khon Kaen (3) Nakhon Sawan (4) Nakhon Ratchasima and (5) Songkhla.

Recommendations for improvement in the locations of RBCs is a part of the objectives for this study. Some current RBC sites are not suitable to be a blood service centre, according to the Assistant Director of the NBC (Sakuldamrongpanich, 2010*a*). This is due to several key factors such as geographic position, demography, transportation infrastructure, and distance between hospitals. For example, the RBC at Nakhon Si Thammarat province would be better sited in Surat Thani province. Moreover, it appears that some hospitals pick up blood at RBCs other than those to which they are officially allocated. The allocation of hospitals to each RBC is thus problematic and in need of review. Additionally, building donation rooms as fixed stations to receive blood from donors is proposed in the long-term NBC plan. Donation rooms are expected to help increase the amount of donated blood from donors and to guarantee the standard of the blood donation process for both donors and patients.

A logistics system is also being considered by the NBC to determine the amount of blood equitably allocated to hospitals, with regular routes for blood distribution. Currently, no distribution schedules or routes for blood distribution to hospitals are planned. Hospitals must prepare their own transportation boxes to collect blood using their own vehicles. As a result, a hospital cannot manage its own blood stock efficiently and it is also difficult to control blood standard quality during transportation. Thus, the NBC is developing plans to manage delivery to hospitals and also to manage transportation costs.

Currently, policies for allocation of blood may vary between regions, depending on the policy laid down by an executive manager of each Regional Blood Centre. Day-to-day allocation for hospitals is based on the individual decisions of staff in the distribution department of blood centres. In general, hospitals receive less donated blood than they request because of blood shortages. Hospitals throughout the country are given a priority level for blood allocation. General hospitals, in particular private hospitals, have the highest priority because of the high volume of blood usage for treatment and a lack of capability for supplying safe blood by hospitals.

2.6 Case study: logistics and blood distribution in the upper North region

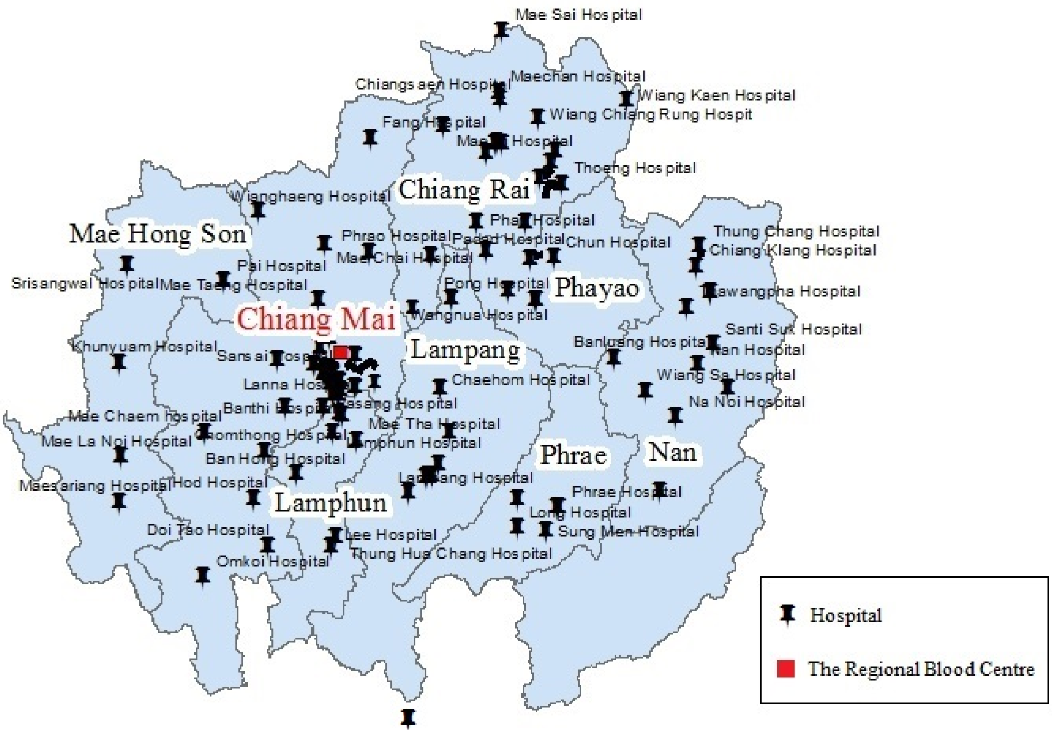


Figure 2.14: Location of hospitals in upper North region

The upper North region of Thailand was proposed by the deputy of the NBC for a case study for the purpose of development of a logistics plan and distribution policies, based on one RBC located in Chiang Mai province. The area includes a total of 112 hospitals of different sizes and types shown in the Appendix D, over eight provinces: (1) Chiang Mai (2) Chiang Rai (3) Lampang (4) Lamphun (5) Mae Hong Son (6) Nan (7) Phrae and (8) Phayao. Geographical locations of all hospitals can be seen in Figure 2.14. This study is expected to be a pilot for other regions of Thailand.

The hospitals are spread across the upper North region. The number of hospitals is different in each province, which vary by population and area as shown in Table 2.9. Hospitals can be divided by funding into Public and Private. Public hospitals can also be hierarchically classified by the number of beds provided to serve people in that area: as Regional, General, and Community hospitals (see Section 2.3. In addition to these three types of Public hospitals, there are military hospitals and specialised hospitals. Complete details of hospital types in this area are given in Appendix D.

Table 2.9: Profiles of provinces in the upper North region

Province	**Population**	**Area(km^2)**
Chiang Mai	1,640,479	20,107.00
Chiang Rai	1,198,218	11,678.40
Lampang	761,949	12,534.00
Lamphun	404,560	4,505.90
Mae Hong Son	242,742	12,681.30
Nan	476,363	11,472.10
Phrae	460,756	6,538.60
Phayao	486,304	6,335.10
Total	5,671,371	85,852.40

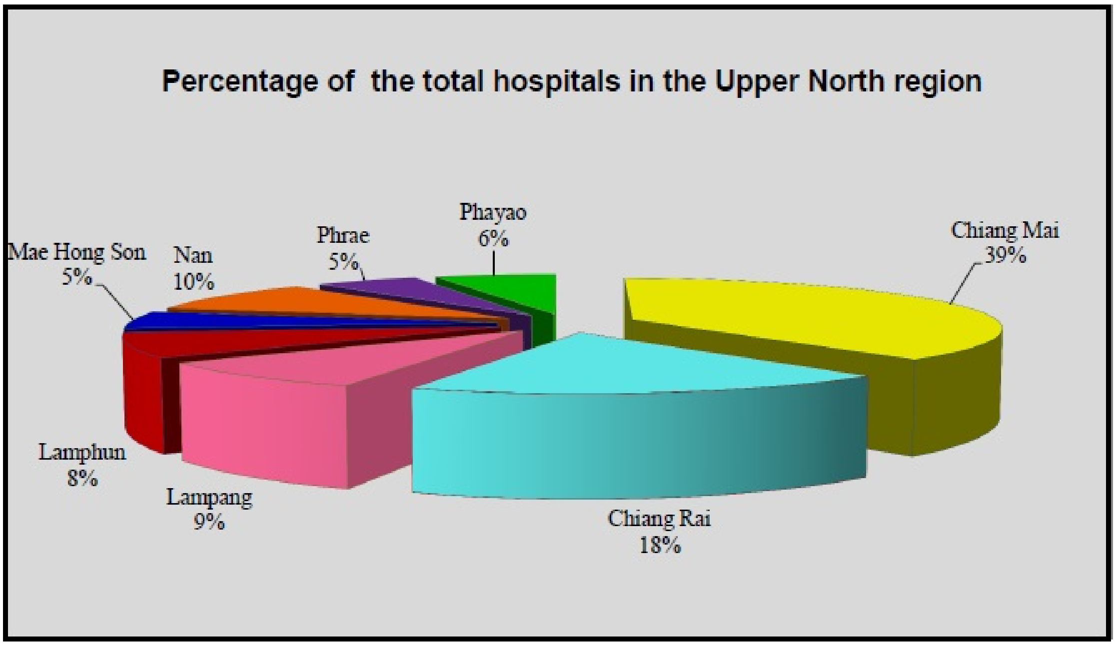


Figure 2.15: Percentages of the total of hospitals of the upper North region located in the eight provinces

Table 2.10: Numbers of hospitals by provinces in the upper North region based on hospital funding

Province	**Public hospital**	**Private hospital**
Chiang Mai	34	11
Chiang Rai	18	2
Lampang	6	2
Lamphun	8	2
Mae Hong Son	6	-
Nan	11	-

Continued on next page

Table 2.10: Numbers of hospitals by provinces in the upper North region based on hospital funding

Province	Public hospital	Private hospital
Phrae	4	1
Phayao	6	1
Total	93	19

The percentages of hospitals in each province out of the total of those in the upper North region are given in Figure 2.15, including both public and private hospitals. The number of hospitals is the greatest in Chiang Mai province: this is the largest province in the upper North region of the country, and it has the highest population. There are 112 hospitals, which consist of 98 public hospitals (83%) and 19 private hospitals (17%) throughout this area. The total numbers by province of both public and private hospitals are given in Table 2.10.

2.7 Summary and Conclusion

In this chapter, we have described important functions of the organisations which have responsibility for blood services in Thailand, the blood supply chain systems and logistics. Key aspects have been highlighted of the problems confronted in the country in the blood supply chain and logistics. Blood shortage is a serious problem, in particular in the provinces. Therefore, the design of locations for blood facilities and the logistic system are included in a long-term plan in order to improve the blood supply chain network over the country. A policy of establishing more fixed donation rooms and distribution sites is proposed to help increase the amount of donated blood and to transport blood to hospitals directly. Increased numbers of fixed collection stations are expected to make improved access for donors. Moreover, the building of new distribution centres can reduce total travel distances or the time taken to transport blood to hospitals. Furthermore, currently, there is no regular delivery plan for the hospitals and there is no equitable process for allocating scarce blood resources to hospitals. The blood inventory of hospitals is consequently difficult to manage and hospitals may waste time and money collecting blood at the NBC or RBCs, especially hospitals which are far from the blood centres.

In collaboration with the NBC, this research focuses firstly on the locations both of full RBCs, described in Chapter 5, and of fixed donation stations and distribution sites throughout the country, in Chapter 6. The upper North region is then studied as a prototype for design of weekly schedules for equitable blood allocation and delivery, with fixed routing analysed in Chapter 7 and variable routing in Chapter 8.

Chapter 3

Literature Review

Chapter 2 highlighted shortcomings of Thailand's blood supply chain and logistics in terms of location of blood centres and routing of vehicles to deliver blood to hospitals. As already mentioned in Chapter 1, this thesis therefore focuses on the Location-Allocation Problem (LAP) and Vehicle Routing Problem (VRP) and their variations, to conduct research on the supply chain and logistics for blood. These problems are reviewed in this chapter, which commences with a review of papers dealing with problems concerning the blood supply chain and related topics, with methods of solution, to set the stage for future chapters.

3.1 Blood supply chain

Efficient management of the blood supply chain and logistics can reduce costs and balance supply and demand. However, demand that outstrips supply and lack of collaboration between the various stakeholders in the process are challenges for managers. Dobbin et al. (2009) describe the process of the blood supply chain in the United Kingdom (UK) which is managed by National Health Service Blood and Transplant (NHSBT). 90% of blood can be collected by blood mobile vehicles and the rest can be obtained through static donor centres. Most blood comes from repeat donors in the United Kingdom (while 90% of blood in China comes from first-time donors). There are various blood service facilities: static donor centres, blood processing centres, and distribution centres. Whole blood is sent from static donor centres and mobile vehicles to ten blood processing centres around the UK and then sent to distribution centres for delivery to hospitals.

The range of problems related to regional or community blood centres are categorised by Pierskalla (2005): which functions should be performed at blood centres, locations for these centres, the number of community blood centres that should be located in a region, and allocation of transfusion services to the community blood centres. Other problems of the blood supply chain that are highlighted by Pierskalla include the collection of blood, producing multiple products, inventory control, allocating blood to the hospitals, blood delivery to multiple sites, issuing policies and crossmatching policies. Also taking a wide view of the blood supply chain, Rautonen (2007), in a study assessing the Finnish blood supply system, concludes that cooperation between blood services and both donors and hospitals can improve the national blood supply chain.

Delen et al. (2011) develop a blood reserve availability assessment, tracking, management system (BRAMS) which combines data mining, optimization, and GIS-based analytics to analyse the operations of the blood supply chain system. Nagurney and Masoumi (2012) concentrate on operations management for the path flows of a blood supply chain network and develop a multicriteria system-optimization on a single period for regionalized blood bank systems of the American Red Cross. The objective functions minimize the total costs (including the operating costs, discarding costs of waste and loss, the expected blood supply shortage costs, and the discarding costs of outdated blood) and total supply risk depending on a risk aversion factor defined by the decision maker.

Simulation has been widely used as a tool for decision-making in various application areas. It is an approach used to study management of blood supply chains and to investigate different policies because it can deal with a complex system for which it is difficult to find an optimal solution. Rytil and Spens (2006) apply a computer simulation to study the Finnish blood supply chain. The simulation model developed is used to explore eleven different scenarios with considerations of the outdate costs and backorder costs. Katsaliaki and Brailsford (2007) apply discrete event simulation (DES) model to examine policies for blood supply chain management from the donors to the recipients for hospitals in the United Kingdom. The supply chain includes both material flow and information flow.

Mustafee et al. (2009) extend the work of Katsaliaki and Brailsford to cases with numbers of hospitals varying from two to sixteen, using a distributed simulation approach based on parallel computing. Distributed simulation is found to shorten run times in comparison to simulation on a stand-alone platform: the processing time depends on the number of hospitals simulated. Kamp et al. (2010) study the availability of blood in the supply chain of Germany in the event of an influenza epidemic, using simulation to model the spread of influenza, based on a susceptible-infected-recovered model (SIR) model.

Platelets are a blood product with a short shelf life. They are produced in bone marrow, as are red blood cells and white blood cells, and they are used for treating patients with clotting problems. Management of platelets is more difficult than that of other blood products because they have a short shelf life of about five to seven days. Additionally, their production is expensive and complex. Ghandforoush and Sen (2010) develop a decision support system to support a supply chain of platelets, by optimizing the schedule of shuttles for transporting blood between regional blood centres and donation sites. A formulation based on non-convex integer programming cannot be guaranteed to reach global optimal: it is therefore converted to a linear 0-1 approach so that solutions can be obtained.

Supply chain systems for blood involve several sub-problems, which can be divided into inbound and outbound problems. Inbound problems relate to ordering policy and inventory management. Distribution and transportation of blood to hospitals are addressed in outbound problems, including policies to increase the blood distributed to hospitals. We continue by presenting literature categorised according to different issues in the blood supply chain.

3.1.1 Planning for donor recruitment and blood collection

A number of papers study factors or policies to increase the donor supply. Pitocco and Sexton (2005) evaluate the performance of blood centres for blood supply using Data Envelopment Analysis (DEA). Available resources are considered as constraints which involve the number of full-time and part-time employees, volunteers, budget, and population in that service area. Data used are based on the New York Blood Centre and the American Red Cross Blood Services. Schreiber et al. (2006) investigate important factors that have prevented donors from donating. Madden et al. (2007) examine the impact of using a specific technology for collecting red blood cells. A double red blood cell collection device can enhance the quantity of red blood cells. However, the economic issues for blood collection are not addressed in this study. Evidence shows that transfusion of blood stored for more than fourteen days leads to complicated sepsis and death in trauma victims. The model proposed by Cumming et al. (1976) is derived to schedule and reschedule a plan of blood collections in order to reach the target for donors. Pegels et al. (1993) argue for different policies for blood service by using a scheduling algorithm to arrange visits to organizations. Michaels et al. (1993) study donor scheduling systems for the American Red Cross using simulation.

3.1.2 Blood inventory management and blood issuing policy

Blood inventory management is a popular issue for researchers in healthcare and operational research. It is an important part of blood supply chain management since it can be used as a buffer to help balance blood supply and blood demand. Blood inventory management is different from that for other products due to the special nature of blood products. Jennings (1968, 1973) uses simulation to study the performance of inventory management for a hospital and region blood bank. Dumas and Rabinowitz (1977) study cross-matching policies to reduce blood wastage, focusing on a double cross-matching policy. In this policy, one unit of blood is reserved for two potential receivers instead of one.

Pereira (2005) studies the routine operation of hospital blood bank inventory using simulation modelling. The following factors which have affected the outdates and shortages are considered in the model: (1) the mean (MEAN) of daily blood transfusion (2) the variation (CVAR) of daily blood transfusion (3) the remaining shelf life of blood shipped from the suppliers (RSL) (4) the number of days between consecutive shipment (INT). The results show that MEAN and INT have little effect on the inventory, while RSL has a greater impact on inventory than INT. CVAR is the most significant factor in performance of blood inventory. In addition it is shown that hospitals where blood inventory has high CVAR should be supplied with the freshest blood; conversely, hospitals with low CVAR can be supplied with older blood.

Kopach (2008) uses simulation to compare models for inventory management with both urgent and non-urgent demand. Pegels (1978) describes development of OR models to determine inventory level based on the statistical distribution of the use of each blood type and forecast models which include collection, transfusion, and expiration forecasts. The results obtained from these models are used to define issuing policies for a blood bank to decrease blood shortage, the average age of blood transfused, outdating of blood and costs. It is found that a First-In, First-Out (FIFO) issuing policy is better than a Last-In, First-Out (LIFO) policy if the average number of days a blood unit remains on cross match is less than seven.

Sirelson and Brodheim (1991) develop simulation modelling to manage platelet inventory. Outdate and shortage rate are measured to evaluate performance. The results show that a base stock level based on the mean of demands added to the standard deviation can reduce the outdate and shortage rates. Moreover it is demonstrated that it is difficult to achieve low shortage and outdate rates for blood banks at a hospital level but this can be achieved for inventory on the regional level. Hesse et al. (1997) present an application of inventory management for platelets applied to a centralized blood bank which supplies 35 hospitals. The (s, S, t) policy is developed: the product inventory level is reviewed every t periods and if inventory is less than s, then an order is placed to increase inventory to S. Moreover dynamic programming is used for management of inventory; the simulation model is then used to test the results.

Haijema et al. (2007) propose a five-step approach to production and inventory management of platelets, based on a combination of a Markov Decision Process (MDP) and simulation. A double level order-up-to rule is shown to provide nearly optimal policies for a Dutch blood bank.

Prediction of blood demand at hospitals is another issue necessary to supply chain management (Rautonen, 2007). Frankfurter et al. (1974) propose a short-term blood inventory level forecast system in order to inform blood centres about the need for reducing or increasing blood collections. In addition, Lindsey and McGlynn (1988) find that the procedure of organ transplantation uses more blood than other surgical procedures. Pereira (2004) compares the performance based on goodness-of-fit statistics of three time-series methods: autoregressive integrated moving average (ARIMA), the Holt-Winters family of exponential smoothing models, and neural-network based methods to forecast the blood demand. It was found that ARIMA and exponential smoothing can provide the more accurate results over a one-year time horizon, while exponential smoothing generally outperforms the other methods.

3.1.3 Blood distribution scheduling

Prastacos (1978) derives a blood allocation algorithm to examine distribution policies. In particular, a rotation policy is used to allocate blood for each hospital in order to minimise shortage and outdate costs. In this policy, good unused blood can be returned to the blood centres and reallocated to other hospitals in the next period of time. The rotation policy is used in blood service centres in several regions of the United States. In this study, demand is modelled as a discrete random variable with a Poisson distribution. Results indicate that unused blood from one hospital should be reallocated to hospitals which have the same probability of blood outdate and shortage.

Brodheim and Prastacos (1979) develop the Programmed Blood Distribution System (PBDS) for the Long Island blood distribution system, for transfers of blood between a regional blood centre and hospitals. The delivery schedule is arranged based on statistical estimates of the demands of each hospital. Federgruen et al. (1986) discuss an allocation model for perishable products in order to distribute blood from a regional centre to hospitals which have random demands. Denesiuk et al. (2006) propose redistribution for near-outdated red blood cell units from low-usage sites to high-usage hospitals to reduce discard rates. Hemmelmayr et al. (2008) focus on daily delivery of blood to hospitals in Austria using fixed routes. The concept of a vendor-managed inventory system is considered in this study. An integer programming is formulated to minimize transportation costs; inventory and penalty costs are also included in the model.

3.2 Facility Location Problems

The facility location problem involves finding the optimal placement of one or more facilities to provide products or services at the right time and to the right people. Rapid distribution has an impact on the quality of healthcare products. It is clear that the closer a facility is located to a demand point, the better the quality of coverage (Dessouky et al., 2006). This section proceeds with descriptions and formulations of different versions of the Location-Allocation Problem, including particular blood-related problems.

3.2.1 Location-Allocation Problem

The Location-Allocation Problem (LAP) simultaneously addresses decisions on selection of locations for facilities providing products or services while allocating demand (or customer) points to such facilities, in order to optimise specific objective functions. Distance travelled or time taken to travel between demand points and facilities is often an objective component.

The discrete location problem is applied to finite sets of separate candidate location sites. Such problems can be classified (Dileep, 2001) into several broad groups, such as the p-median problem and variations, p-centre problems, covering problems and hub problems. Objective functions vary widely, whether in the public or private sectors. When considering the location of blood centres, this study seeks to improve donation while decreasing travel costs in supplying hospitals. We thus proceed to discuss two discrete models related to the study: the p-median model and the Maximal Covering Location model.

3.2.1.1 p-median Models

The p-median Problem, which represents a class of minisum location models, is introduced by Kuehn and Hamburger (1963). The objective minimises the demand-weighted average distance from demand points to nearest facilities, in order to find the optimal location sites for a given fixed number of facilities, p. The problem has been applied widely to public sector facilities. The formulation of the model is given below.

Notation

I	set of demand points
J	set of potential facility sites
p	maximum number of potential facility locations selected
q_i	demand associated with demand point i, $i \in I$
d_{ij}	distance between demand point i and potential facility at j, $i \in I, j \in J$

Decision variables are:

$$x_j = \begin{cases} 1, & \text{if a facility at node } j \text{ is open, } j \in J, \\ 0, & \text{otherwise.} \end{cases}$$

$$y_{ij} = \begin{cases} 1, & \text{if the demand node } i \text{ is assigned to a facility at node } j, \ i \in I, j \in J, \\ 0, & \text{otherwise.} \end{cases}$$

Minimise

$$Z = \sum_{i \in I} \sum_{j \in J} q_i d_{ij} y_{ij}, \tag{3.1}$$

subject to

$$\sum_{j \in J} x_j = p, \tag{3.2}$$

$$\sum_{j \in J} y_{ij} = 1, \quad \forall i \in I, \tag{3.3}$$

$$y_{ij} - x_j \leq 0, \quad \forall i \in I, \quad \forall j \in J, \tag{3.4}$$

$$x_j \in \{0, 1\}, \quad \forall j \in J, \tag{3.5}$$

$$y_{ij} \in \{0, 1\}, \quad \forall i \in I, \quad \forall j \in J. \tag{3.6}$$

The objective function (3.1) minimises the demand-weighted total distance travelled. Constraint (3.2) determines that p facilities are to be established. Constraints (3.3) mandate that demand nodes are assigned to exactly one facility. Constraints (3.4) mandate that demand nodes must be assigned to an open facility.

3.2.1.2 Maximal Covering Location Models

The model is formulated firstly by Church and ReVelle (1974). It has been widely employed in the sector of healthcare service and emergency services; the objective maximises the demand covered by a predetermined number of facilities, p.

Parameters are as follows:

D the distance beyond which a demand point is considered "uncovered"

M_i set of facility sites eligible to provide cover to demand point i: $\{j \in J | d_{ij} \leq D\}, i \in I$

Decision variables are:

$$x_j = \begin{cases} 1, & \text{1 if a facility at node } j \text{ is open, } j \in J, \\ 0, & \text{otherwise.} \end{cases}$$

$$z_i = \begin{cases} 1, & \text{if the demand node } i \text{ is covered, } i \in I, \\ 0, & \text{otherwise.} \end{cases}$$

Maximise

$$Z = \sum_{i \in I} q_i z_i, \tag{3.7}$$

subject to

$$\sum_{j \in M_i} x_j - z_i \geq 0, \quad \forall i \in I, \tag{3.8}$$

$$\sum_{j \in J} x_j \leq p, \tag{3.9}$$

$$x_j \in \{0, 1\}, \quad \forall j \in J, \tag{3.10}$$

$$z_i \in \{0, 1\}, \quad \forall i \in I. \tag{3.11}$$

The objective function (3.7) maximises the total demand that is covered. Constraints (3.8) ensure that demand at node i is counted as covered only if a facility site that can cover it is open. Constraint (3.9) determines the maximum number of facilities.

A formulation for a Capacitated Maximal Covering Location Problem based on that of Pirkul and Schilling (1989) is shown below. All demand is allocated to an open facility, given sufficient capacity. The demand covered within a given distance, D, is maximised. The following parameters are used:

Q_j capacity of facility at site j, $j \in J$

h_{ij} $\begin{cases} 1, & \text{if } d_{ij} \leq D, i \in I, j \in J, \\ 0, & \text{otherwise.} \end{cases}$

Decision variables are:

$$x_j = \begin{cases} 1, & \text{if a facility at node } j \text{ is open, } j \in J, \\ 0, & \text{otherwise.} \end{cases}$$

$$y_{ij} = \begin{cases} 1, & \text{if the demand node } i \text{ is served by facility } j,\ i \in I, j \in J, \\ 0, & \text{otherwise.} \end{cases}$$

Maximise

$$Z = \sum_{i \in I} \sum_{j \in J} h_{ij} y_{ij} q_i, \tag{3.12}$$

subject to

$$\sum_{j \in J} y_{ij} = 1, \quad \forall i \in I, \tag{3.13}$$

$$\sum_{i \in I} q_i y_{ij} \leq x_j Q_j, \quad \forall j \in J, \tag{3.14}$$

$$\sum_{j \in J} x_j \leq p, \tag{3.15}$$

$$x_j \in \{0, 1\}, \quad \forall j \in J, \tag{3.16}$$

$$y_{ij} \in \{0, 1\}, \quad \forall i \in I, \quad \forall j \in J. \tag{3.17}$$

The objective function (3.12) maximises the total demand that is covered within the coverage distance. Constraints (3.13) ensure that all demand nodes are served by exactly one open facility. Constraints (3.14) are the facility capacity constraints. Constraint (3.15) determines the maximum number of facilities.

3.2.2 Location problems related to blood

The Blood Transportation-Allocation Problem (BTAP) is defined by Or and Pierskalla (1979) in terms of how many central blood banks to set up and in which locations, which hospitals should be allocated to each blood bank, and how to route the periodic supply distribution so that the total of system and transportation costs, both emergency and periodic, are at a minimum. This problem is a combination of the General Transportation Problem (GTP) and the Location-Allocation Problem (LAP) with added considerations of emergency and periodic delivery costs. A heuristic algorithm is successfully used to provide solutions with data for the Chicago area.

Some complex problems of blood supply chain management have been decomposed into simpler sub-problems. Different objectives for each sub-problem are presented, with most papers focusing on minimising system costs, especially transportation costs. For example, Jacobs et al. (1996) consider a facility relocation problem of blood services in the mid-Atlantic region of the American Red Cross (ARC) in Norfolk, Virginia. Two Integer Programming models for collection and distribution are used to evaluate the total transportation costs. The costs of collection include a labour cost, which is, however, excluded in the distribution model. Dessouky et al. (2006) present separate models for location of facilities and vehicle routing in emergency distribution of supplies, motivated by supply of medicines but relevant to blood supplies.

Similarly, a sequence of models are designed by Sahin et al. (2007) to address the hierarchical location-allocation problem of the Turkish Red Crescent Society in organising blood supplies. The problem is formulated as three sub-problems. Firstly, a pq-median location model is proposed, where p and q refer to the number of lower-level and higher-level facilities respectively, in order to minimize the total of population-weighted distances travelled. Next, a set-covering model is used to find locations for blood donation stations. The final model based on integer programming is formulated to determine distribution of mobile units among the service regions.

Contrastingly, a multi-objective goal programming approach is employed by Cetin and Sarul (2009) for the blood bank location-allocation problem. A binary nonlinear goal programming model is formulated to minimise three objectives: the total fixed cost of location blood banks, the total distance travelled between blood banks and hospitals, and, unusually, an inequality index as a fairness mechanism for the distance. Sha and Huang (2012) propose a multi-period location-allocation model with Lagrangian relaxation for solving an emergency blood supply problem.

Some research combines blood inventory issues with location problems. Motivated by distribution of perishable produce such as blood products, Xu (1999) develops a joint inventory-location model for hospital blood banks. Total system costs are minimised: fixed costs, transportation costs and pooled inventory costs. A substitution algorithm is used to find solutions. A joint location-inventory problem with risk pooling is also considered by Shen et al. (2003) who group retailers and select one to be a regional blood centre for managing an inventory for platelets. The nonlinear integer programming model proposed is a modification of a set-covering model: it includes the inventory cost and the safety stock maintenance of the regional blood centres. Solutions are provided by a column generation algorithm.

3.2.3 Location problems related to other applications

Heuristics and meta-heuristics have been used to obtain results for large-sized facility location problems that cannot be solved using optimisation software. Valipour et al. (2013) propose Improved Particle Swarm Optimization (IPSO) to maximise the population-to-healthcare-facility ratio within a coverage distance. Shariff et al. (2012) present genetic algorithms to solve the Maximal Covering Location Problem for healthcare facility planning in Malaysia and compare results with those obtained using CPLEX. Mahmoudi and Shahanaghi (2013) propose Genetic Algorithm (GA) with randomly choosing one and two points for crossover operator and randomly choosing one, two, and three points for mutation operators to solve p-median location problem. It shows a better solution than that obtained using Daskin's Sitation software (Daskin, 1995).

3.3 Vehicle Routing problem (VRP)

The Vehicle Routing Problem (VRP) is recognized as an extensive problem in the transport and logistics areas of Operational Research. The VRP, proposed by Dantzig and Ramser (1959), designs a route for a vehicle to provide a physical product or services to a set of customers. It has been widely extended in a large variety of applications and has influenced the efficiency of supply chain systems. It is a generalization of the Traveling Salesman Problem (TSP) which involves determining the optimal route that starts and ends at the same location, while the VRP adds a decision about which customers are assigned to available vehicles with their capacity constraint.

The VRP can be represented on a direct graph $G = \{N \cup \{0\}, A\}$ as follows. The set of customers (N) are represented by nodes 1 to n, the depot is represented by node 0, and the entire set of nodes is represented by set $M = \{0, 1, \ldots, n\}$. The arc set is $A = \{(i, j) : i \in M, j \in M, i \neq j\}$ and each arc (i, j) has an associated travel distance $d_{ij}, i \in M, j \in M$. We assume link $d_{ij} = d_{ji}$, for $(i, j) \in A$. In the following chapters, arcs may also be described as links. A set of vehicles is denoted as $K = \{1, 2, \ldots, k\}$, where vehicles have capacity (Q_k); k represents the number of vehicles and each customer is associated with a demand (q_i).

3.3.1 The classical Capacitated Vehicle Routing Problem

The basic mathematical model for the capacitated vehicle routing problem proposed by Laporte and Nobert (1987) can be formulated as follows. The decision variables are

$$x_{ijk} = \begin{cases} 1; & \text{if node } i \text{ precedes node } j \text{ on the delivery route of vehicle } k,\ i \in M, \\ & j \in M,\ k \in K,\ i \neq j, \\ 0; & \text{otherwise.} \end{cases}$$

s_{ik} = auxiliary variable for sub-tour elimination constraints of node at site i in vehicle $k, i \in N, k \in K$.

Minimise

$$Z = \sum_{i \in M} \sum_{j \in M} \sum_{k \in K} d_{ij} x_{ijk}, \tag{3.18}$$

subject to

$$\sum_{j \in M} \sum_{k \in K} x_{ijk} = 1, \quad \forall i \in N, \tag{3.19}$$

$$\sum_{i \in N} \sum_{j \in M} q_i x_{ijk} \leq Q_k, \quad \forall k \in K, \tag{3.20}$$

$$\sum_{j \in M} x_{ijk} - \sum_{j \in M} x_{jik} = 0, \quad \forall i \in M, \quad \forall k \in K, \tag{3.21}$$

$$\sum_{j \in M} x_{0jk} = 1, \quad \forall k \in K, \tag{3.22}$$

$$s_{ik} - s_{lk} + n x_{ilk} \leq n - 1, \quad \forall i \in N, \quad \forall l \in N, \quad \forall k \in K, \tag{3.23}$$

$$x_{ijk} \in \{0, 1\}, \quad \forall i \in M, \quad \forall j \in M, \quad \forall k \in K. \tag{3.24}$$

$$s_{ik} \in \mathbb{I}^+, \quad \forall i \in M, \quad \forall k \in K. \tag{3.25}$$

The objective function (3.18) minimises the total distance travelled. Constraints (3.19) ensure that each customer is assigned to exactly one vehicle. Constraints (3.20) are used to guarantee that the total of items delivered by vehicle k does not exceed the vehicle capacity. Constraints (3.21) are the flow conservation constraint. Constraints (3.22) state that a vehicle must be used exactly once. Constraints (3.23) are the subtour-elimination conditions, derived for the TSP (Miller et al., 1960).

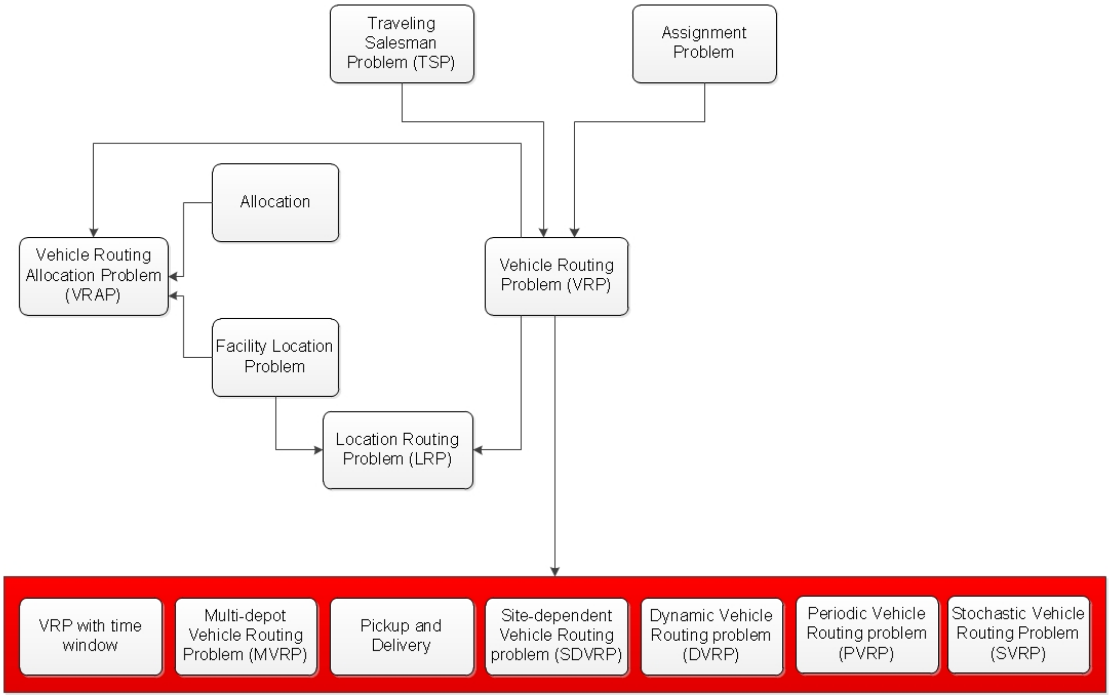


Figure 3.1: Vehicle Routing Problem and variant

There are variations of the VRP with different assumptions (see Figure 3.1). The Vehicle Routing Problem with Time Windows (VRPTW) (Desrosiers et al., 1995) defines that customers must be served within a specific time. The assumption with the Capacitated VRP (CVRP) (Dantzig and Ramser, 1959) is that the vehicles are homogenous and each vehicle has a certain capacity. The Vehicle Routing Problem with Pickup and Delivery (VRPPD) (Savelsbergh and Sol, 1995) focuses on the optimal routes to move products from certain pickup locations to different delivery locations. The assumption of the VRP with Backhaul (VRPB) (Goetschalckx and Jacobs-Blecha, 1989) is that all products must be delivered before they are collected at pickup locations. The Site-Dependent Vehicle Routing Problem (SDVRP) (Nag et al., 1988) allows several types of vehicles (heterogeneous) where some customers can be visited only by specific vehicles. The problem where vehicles are based at more than one depot is known as the Multi-depot Vehicle Routing Problem (MVRP) (Laporte et al., 1988). The Periodic VRP (PVRP) (Beltrami and Bodin, 1974) is a problem where a customer must be visited with a given frequency: this is explained in detail in the next sub-section. The Stochastic Vehicle Routing Problem (SVRP) (Gendreau et al., 1996) is a Vehicle Routing Problem where one or several components of the problem are random, such as stochastic demands, or stochastic times.

Only small VRP instances can be solved using exact solution methods to obtain optimal solutions (Toth and Vigo, 2002; Baldacci et al., 2010), while it takes a long time for computation of large scale instances of this problem because it is proved to be NP-hard (Lenstra and Rinnooy Kan, 1981; Mingozzi et al., 1999). Therefore, heuristic and meta-heuristic approaches have been applied to find near-optimal solutions within a reasonable processing time, such as the Clark and Wright algorithm (Caceres et al., 2013), Tabu Search (Sterzik and Kopfer, 2013), Simulated Annealing (Lin et al., 2006), Genetic Algorithm (Berger and Barkaoui, 2003; Wang and Lu, 2009; Ren, 2012), and Ant Colony Optimisation (Bullnheimer et al., 1999; Mazzeo and Loiseau, 2004).

3.3.2 The Periodic Vehicle Routing problem

The Periodic Vehicle Routing Problem (PVRP), which is considered as a generalisation of the vehicle routing problem for tactical and operational planning, dates back to the 1970s. It was first introduced by Beltrami and Bodin (1974) for waste collection. In principle, different customers can be served more than once in a given time horizon and the total demand in each route must not exceed a vehicle's capacity. The problem simultaneously selects a combination of visit days for customers and designs routes for vehicles in each day. The PVRP has been applied in various areas such as grocery distribution, waste collection, milk farm, and others.

Cordeau et al. (1997) first formulated the PVRP as a linear programming model. In the formulation, each customer may be visited more than once over consecutive periods of the planning horizon (T). Customer locations are defined as nodes on a complete directed graph with node set N and arc set $A = \{(i,j) \| i,j \in N, i \neq j\}$. Node 0 represents the depot and S is a subset of set N. The travel distance from node i to node j is given by d_{ij}. The capacity of vehicle k is Q_k, $k \in K$. The demand of customer i is denoted by q_i, $i \in N$. The allowable visit day combinations to node i are given by elements of set V_i : a_{rt} equals 1 if and only if day $t, t \in T$, belongs to visit combination $r, r \in V_i$. The PVRP can be formulated as shown below.

Decision variables are:

$$x_{ijkt} = \begin{cases} 1, & \text{if customer } j \text{ is visited immediately after visiting customer } i \text{ by vehicle} \\ & k \text{ on day } t,\ i \in N, j \in N, k \in K, t \in T; i \neq j, \\ 0, & \text{otherwise.} \end{cases}$$

$$y_{ir} = \begin{cases} 1, & \text{if visit combination } r \text{ is assigned to customer } i,\ i \in N, r \in V_i, \\ 0, & \text{otherwise.} \end{cases}$$

Minimise

$$Z = \sum_{i \in N} \sum_{j \in N} \sum_{k \in K} \sum_{t \in T} d_{ij} x_{ijkt}, \tag{3.26}$$

subject to

$$\sum_{r \in V_i} y_{ir} = 1, \quad \forall i \in N \setminus \{0\}, \tag{3.27}$$

$$\sum_{j \in N} \sum_{k \in K} x_{ijkt} = \sum_{r \in V_i} a_{rt} y_{ir}, \quad \forall i \in N \setminus \{0\}, \quad \forall t \in T, \tag{3.28}$$

$$\sum_{i \in N} \sum_{j \in N} q_i x_{ijkt} \leq Q_k, \quad \forall k \in K, \quad \forall t \in T, \tag{3.29}$$

$$\sum_{i \in N} x_{ilkt} - \sum_{i \in N} x_{likt} = 0, \quad \forall l \in N, \quad \forall k \in K, \quad \forall t \in T, \tag{3.30}$$

$$\sum_{i \in S} \sum_{j \in S} x_{ijkt} \leq |S| - 1, \quad S \subseteq N \setminus \{0\}; \quad |S| \geq 2, \quad \forall k \in K, \quad \forall t \in T, \tag{3.31}$$

$$y_{ir} \in \{0, 1\}, \quad \forall i \in N \setminus \{0\}, \quad \forall r \in V_i, \tag{3.32}$$

$$x_{ijkt} \in \{0, 1\}, \quad \forall i \in N, \quad \forall j \in N, \quad \forall k \in K, \quad \forall t \in T. \tag{3.33}$$

The objective function (3.26) of the model minimises the total distance travelled over the planning horizon. Constraints (3.27) ensure that one visit combination must be assigned to each customer. Constraints (3.28) are used to guarantee that each customer is visited on days corresponding to the visit combination assigned. Constraints (3.29) guarantee that the total of items delivered by vehicle k does not exceed the vehicle capacity. Constraints (3.30) are the flow conservation constraints. Constraints (3.31) are standard subtour elimination constraints.

3.3.3 Applications of the PVRP

The PVRP is more complex than the VRP: Cordeau et al. (2002) demonstrate that it is difficult to obtain optimality for large scale problems with greater than 50 customers. Thus, heuristics approaches are a potential way to solve this problem, as proposed by several authors. Beltrami and Bodin (1974) present a solution method with two phases: 1) routes are developed and assigned to day of the week, and 2) classical techniques of the VRP are used for individual days. Tan and Beasley (1984) assign customers to days, so that the total demand in each day does not exceed capacity, and then the VRP is solved for each day during the planning horizon. Customers are assigned priorities which are addressed in descending order for adding routes in each day in the model by Christofides and Beasley (1984). Francis et al. (2006) investigate metaheuristic approaches applied to this problem. Angelelli and Speranza (2002) introduce the PVRP with intermediate facilities for replenishment. Campbell and Hardin (2003) propose a greedy algorithm to minimize the number of vehicles for delivering products during the periods of the planning horizon. Claassen and Hendriks (2007) apply the periodic vehicle routing problem to collection of milk which is a perishable product. Pourghaderi et al. (2008) propose a simple heuristic for the periodic vehicle routing problem by applying insertion and removal rules.

Francis et al. (2006) study the PVRP in which the frequency of visits is not fixed but a minimum service level for each customer must be satisfied. Service frequencies are considered as variables. Coene et al. (2010) deal with collection of waste which is divided into low-risk waste and high-risk waste, with different planning periods in the two classes of waste. Each customer needs to be assigned a scenario which corresponds to their requested frequencies. Each vehicle can be assigned only a single route per day, and the number of driving hours per day and per week is restricted. The vehicles do not always need to be empty at the end of the day. There are time windows at certain disposal facilities, and a vehicle can dispose of its load during the route at the disposal facilities. The solution method has two phases: 1) customers are assigned to days 2) the VRP is solved. When assigning customers to days, there are two approaches: 1) striving for an even spread of the number of visits on a day and 2) using a geographically-based clustering approach. The results show that routing the customers before assigning them to different days in the planning horizon does not yield a good solution for this particular instance, while using the geographic structure yields a better routing plan.

Tabu Search (TS) has been widely used to solve the PVRP. Cordeau et al. (1997) explain the relationships among the PVRP, the Periodic Traveling Salesman Problem (PTSP), and the Multi-Depot Vehicle Routing Problem (MDVRP). Both PVRP and MDVRP are generalised versions of the VRP, while the PTSP is a special case of the PVRP obtained by setting the number of vehicles to one and the total duration and vehicle capacity to infinity. A TS heuristic is proposed to solve the three problems with the same algorithm for each problem except for a slight difference of the initialization procedure. Movement of neighbourhood in the TS becomes moving a customer between different routes and reassigning a new visit combination to a customer. The algorithm contains very few user-controlled parameters when compared with other TS applications developed for this problem. Angelelli and Speranza (2002) implement TS for the problem with intermediate facility warehouses for loading and unloading products. Yang and Chu (2000) solve a multi-depot PVRP to find the minimum number of delivery routes, by constructing routes for each day and combining routes on different days. Parthanadee and Logendran (2006) develop a TS algorithm to find the solution for the multi-depot

PVRP under limited supplies but allowing backordering requests (on returned stocks) by customers. The solution methods consist of two phases: firstly, constructing the initial solution using the cheapest insertion; and, secondly, generating neighbouring solutions.

In addition to the TS method, there are several heuristic approaches applied to solve the PVRP. Variable Neighbourhood Search (VNS) is first applied to the PVRP as a solution method by Hemmelmayr et al. (2008). VNS, which is a local search introduced by Mladenovic and Hansen (1997), consists of initialization, shaking, and iterative improvement steps. Nguyen et al. (2011) propose a hybrid Genetic Algorithm to handle the Periodic Vehicle Routing Problem with Time Windows. This is a population-based meta-heuristic method which provides high quality solutions when compared to other methods: VNS, Evolutionary Algorithm (EA), and a combination of column generation and evolutionary algorithm (CG-EA).

The PVRP is applied to blood delivery by Hemmelmayr et al. (2008). The solution approaches employed, based on integer programming and VNS, produce a regular timetable for the periodic delivery of blood products to hospitals, by the Austrian Red Cross. The authors consider a single blood product and assume known and constant daily demand for each hospital, estimated from a year's worth of historical demand data. However, the vehicle capacity is not included in the model. Results indicate that travel costs can be reduced by approximately 30% using this method.

Table 3.1: Summary of papers applying the Periodic Vehicle Routing Problem

Authors and Year	**Multiple vehicles**	**Supply constraint**	**Visit Frequency**
Tan and Beasley (1984)	Yes	No	Fixed
Cordeau et al. (1997)	Yes	No	Fixed
Francis et al. (2006)	Yes	No	Treated as a constraint
Parthanadee and Logendran (2006)	Yes	Yes	Fixed
Alonso et al. (2008)	Yes	No	Fixed
Hemmelmayr et al. (2008)	No	No	Fixed
Pirkwieseri and Raidl (2008)	Yes	No	Fixed
Pourghaderi et al. (2008)	Yes	No	Fixed
Wen et al. (2009)	Yes	No	Fixed
Coene et al. (2010)	No	No	Treated as a variable

A summary of some aspects of problems related to the PVRP in the literature is provided in Table 3.1. Many examples are concerned with multiple vehicle deliveries. However, it can be observed that only a few problems are concerned with supply restrictions or variable delivery frequency. Additionally, in all cases, demand is defined to be purely deterministic. Moreover, a single-, rather than multi-, criteria objective function is the focus of all the papers listed.

3.3.4 Dynamic Vehicle Routing problem (DVRP)

The Dynamic Vehicle Routing Problem (DVRP) (Wilson and Colvin, 1977), is a variant of the VRP in which requests from customers appear dynamically. More recently, this problem has been referred to as the Online Vehicle Routing Problem (Jaillet and Wagner, 2008) as advances in information and communication technology (ICT) have been applied to tracking and managing vehicles via online systems. Customer requests demanding goods or services can arrive dynamically, and the delivery routes are updated in real time. Requests from new customers who ask for service during the execution of planned routes is one dynamic component; other dynamic aspects of this real-world problem may be taken into account, such as unexpected traffic congestion, vehicle breakdown, and blocked roads. Most published papers focus on the dynamic request or demand side of the issue. In contrast, this research focuses on the dynamic supply side.

There are several variations to the DVRP. Campbell and Savelsbergh (2005) define the Home Delivery Problem as one that considers service to dynamic customer requests within a specific time. A Greedy Randomised Adaptive Search Procedure (GRASP) is proposed for solving this problem, to maximise the total expected revenue. Montemanni et al. (2005) apply an Ant Colony System (ACS) to solve the problem; a vehicle capacity constraint is included. Azi et al. (2011) focus on uncertainty of demand by generating different scenarios of the possible demands and applying an Adaptive Large Neighbourhood Search (ALNS). Ferrucci (2013) forecasts requests based on historical data to perform routing. Xu et al. (2013) formulate a mathematical model and apply an improved Variable Neighbourhood Search (VNS) algorithm into which a Simulated Annealing algorithm is integrated to solve the DVRP.

The Dynamic Multi-Period Vehicle Routing Problem (DMPVRP) is another problem related to the PVRP in which customer requests appear dynamically. Information about customer orders is not known at the beginning of the planning horizon and customers are visited exactly once. Wen et al. (2009) formulate a mixed integer linear program with multi-objectives and developed a three-phase heuristic to solve the problem: (1) selection of customers to be visited in the period of time, by considering travel time needed to visit each customer, (2) construction of the routes for each day using VNS and (3) post-optimization in order to minimize customer waiting and balance the daily workload as in the Capacitated Vehicle Routing Problem. The results show that the method can provide good solutions within a reasonable running time.

3.4 Location Routing Problem

The Location Routing Problem (LRP) involves making decisions both on the locations of distribution centres (DC) or depots and also on the allocation of customers to each DC by determining the transportation routes connecting customers and DCs. The LRP, which is important for supply chain and logistic systems, has been used since the 1970s; a review of the LRP is provided by Min et al. (1998). The main methodologies for solving the LRP can be classified into two approaches, namely exact algorithms and heuristics. Heuristic methods have been more widely used than exact methods, which have difficulty in handling the LRP when viewed as a combinatorial optimization problem (Liu and Lee, 2003, Tai-Hsi et al., 2002).

Table 3.2: Summary of methodologies for the Location Routing Problem (LRP)

No	Authors and Year	Solution methods
1	Gillett and Johnson (1976)	Multi-terminal sweep algorithm
2	Burness and White (1976)	An iterative procedure
3	Harrison (1979)	Location-Allocation First, Route Second and Saving
4	Or and Pierskalla (1979)	Location-Allocation First, Routing Second
5	Jacobsen and Madsen (1980)	Location-Allocation First, Routing Second and Saving and Tree Tour method
6	Laporte and Nobert (1981)	Two branching strategies
7	Nambiar et al. (1981)	Location-Allocation First, Routing Second
8	Laporte et al. (1983)	Integer programming
9	Perl and Daskin (1985)	Routing First, Location-Allocation Second, Improvement Procedure
10	Laporte et al. (1986)	Integer Programming
11	Bookbinder and Reece (1988)	Location-Allocation First, Routing Second
12	Simchi-Levi and Berman (1988)	Tour approximation and 1-median
13	Zografos and Samara (1989)	Mixed Integer and Goal Programming
14	Laporte and Dejax (1989)	Integer programming and Partition algorithm
15	Laporte et al. (1989)	Branch and Bound
16	Srivastava and Benton (1990)	Saving and Clustering
17	List and Mirchandani (1991)	Multiobjective and Partition algorithm
18	ReVelle et al. (1991)	Integer+Shortest Path and Weighting Method
19	Simchi-Levi (1991)	An iterative improvement algorithm and 1-median
20	Stowers and Palekar (1993)	Nonlinear Programming
21	Averbakh and Berman (1994)	Dynamic Programming
22	Min et al. (1998)	Location-Allocation First, Routing Second and Integer Programming
23	Chan et al. (2001)	Modified Clark-Wright heuristic (a saving - insertion method)

Continued on next page

Table 3.2: Summary of methodologies for the Location Routing Problem (LRP)

No	Authors and Year	Solution methods
24	Wu et al. (2002)	Simulated annealing algorithm
25	Liu and Lee (2003)	Route first, Location-Allocation Second
26	Barreto et al. (2007)	Sequential heuristic and Clustering
27	Ye and Li (2007)	Genetic Algorithm
28	Berger et al. (2007)	Branch-and-Price algorithm
29	Lopes et al. (2008)	Clustering and Integer Programming
30	Bozkaya et al. (2010)	GIS and Genetic Algorithm for optimization location and Meta-heuristics for vehicle routing problem
31	Prodhon (2011)	Hybrid evolutionary algorithm

Heuristics can solve large-scale problems with multi-phase decomposition solution procedures which are combinations of several algorithms, such as (1) location-allocation first, routing second (2) route first, location-allocation second (3) saving/insertion (4) tour improvement/exchange heuristics etc. Methods used for the LRP are summarised in Table 3.2.

There is plentiful research literature concerning the LRP: some highlights of papers follow. Wu et al. (2002) apply Tabu Search (TS) and Simulated Annealing algorithms (SA) for solving the multi-depot LRP without concern for inventory control decisions. Lagrangian relaxation with a sub-gradient search method is employed (Lashine et al., 2006) to solve the problem formulated as a mixed integer linear programming model. Ahmadi Javid and Azad (2010) introduce stochastic customer demand with Normal distribution and applied a hybrid algorithm based on TS and SA to improve a solution for the location-allocation and vehicle-routing phases.

In the combined location routing and inventory problem (CLRIP) (Liu and Lee, 2003), decisions are taken regarding vehicle routing, location-allocation and also inventory control. Both travel and inventory costs affect the total costs for a location decision. Liu and Lee (2003) apply a heuristic method to improve an initial solution for the multi-depot CLRIP obtained from considering the route first and the location-allocation second. Later, Liu and Lin (2005) propose using TS and SA to improve search heuristic methods in order to prevent being trapped in local optima.

3.5 Summary and Conclusion

In this chapter, we have reviewed literature focusing on blood supply chain management, facility location problems, and vehicle routing problems. The literature about the blood supply chain can be classified by the types of the problems as follows: (1) planning for collections (2) inventory management (3) distribution scheduling.

We highlight lacks in the literature that our research addresses. Papers concerned with location analysis for blood centres are generally focused on the objective of reducing costs such as those incurred through distances travelled. Cetin and Sarul (2009) provide an example of use of multi-objective goal programming approach, but without regard to improving blood supplies. Location of low-cost blood service facilities to extend an existing network of blood centres is also not considered to our knowledge. There are a few research papers concerning the PVRP and DVRP; heuristics and meta-heuristics are solution methods used often to solve these problems. However, no paper focuses on an imbalance between blood demand and blood supply, so often the situation in a developing country. To the best of our knowledge, no research has linked the DVRP to the situation of dynamically-changing availability of blood supplies or supplies of any other perishable product in a situation of shortage of supply.

Chapter 4

Data provision and preprocessing; preliminary statistical analysis

This chapter explains the data made available and the distance data preprocessing carried out before use in the models and algorithms implemented in Microsoft Visual Basic.NET. Significant results of statistical analyses of supply and demand data are illustrated. The penultimate section gives the specification of the computer used for calculations, and shows the conceptual layout of the database used to store the data used in the modelling. Finally, the conclusion summarises usage made of these data analyses in subsequent chapters.

4.1 Data provided

The main sources of data regarding nationwide blood donations were obtained from ten years of the National Blood Centre (NBC) Annual Reports (NBC, 1999-2009), supplemented by unpublished documents for 2010-11. These data included blood donated within each province of Thailand. Donations took place at the NBC, at RBCs and at individual hospitals; all blood donations were sent on to testing facilities at the NBC or RBCs. Figures used in calculations include only blood donations found to be safe.

Data were made available for the case study of blood distribution in the upper North region. Daily blood requests from each hospital in the upper North region are manually recorded on paper by staff working at Chiang Mai's RBC: these data were collected from March 2011 to July 2012 and hand transcribed to the database.

Costs of establishing donation rooms and distribution centres depend on land prices, equipment costs, and operations costs: these costs were obtained from proposals made to the NBC. Land prices depend on the different location areas, as shown in Appendix B.1. Distribution sites need additional equipment for preparing and storing blood. Thus, costs of equipment for distribution sites are higher than costs of donation rooms: approximately 2,073,000 Thai Baht (or 41,460 Pound Sterling) for the donation rooms and 13,773,000 Thai Baht (or 275,460 Pound Sterling) for the distribution sites.

4.2 Distance Data Preprocessing

All paired shortest paths between nodes were obtained using OD Cost Matrix in ArcGIS software based on the real road network in Thailand provided by the Thailand MOT Transport Fundamental Geographic Data Set (FGDS).

Distance data were obtained by the Geographic Information System and then imported to a Microsoft Excel file for pre-processing prior to exporting to a Microsoft Access database. Figure 4.1, 4.2 and 4.3 show the procedures to calculate distances between locations of the NBC, RBCs, and hospitals, along the road network. The steps are as follows:

1. The specific addresses of the NBC, the 12 RBCs, the candidate locations for blood service facilities, and 112 hospitals in the upper North region were marked. Those placemarks were saved as a kml file format of Google Earth.

2. DNR Garmin software was then used to convert from a kml file to a shape file using ArcMap 9.x projection capabilities.

3. The OD Cost matrix tool of the ArcGIS Network Analyst Extension was used to calculate the shortest path and the transportation cost between a finite set of network points. The distance matrix or an origin-destination matrix was exported as a spreadsheet file.

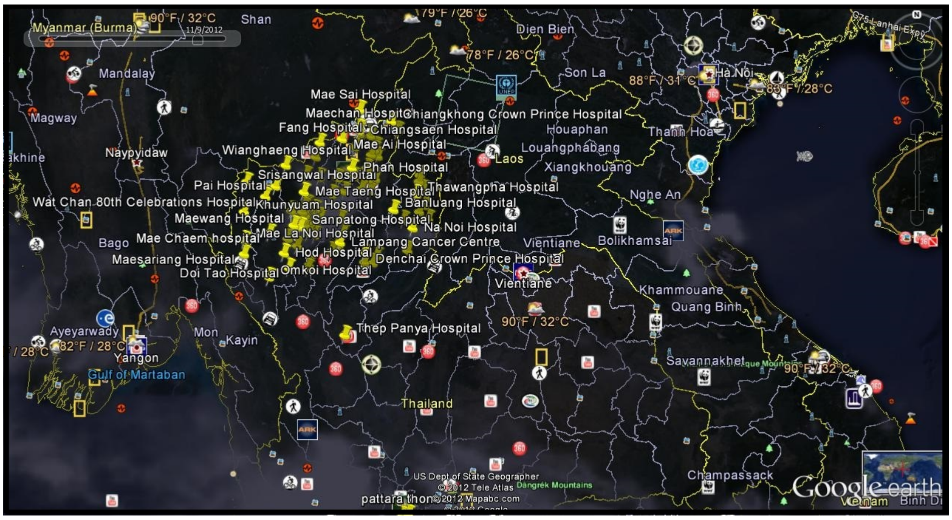


Figure 4.1: Plotting hospitals in Google Map

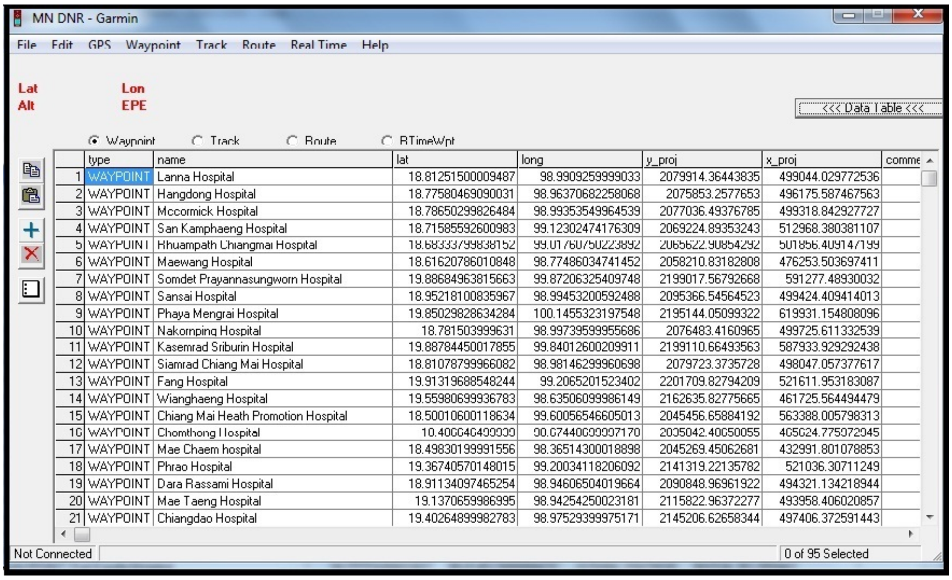


Figure 4.2: Snapshot screen of MN DNR Garmin software

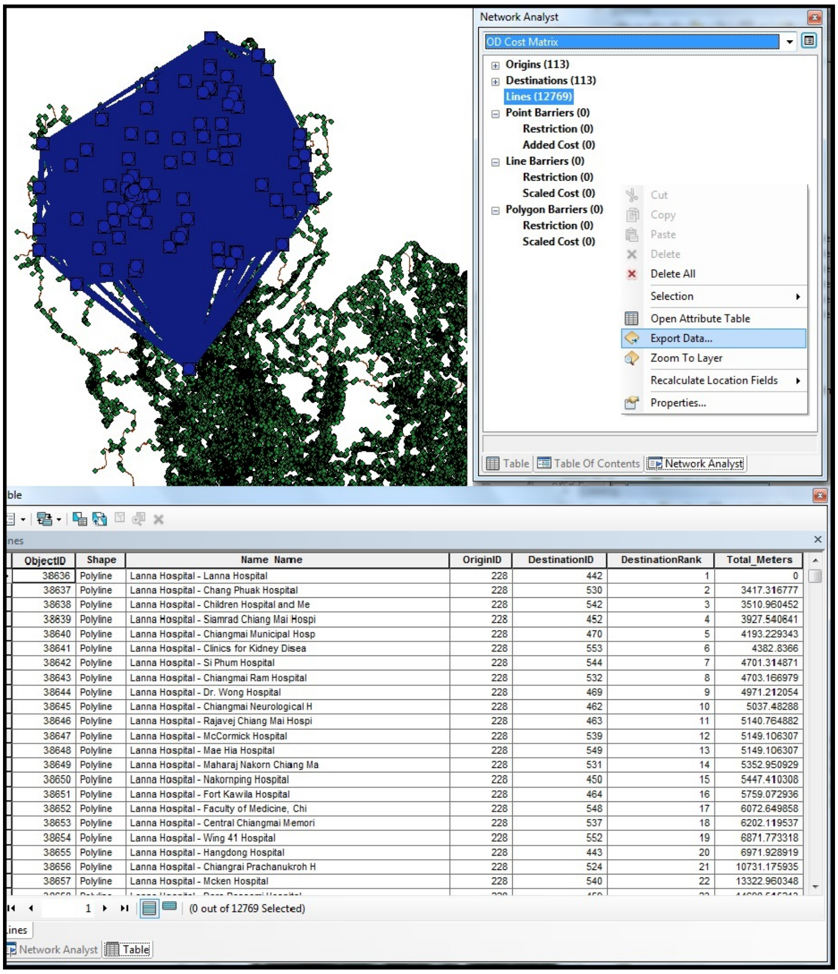


Figure 4.3: Calculating distances using O-D matrix in ArcMap and exporting data

The maximum speed limit for roads in the rural parts of Thailand is 90 kph: this speed is assumed for all travel time calculations. In particular, the upper North region is largely rural and so such speeds apply for the routing calculations. Travel times were calculated between each pair of nodes in the distance matrix.

4.3 Descriptive Statistical Analysis

This section describes statistical analysis of data collected at the RBC at Chiang Mai regarding blood requests by hospitals in the upper North region and blood supplied by the RBC to these hospitals. Firstly, data are analysed regarding frequency of blood collections made by hospitals: these data inform the subsequent designs of blood allocation and routing policies for this region. Next, average daily blood requests are analysed by month of the year and compared to average quantities supplied. A second comparison is then made of actual supply and demand for one week of the study period: both these comparisons demonstrate blood shortages in the region. Subsequently, time plots are examined and autocorrelations carried out for daily amounts of blood both requested and supplied over the study period, in order to determine trends and weekly patterns. Finally, histograms are presented and tests for normality carried out of amounts of blood supplied on each weekday: these analyses enable samples of daily blood supplies to be generated for subsequent algorithm tests.

4.3.1 Frequencies of blood collections made by hospitals

Data regarding frequency of blood collections and quantities of blood requested were analysed for hospitals in the upper North region of Thailand. Figure 4.4 shows monthly frequencies of blood collections carried out by hospitals, plotted against distance of the hospitals from the RBC. There is a moderate negative correlation between frequency and distance, with Pearson's correlation coefficient equal to -0.528, significant at the 0.01 level. It can be observed that as the distance from the Regional Blood Centre (RBC) to the hospital increases, the visit frequency mostly decreases. In particular, the number of collections made by hospitals drops off to no more than twice weekly where hospitals are more than about 70km from the RBC. These patterns of making collections are made use of in the planning of blood deliveries from the RBC, described in Chapters 7 and 8.

Figure 4.5 shows quantities of blood requested by hospitals over the period of one month, plotted against the numbers of beds in the hospitals. There is a moderate positive correlation between the quantity of blood requests made by a hospital and its number of beds: the Pearson's coefficient for the correlation between these variables is 0.575. These

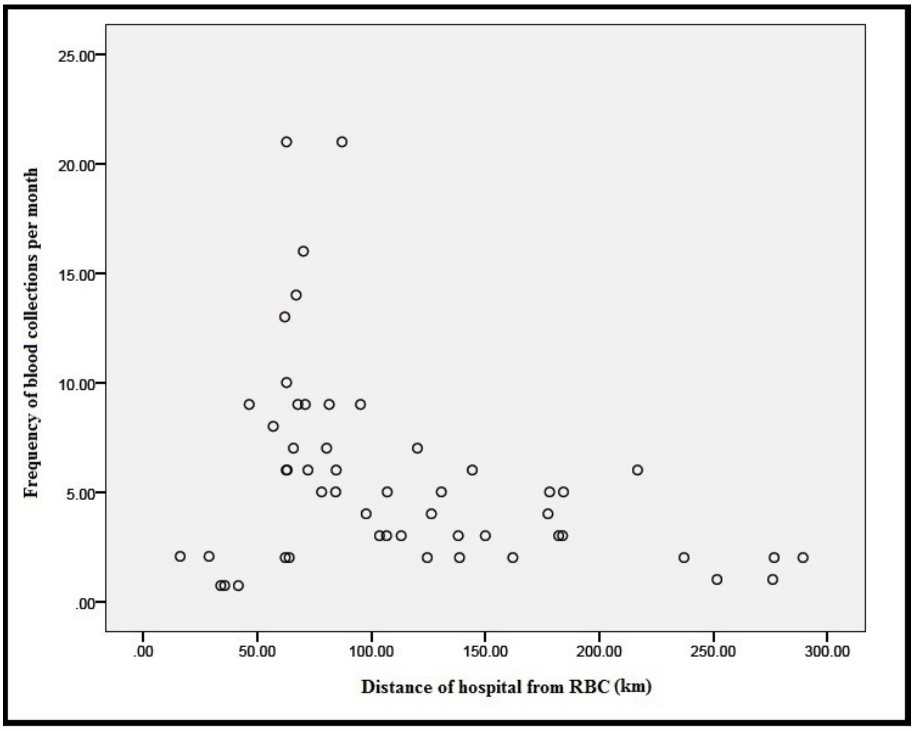


Figure 4.4: Scatter plot of frequency of blood collections by hospitals against distances from RBC

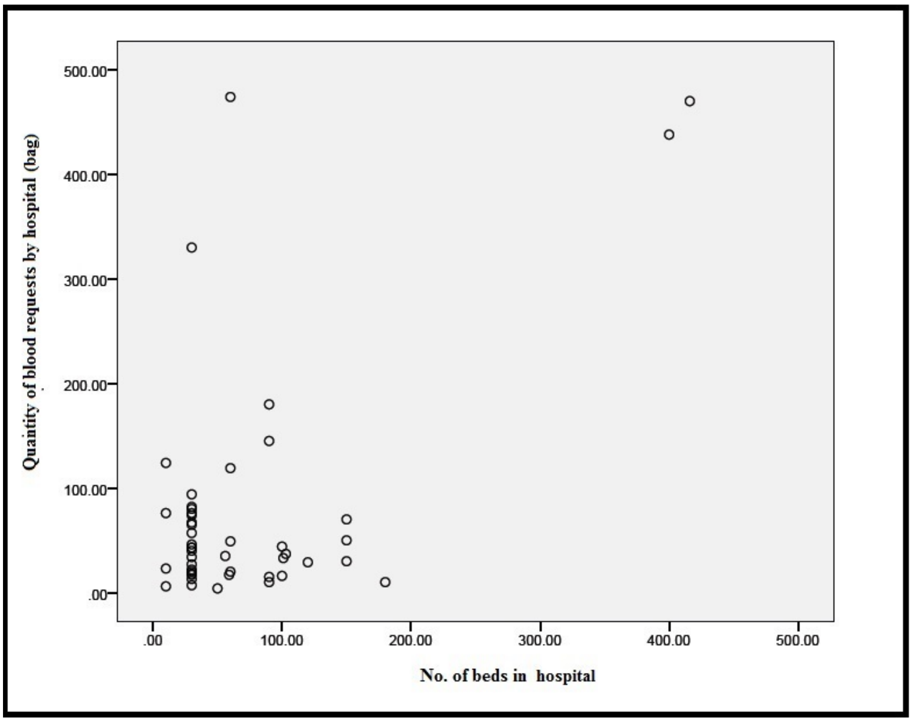


Figure 4.5: Scatter plot of quantities of blood requested by hospitals against numbers of beds

observations are made use of in prioritising blood allocations in conditions of scarcity, as described in Chapter 8.

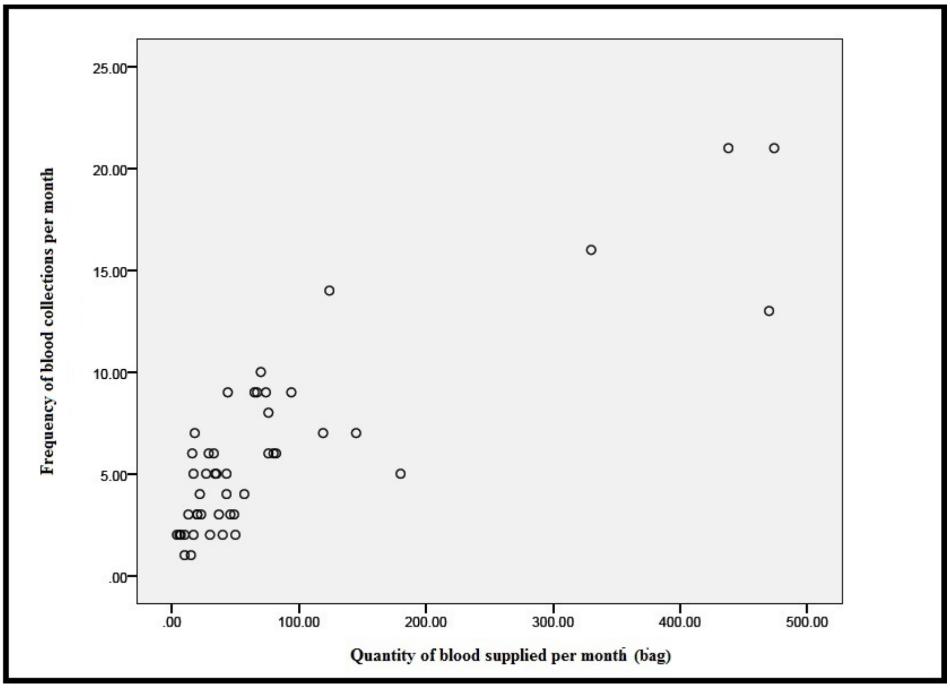


Figure 4.6: Scatter plot of the visit frequency and the amounts of blood requested

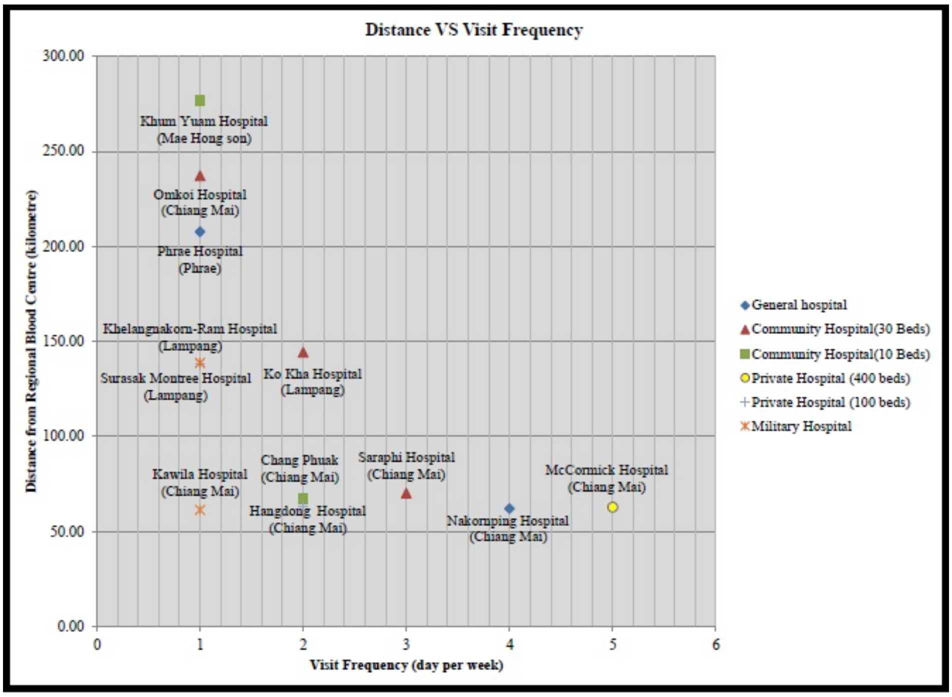


Figure 4.7: Relationship between visit frequency for selected hospitals and distance from RBC

On the other hand, it can be seen in Figure 4.6 that the delivery frequency of the hospitals varies according to the amount of blood requested, with high correlation (r = 0.845). This results from the fact that the RBC cannot allocate enough blood to satisfy the demand of hospitals in one delivery.

The visit frequencies of selected hospitals in the upper North region were analysed according to distance from the RBC and type/size of hospital. According to Figure 4.7, blood is more often collected by hospitals which are not far from the RBC at Chiang Mai. Moreover, the visit frequencies for each hospital depend on the size of the hospital, as this has an effect on the blood usage.

4.3.2 Daily blood requests by hospitals

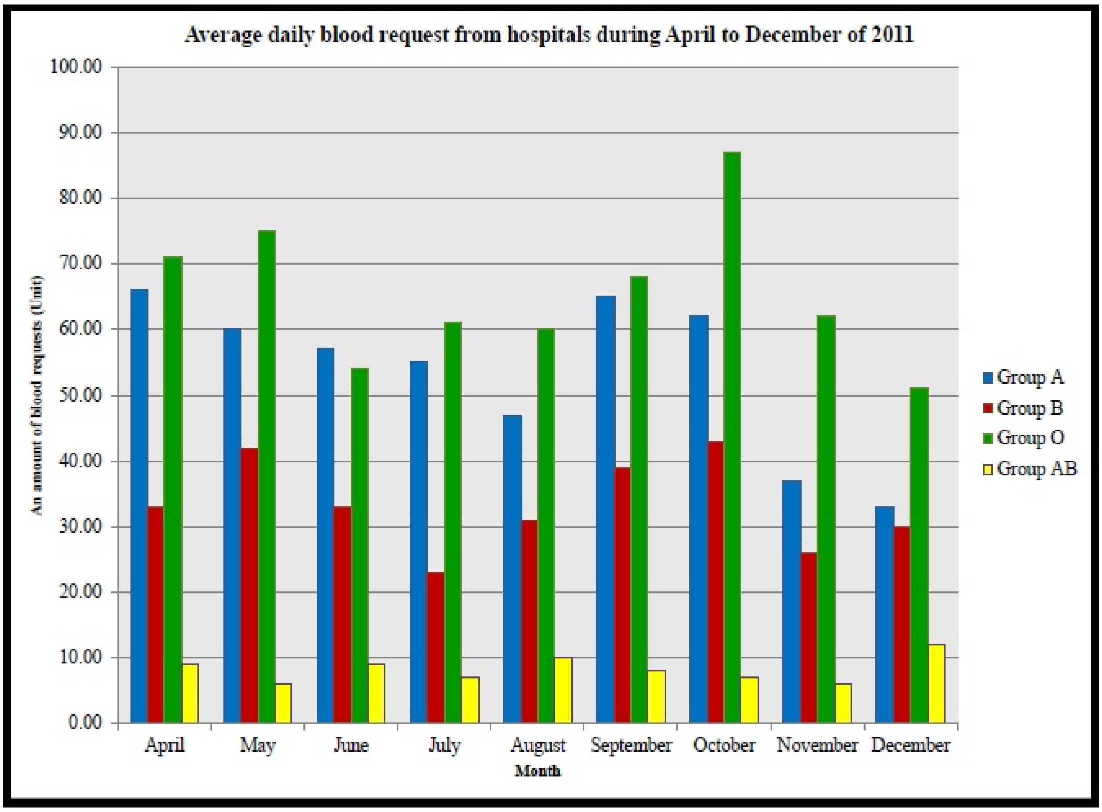


Figure 4.8: Average daily total blood requests (in bags) of hospitals in the upper North Region from April to December, 2011

Blood requests to the RBC were studied from all hospitals in the upper North Region, during the study period of April to December, 2011. It can be seen in Figure 4.8 that blood groups A and O are much required. This corresponds to the fact that the proportion of the population having blood groups A and O is higher than that of other blood groups in the country.

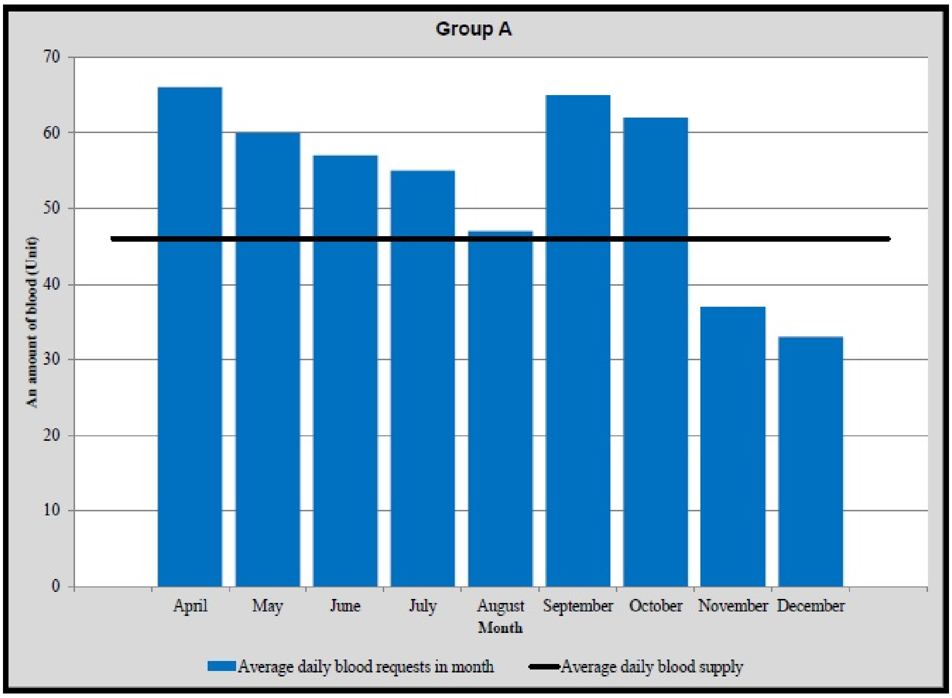


Figure 4.9: Average daily blood requests and supply (in bags) for blood group A in the upper North Region between April and December of 2011

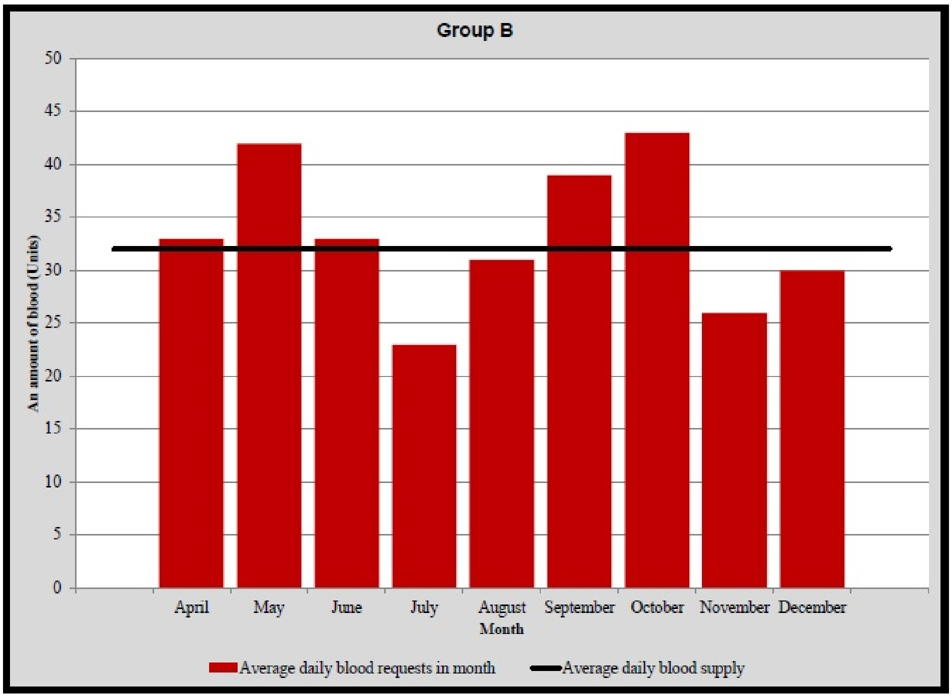


Figure 4.10: Average daily blood requests and supply (in bags) for blood group B in the upper North Region between April and December of 2011

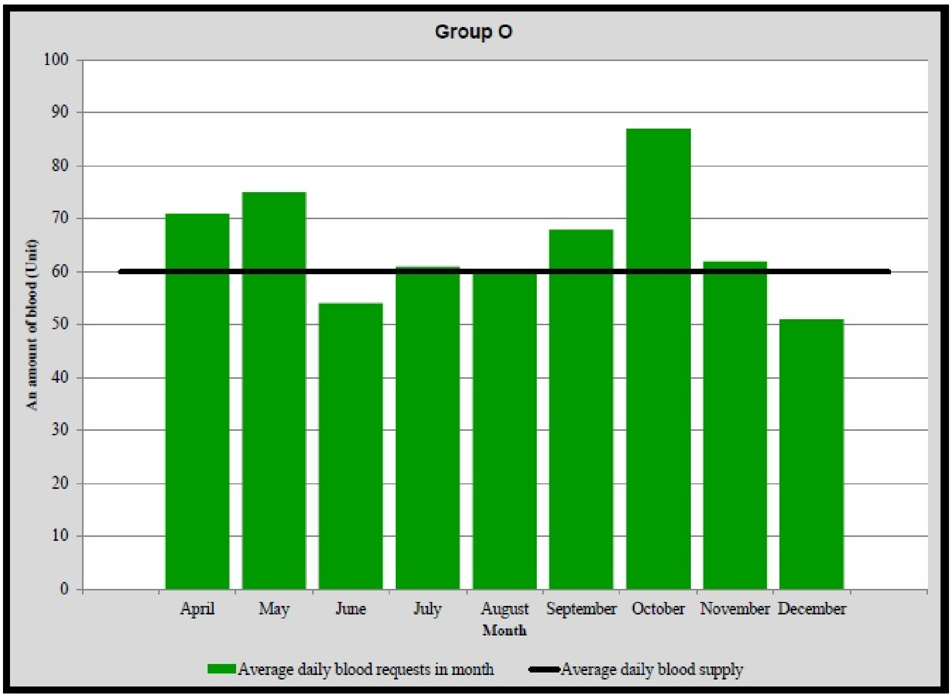


Figure 4.11: Average daily blood requests and supply (in bags) for blood group O in the upper North Region between April and December of 2011

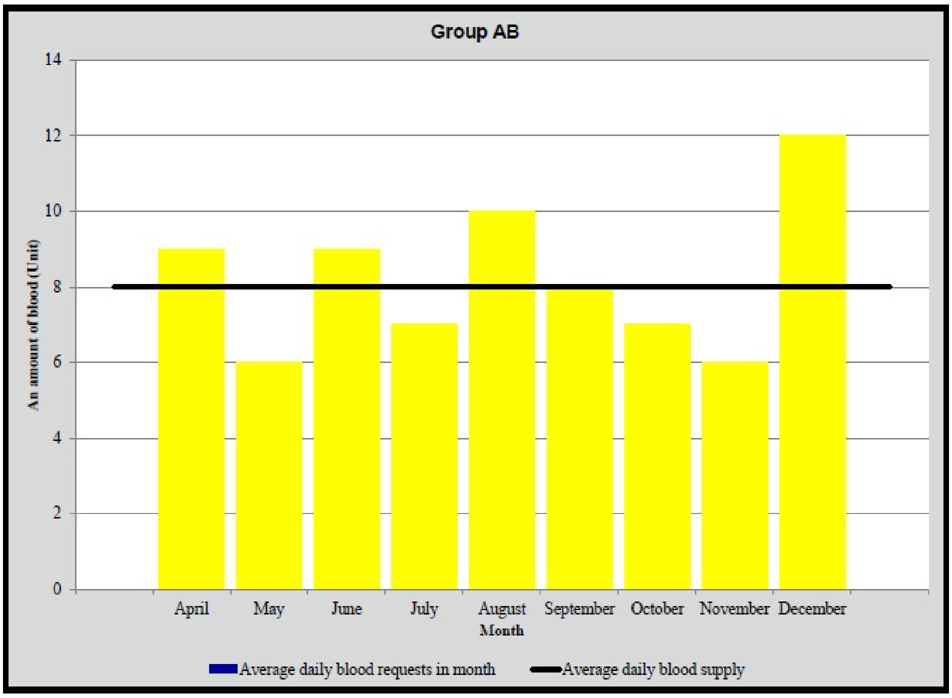


Figure 4.12: Average daily blood requests and supply (in bags) for blood group AB in the upper North Region between April and December of 2011

Figures 4.9, 4.10, 4.11, and 4.12 show the average daily blood requests over the study period (in units of blood bags) from the hospitals located in the upper North region (see details in Chapter 2) in comparison to the average daily blood supplies for the different blood groups (shown by a solid line). These averages were 46 blood bags for group A, 32 bags for group B, 60 bags for group O, and 8 bags for group AB. It can be seen that blood shortages and excessive blood supplies occur in some months. Blood requests are the highest in October for group O: Thai schools have term breaks in October of every year, and consequently there are a lot of accidents occurring in that month.

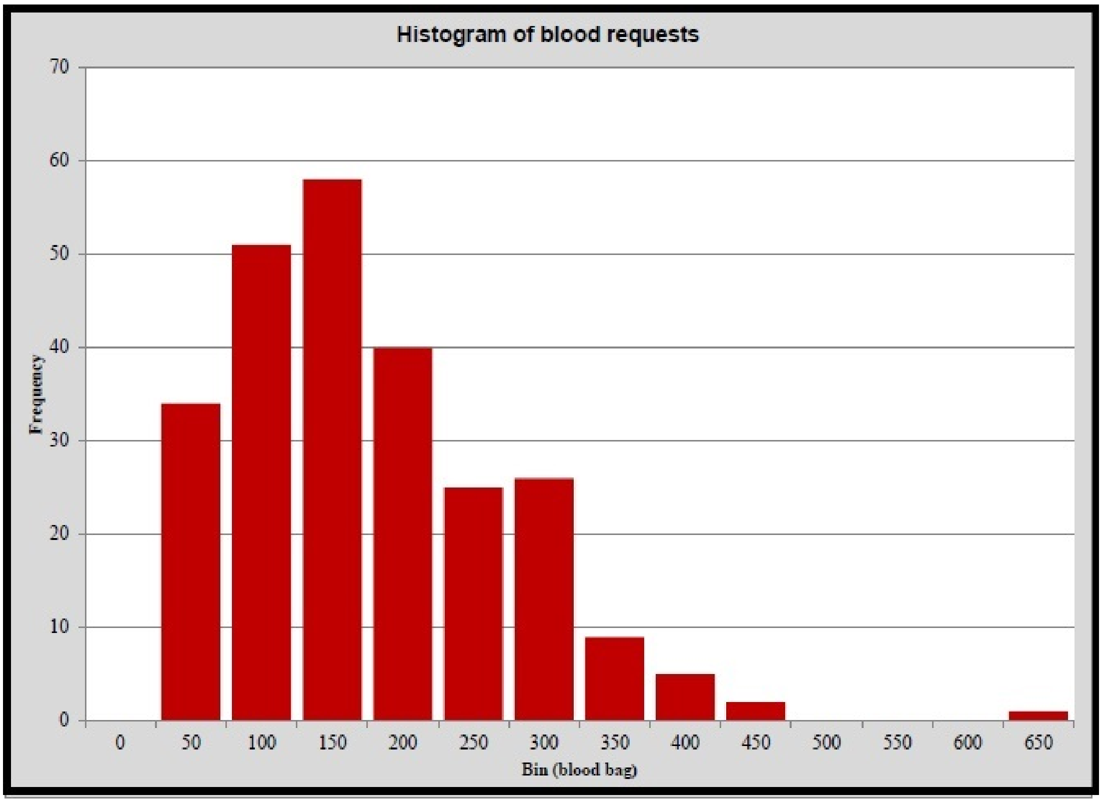


Figure 4.13: Histogram of monthly blood requests (in bags) for all blood groups during April and December of 2011

Total numbers of blood bags requested daily by all hospitals over the study period is shown in Figure 4.13. The shape of the histogram is said to be right-skewed which means there is a tail in high values. For this distribution, the median is less than the mean: the median and mean values are 140.00 and 152.40 blood bags respectively.

4.3.3 Analysis of an actual week of blood supply and demand

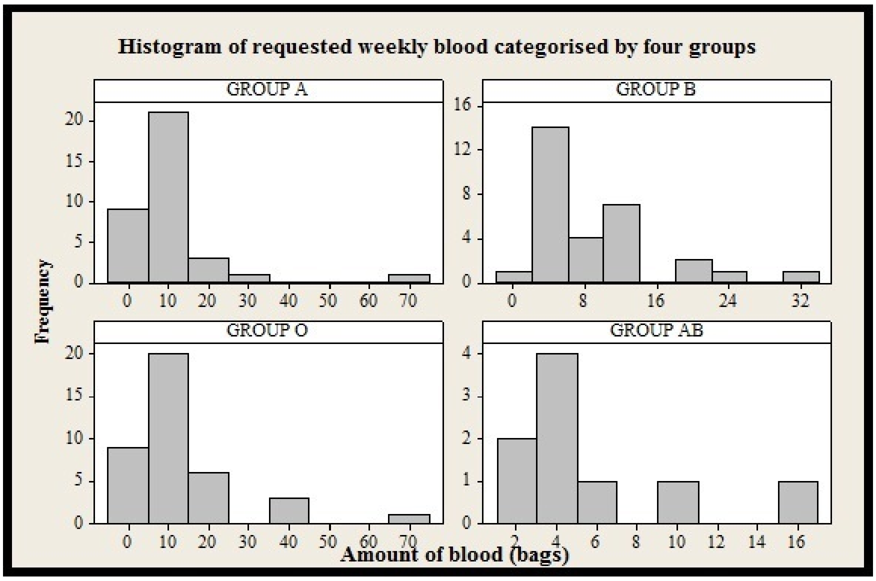


Figure 4.14: Histogram of weekly blood requests (in bags) from hospitals

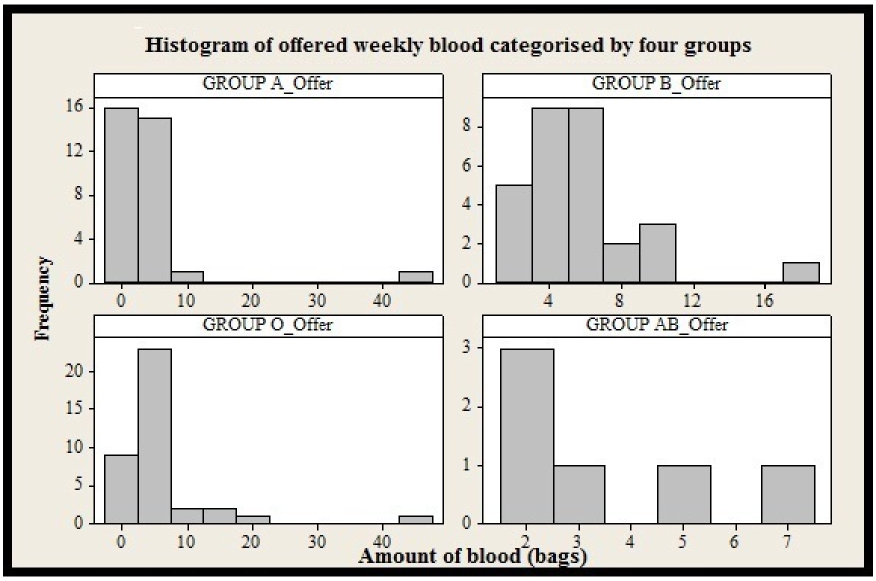


Figure 4.15: Histogram of weekly blood (in bags) supplied to hospitals

Actual total supply by the RBC in Chiang Mai and demand from hospitals in the upper North region were compared for a week of early July 2011. Figure 4.14 shows the frequencies of the number of units red blood cells requested by hospitals. It demonstrates that A and O blood are the blood types most required by hospitals during this week. The frequencies of the amounts of blood (in bags) supplied to hospitals by the RBC during this week are shown in Figure 4.15. Most data points fall to the left of the middle;

there are more exceptionally small than exceptionally large values. The histogram is thus slightly skewed to the right, or positively skewed. Most of the blood supplied to hospitals is between 5 and 10 bags for blood group A, B, and O, while there is little blood of the AB group supplied to hospitals. Comparison of the two figures shows that, in this week, the amount of blood groups A, O and AB collected is less than the quantity of blood requested for patients. In contrast, the amount of B group blood is greater than requested.

4.3.4 Time series plots of blood requested and supplied

Time series were analysed of daily amounts of blood requested and supplied, in order to determine overall patterns. Plots are shown in Figures 4.16 and 4.17, giving numbers of blood bags requested by hospitals and supplied to hospitals. The data covered the period from April 2011 to July 2012, except between January and March of 2012 and some short periods when no data were recorded. The average for this period of time is used to represent missing data and is drawn as a solid horizontal line: at 160 bags for blood requests and 126 bags for blood supplied. Thus, it can be noted that more blood is requested than the amounts of blood collected from donors. It is difficult to detect a pattern in the time plot: there is no consistent trend over the entire time span, but there are considerable random variations. It can be observed, however, that the variance of amounts of blood supplied in the year 2012 is less than the variance in year 2011. There are some obvious outliers, possibly due to a time of rioting in Bangkok.

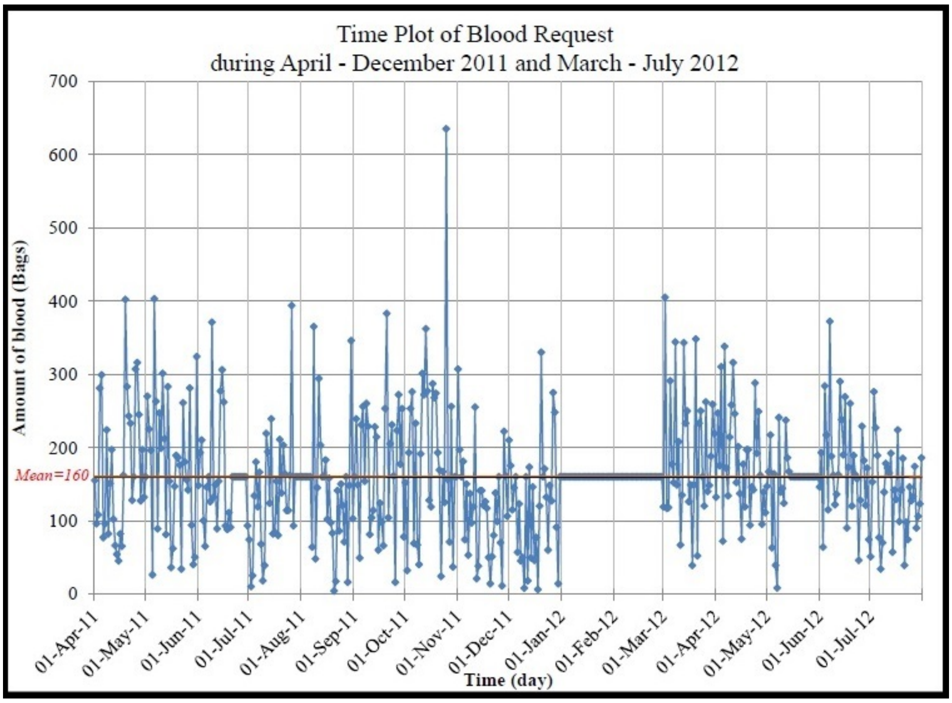


Figure 4.16: Time plot of daily blood requests in bags between April 2011 and July 2012

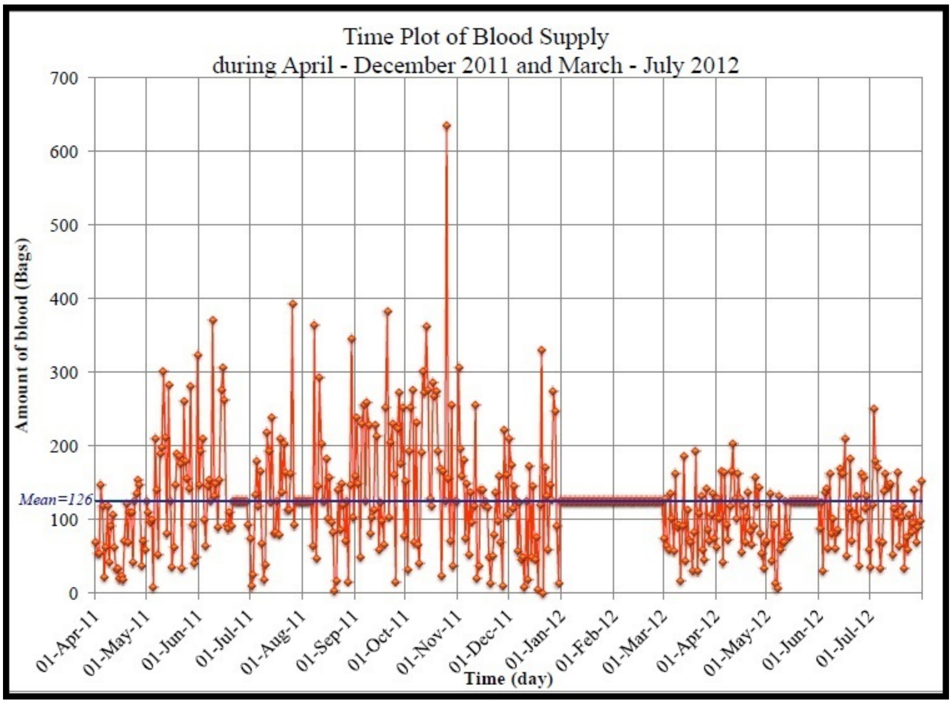


Figure 4.17: Time Plot of daily blood supply in bags between April 2011 and July 2012

4.3.5 Autocorrelations of amounts of blood requested and supplied

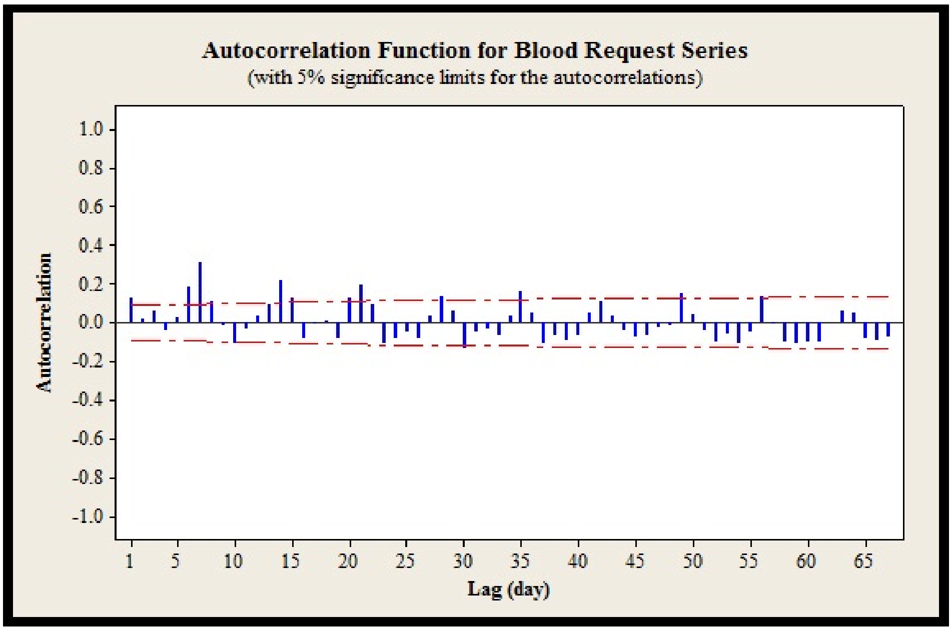


Figure 4.18: Autocorrelation of blood request

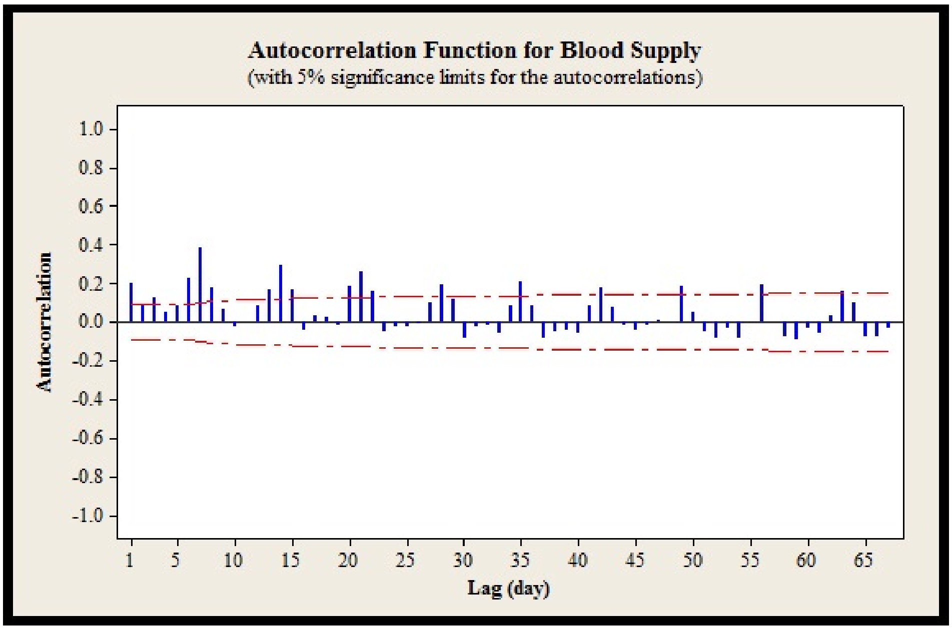
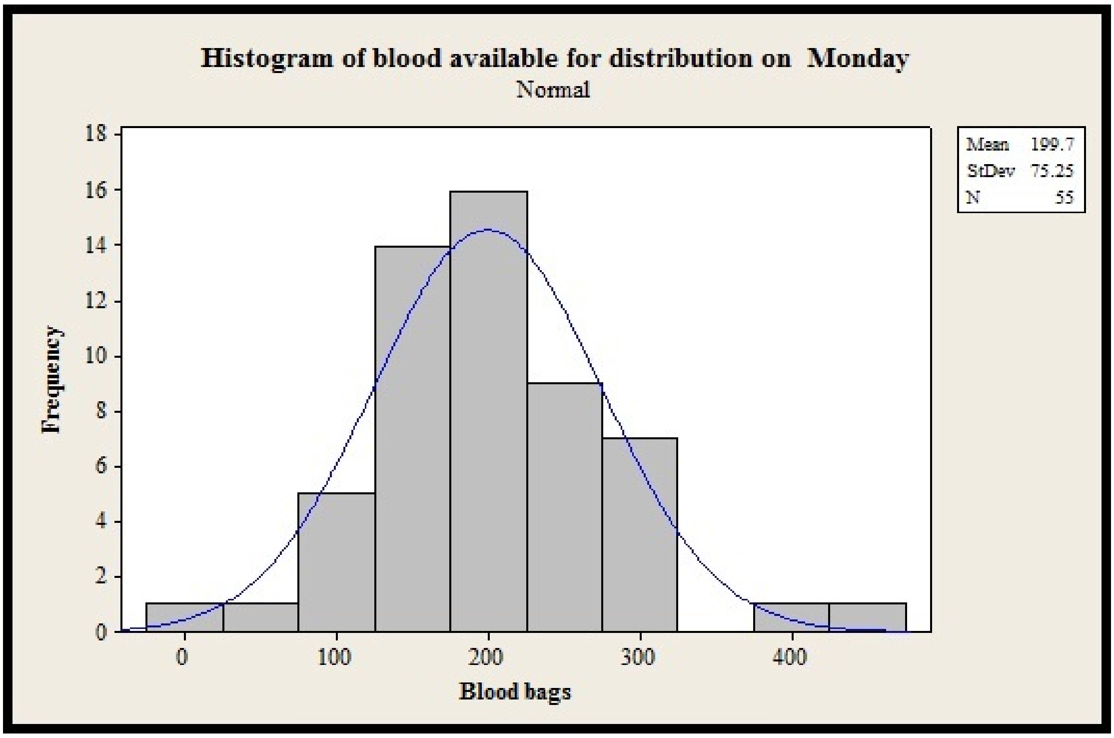


Figure 4.19: Autocorrelation of blood supply

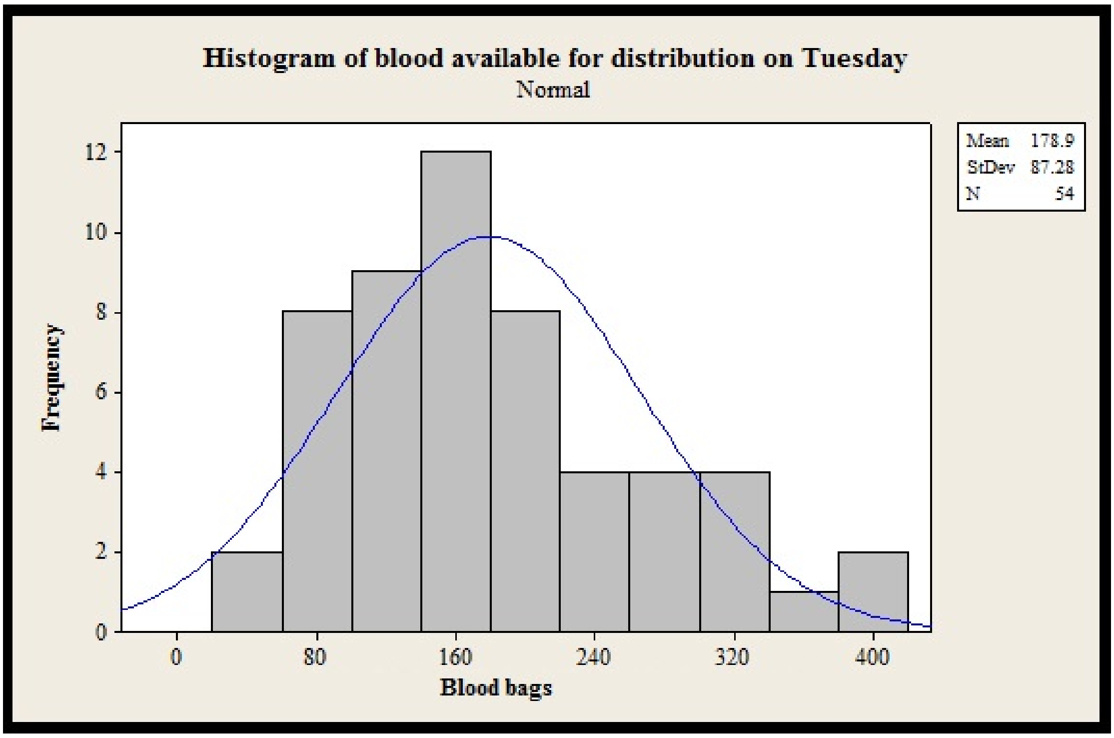
Autocorrelations of the amounts of blood requested and supplied are analysed in order to investigate weekly seasonality of the time series. Figures 4.18 and 4.19 show plots of the autocorrelation functions (ACFs) made using Minitab. The plots continue to $n/4$ or 65 lags which is the standard recommended length of an ACF plot. The dashed red lines show the $\pm$ standard errors. If one or more lags are outside these dashed lines, the lags are significantly different from zero and the series is not white noise, as is indicated for these time series. The ACFs of both blood requested and supplied shows an oscillation: autocorrelation coefficients at time lags 1, 6, and 7 are significantly different from zero. A weekly pattern for both blood requests and blood supplied is thus indicated.

4.3.6 Analysis of daily blood supplies

Histogram charts are displayed in Figure 4.20, showing average daily amounts of blood supplied, from Monday to Saturday, based on data from April 2011 to July 2012, where available. In addition, Figure 4.21 shows probability plots for daily amounts of blood available for supply. The amounts of blood available for distribution on each day of the week were tested for normality using the Kolmogorov Smirnov test: P-values were 0.150, 0.067, 0.062, 0.111, 0.114, and 0.113 for days from Monday to Saturday respectively. These values are greater than the critical value of 0.05 and thus the test does not reject the null hypothesis of population normality. In other words, it can be concluded that the data for all weekdays can be fitted by Normal distributions. These distributions are used to generate samples of blood available on each day for testing the online system of blood distribution (see details in Chapter 8).

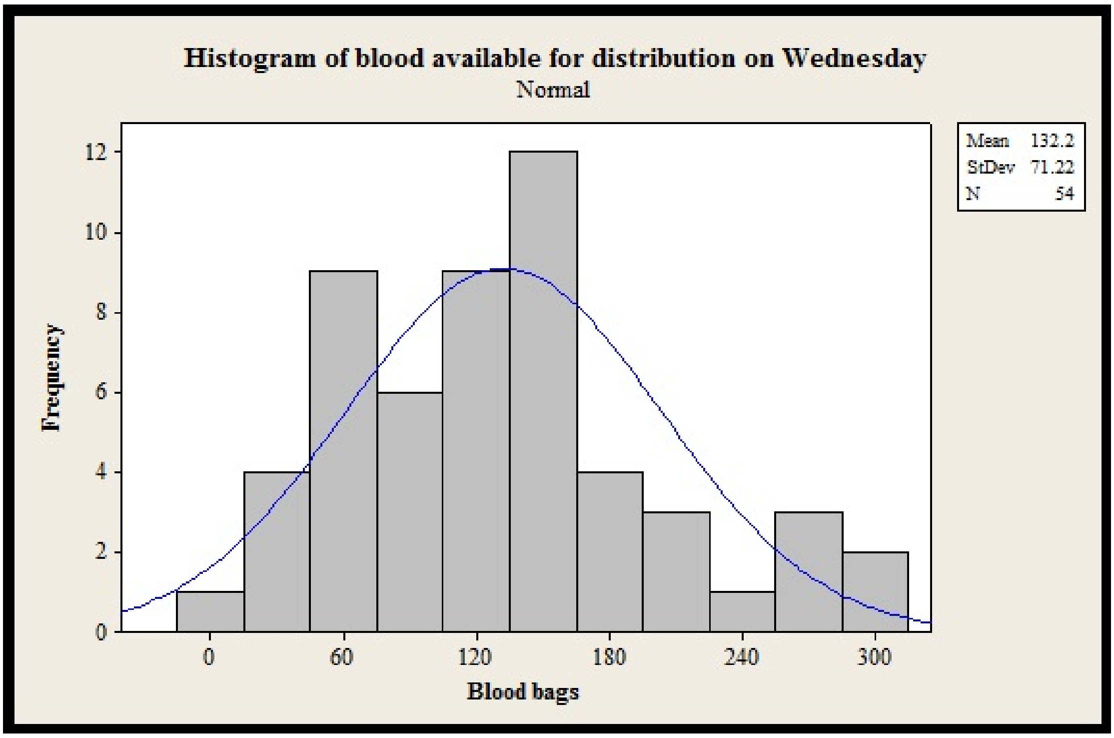


(a) Monday

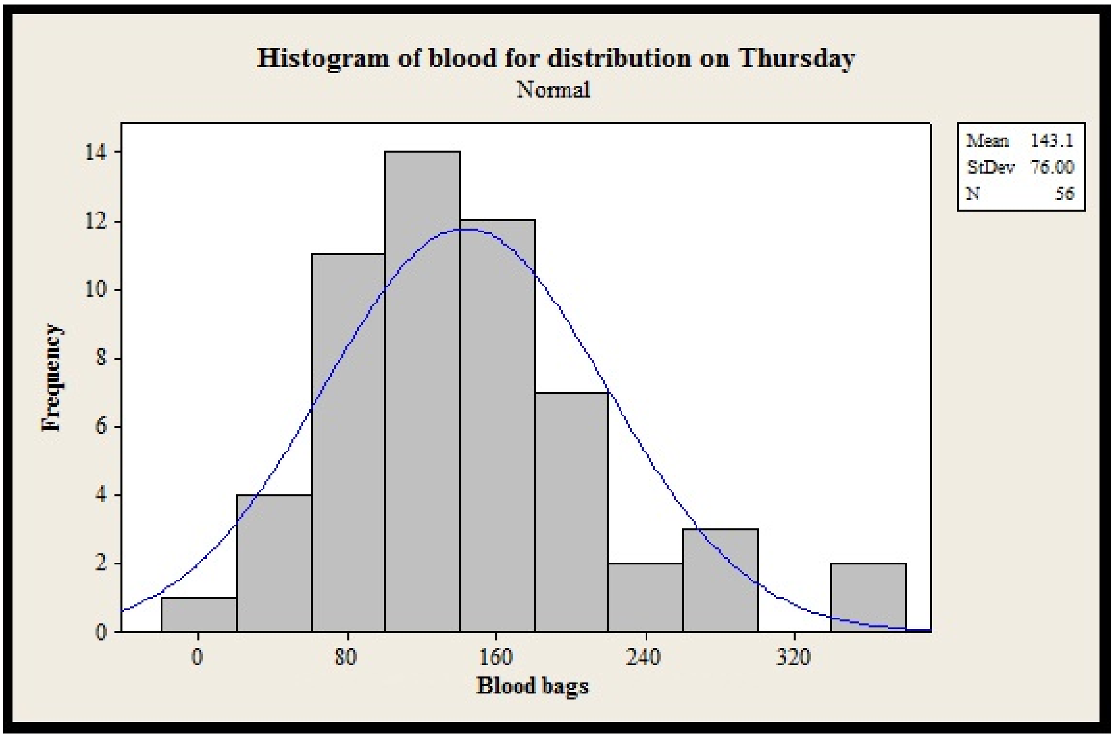


(b) Tuesday

Figure 4.20: Histogram plot of blood available for distribution between Monday and Saturday

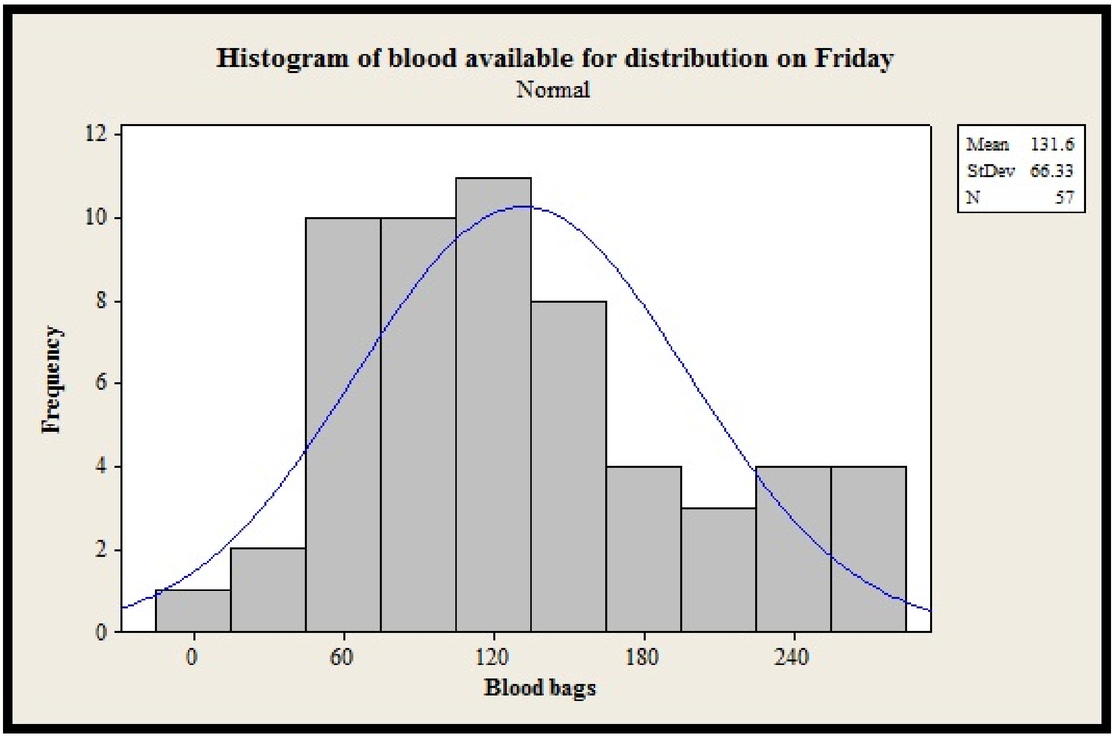


(c) Wednesday

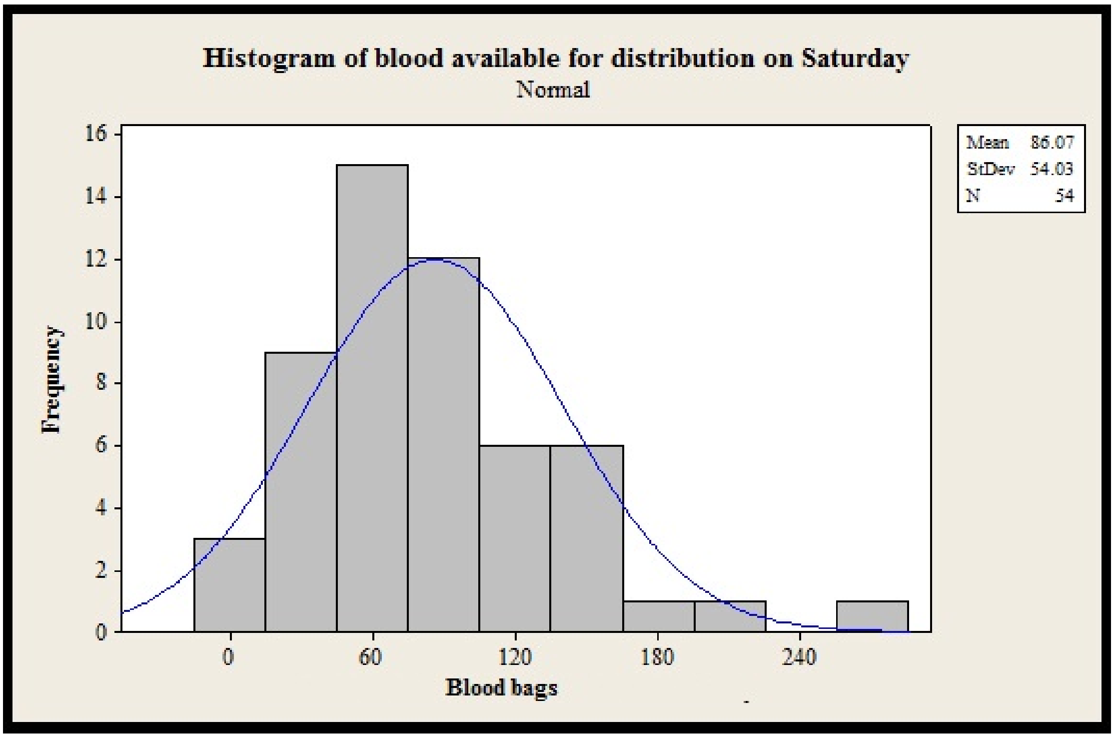


(d) Thursday

Figure 4.20: Histogram plot of blood available for distribution between Monday and Saturday

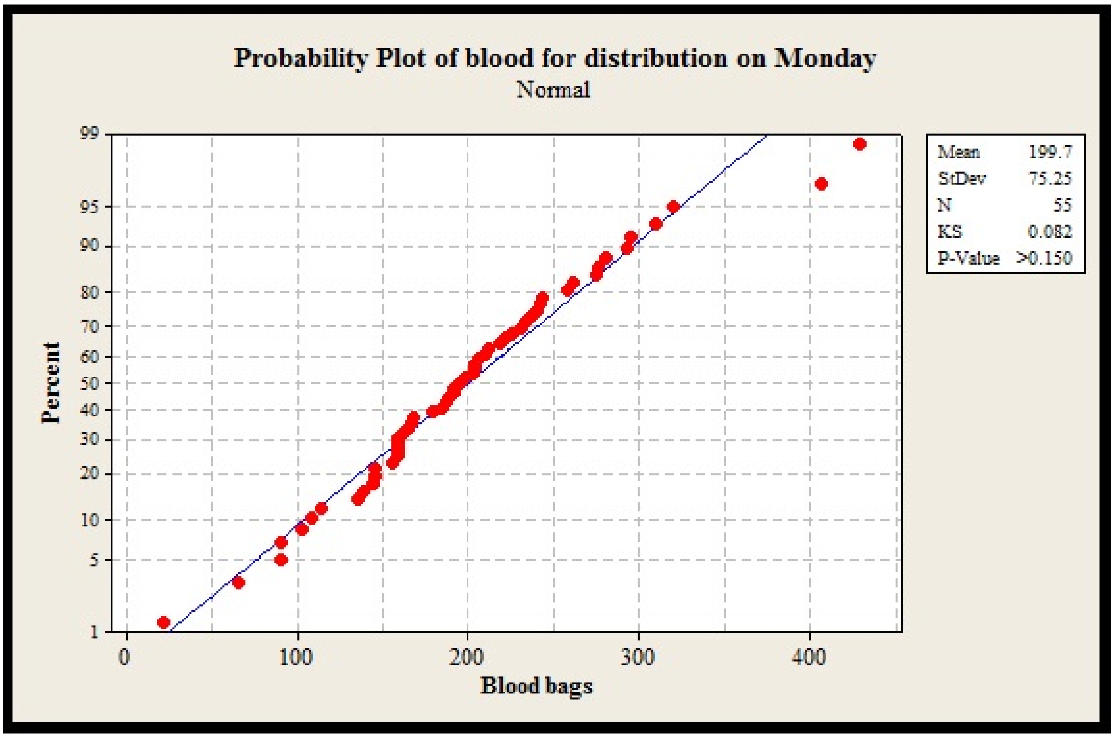


(e) Friday

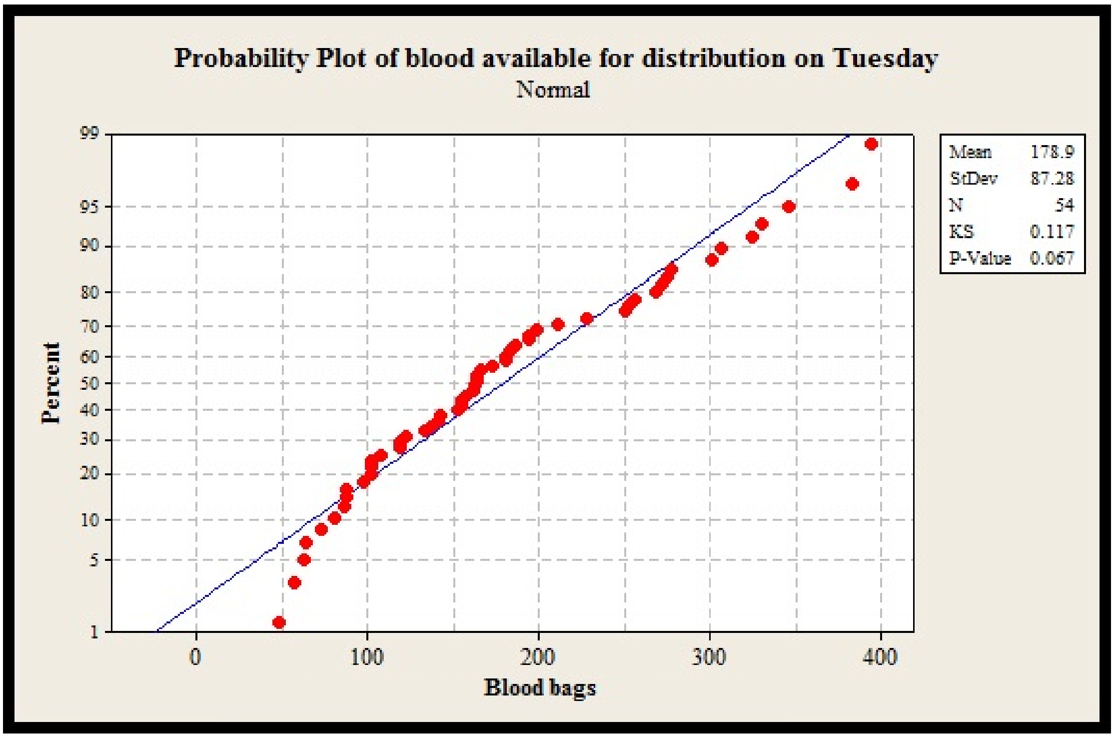


(f) Saturday

Figure 4.20: Histogram plot of blood available for distribution between Monday and Saturday

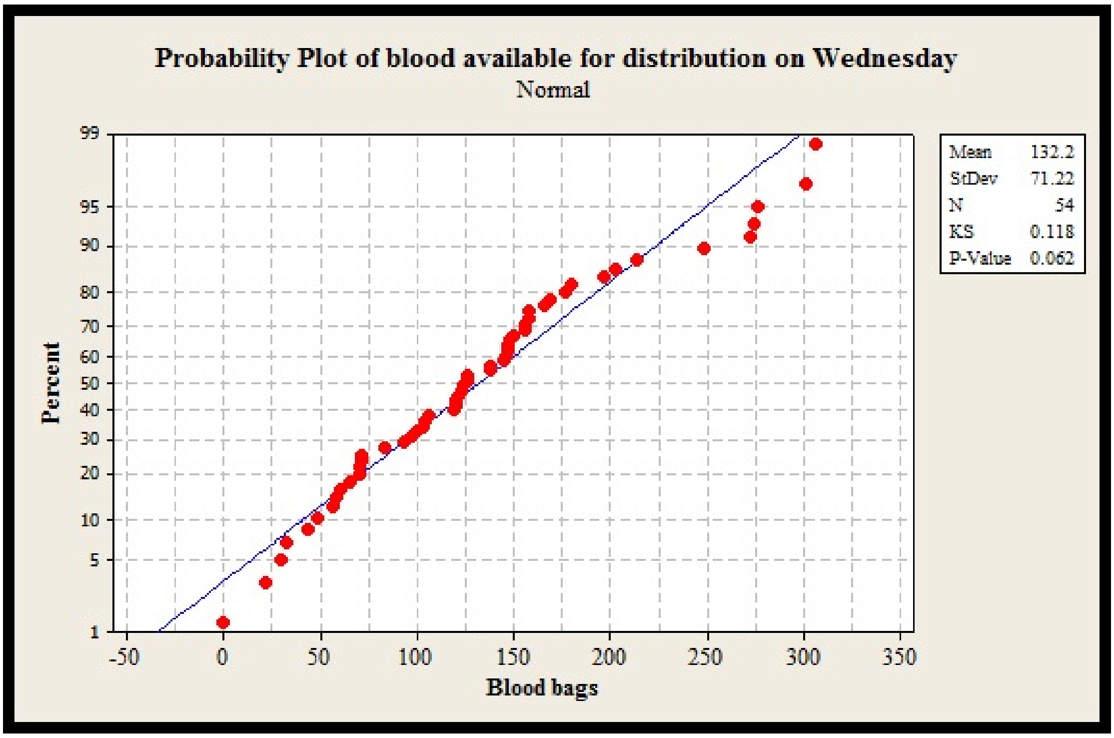


(a) Monday

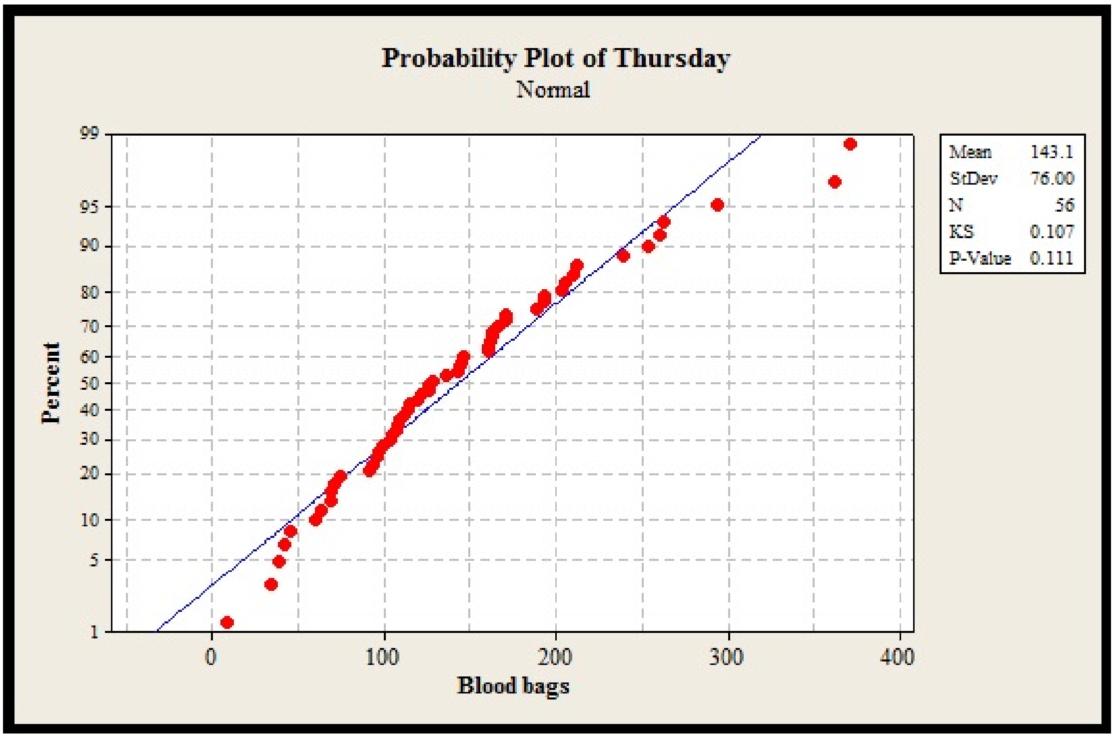


(b) Tuesday

Figure 4.21: Probability plot of blood available for distribution between Monday and Saturday

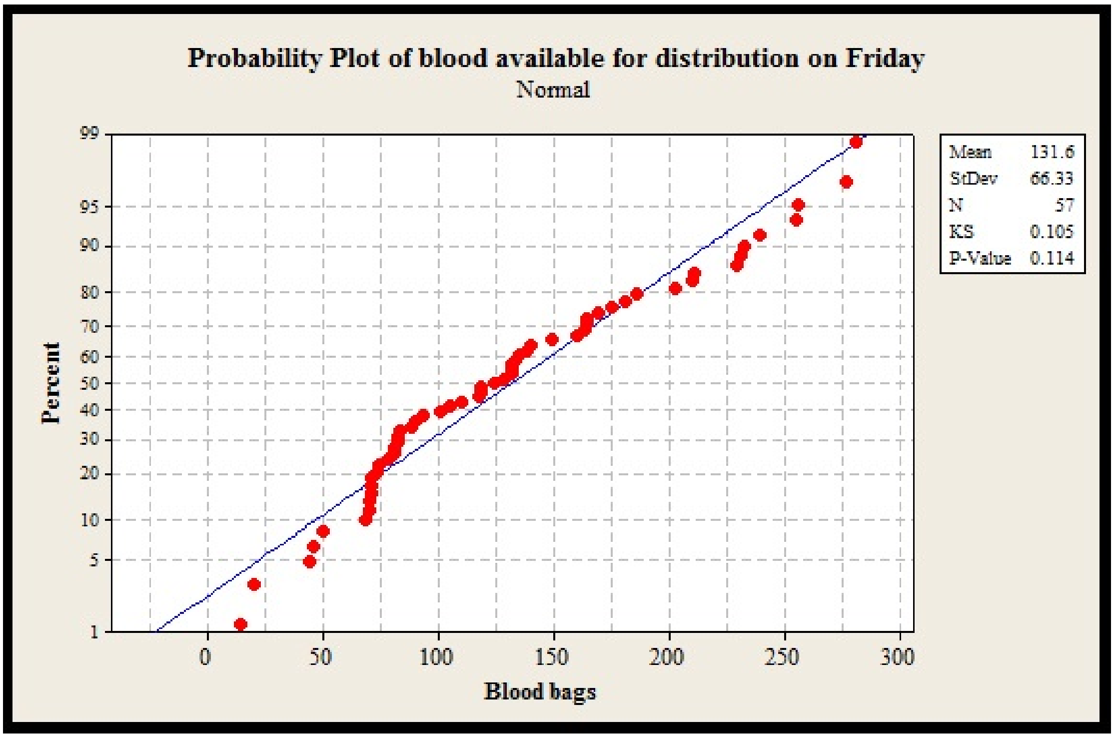


(c) Wednesday

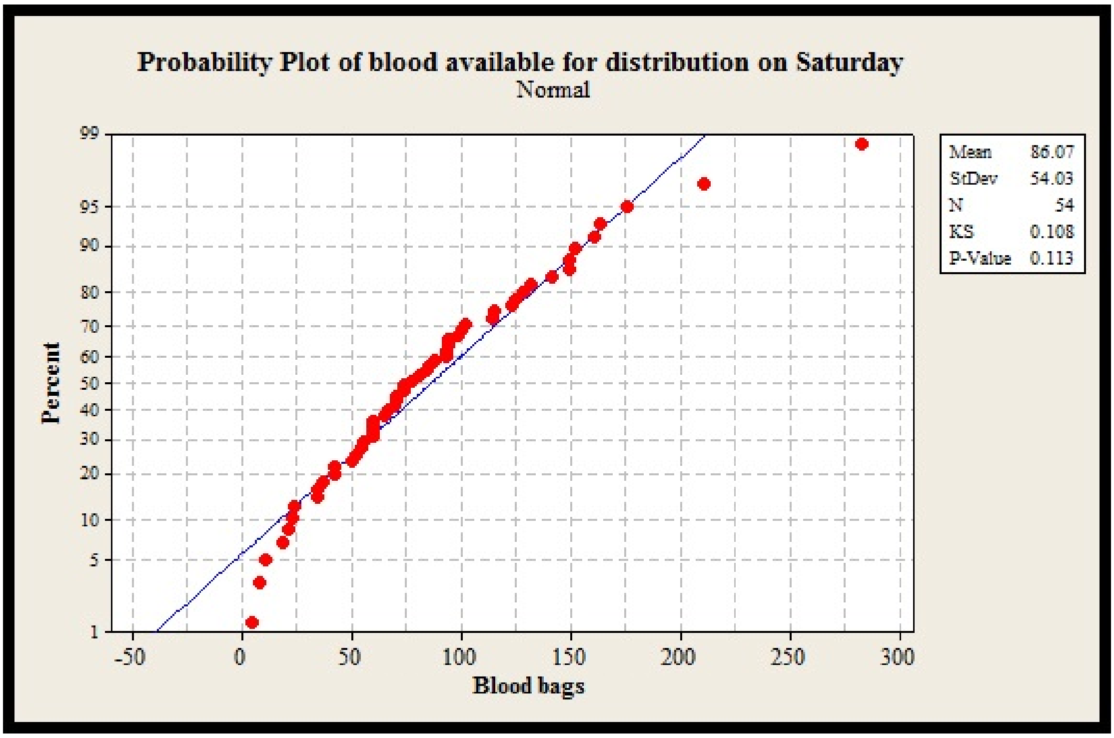


(d) Thursday

Figure 4.21: Probability plot of blood available for distribution between Monday and Saturday



(e) Friday



(f) Saturday

Figure 4.21: Probability plot of blood available for distribution between Monday and Saturday

4.4 Computer specification and Database Design

The applications of the study were developed in Visual Basic.NET 2010. Runs were carried out on a desktop computer with Intel Core^{TM}2 Duo CPU E8500 and speed 3.16 GHz. All data were stored in Microsoft Office Access 2010, which is a database management system. The program was written to access data via Open Database Connectivity (ODBC).

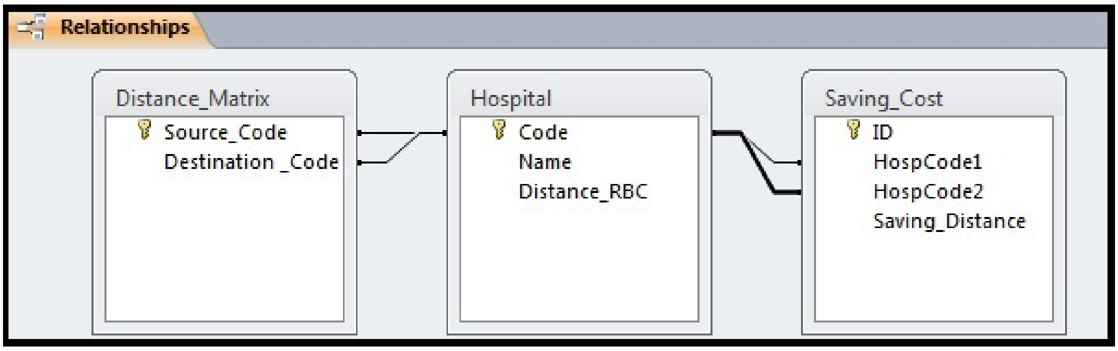


Figure 4.22: Tables and Relationships of Database

The entity relationship model shown in Figure 4.22 describes the database used to store data. The database is used by the application program developed to assign nodes to routes using heuristic algorithms (in Chapters 7 and 8). The three tables consist of the hospital details, the distances between hospitals, and the Clarke and Wright savings costs calculated between pairs of nodes. All are implemented with Microsoft Access 2010.

4.5 Summary and Conclusion

A description has been given in this chapter of the different sources of data and preliminary statistical analyses carried out. Overview data on supply and demand for blood nationally were collected from the annual reports and other documents of the National Blood Centre, Thai Red Cross Society. Distance data were obtained from calculations based on Geographic Information Systems. These nationwide data have been used in the location analyses presented in Chapters 5 and 6. Distance data also used in the fixed and variable routes developed in Chapters 7 and 8.

The Regional Blood Centre at Chiang Mai provided manually written documents containing amounts of blood requested by hospitals and blood allocated to hospitals in the particular study area. Several analyses are made of the data provided. In particular, the relationship between the distance from the RBC to hospitals and the blood collection frequencies of the hospitals is presented using graphs and charts to understand its nature. Analyses of both daily blood requests and blood available for supply are similarly considered. Results of these analyses are made use of in the planning of both fixed and variable blood distribution routes, as described in Chapters 7 and 8.

In addition, this chapter has provided details of the computing facilities and software utilised in the model building described in the chapters to follow, and has included the design of the database used for the routing application development.

Chapter 5

Nationwide location of Regional Blood Centres

In this chapter, we firstly analyse existing allocations of provinces to RBCs and use the p-median location facility model to suggest optimal locations. We then propose two goal-programming formulations for location of new RBCs based firstly on customers collecting blood directly from a RBC (a location-allocation model) and secondly based on the concept of supplier-managed distribution (a location-routing model). Goal programming formulations are used for the problem because of multiple objectives to be considered when siting RBCs. In addition to minimising the total travelling distance, there are many factors to be considered when building a new RBC (see Section 5.3). Results from these models are compared using test data, but not extended to the full nationwide blood supply network.

5.1 Re-allocation of hospitals and p-median location analysis for Regional Blood Centres in Thailand

The locations of the RBCs is one of the factors which have influence not only on the effectiveness of supply of blood but also on the efficiency of distribution of blood to hospitals. There are twelve RBCs throughout the country. As indicated in Section 2.5, some current locations for RBCs are undesirable as the centres of networks to distribute blood to hospitals. Two such examples are in Nakhon Si Thammarat and Phuket provinces. We therefore first reconsider the allocation of hospitals to the twelve current RBCs and the National Blood Centre, based on shortest travel distances. Secondly, we employ the p-median location model in order to reconsider all current locations of RBCs.

5.1.1 Re-allocation of hospitals to existing RBCs

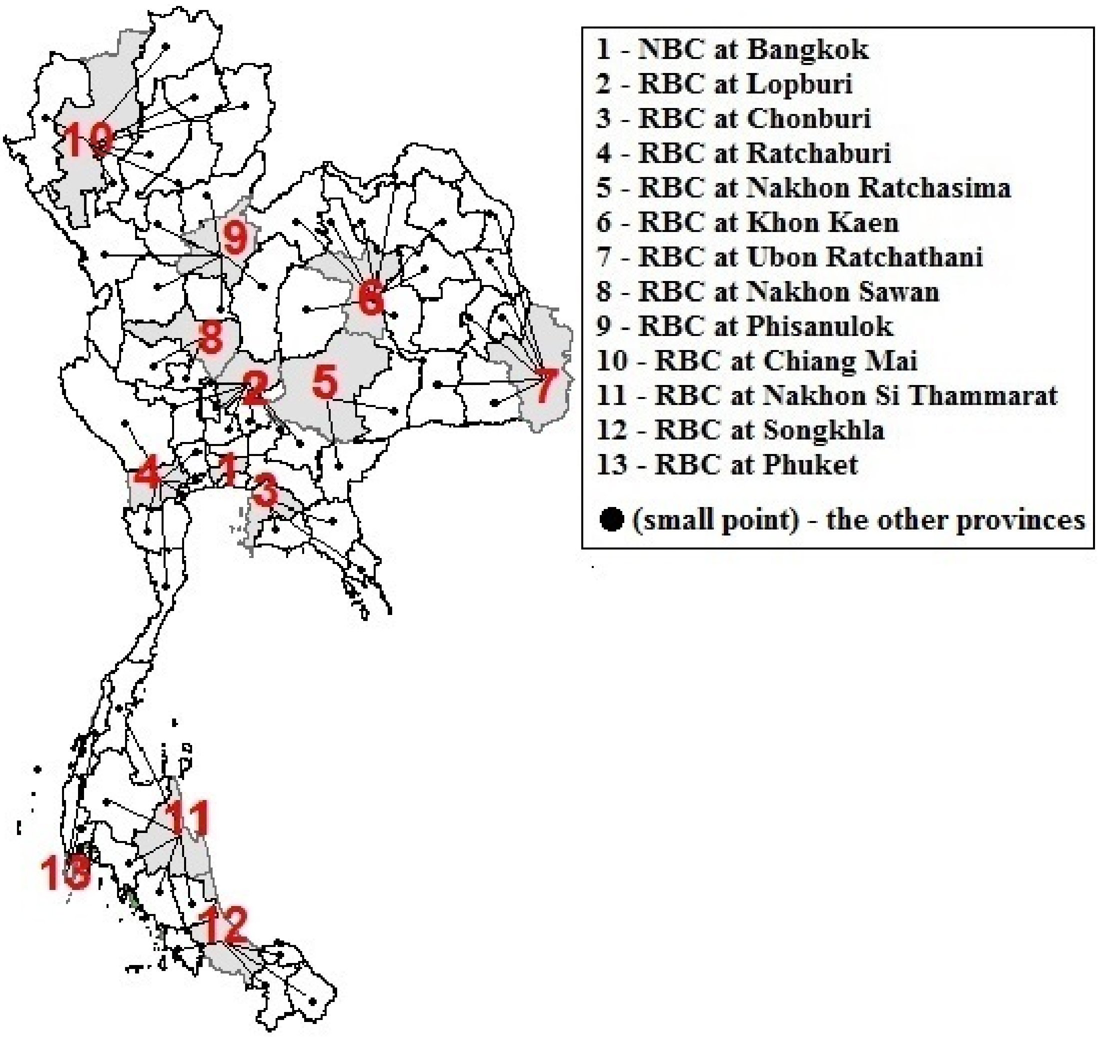


Figure 5.1: Result of re-allocation for existing RBCs

Currently, allocation of provincial hospitals to the NBC or RBCs is determined according to political administration (see Appendix C), which has meant that some provinces are not served by the closest RBC. For example, Nan province and Phrae province are allocated to the RBC located in Phitsanulok province, but it appears in practice that all hospitals in both provinces collect blood at Chiang Mai's RBC. In this section, we re-allocate the provinces to the nearest existing RBC without adding any new RBCs. Hospital demand is assumed to be concentrated in the provincial capitals, a not-unrealistic simplification since the major hospitals are located in the provincial capitals.

The results of re-allocation of hospitals in the provinces to the existing NBC and RBCs is illustrated in Figure 5.1 and the details of re-allocation are shown in Table 5.1.

Table 5.1: The current National and Regional Blood Centres and re-allocation result

Region	Current NBC or RBCs	Provinces re-allocated to the RBCs
Central	(1) Bangkok	Bangkok, Chachoengsao, Nonthaburi, Pathum Thani, Samut Prakan, Samut Sakhon, Saraburi
	(2) Lopburi	Lopburi, Nakhon Nayok, Prachinburi, PhraNakhon Si Ayutthaya, Singburi, Suphanburi, Ang Thong
	(4) Ratchaburi	Ratchaburi, Kanchanaburi, Nakhon Pathom, Prachuap Khiri Khan, Phetchaburi, Samut Songkhram
East	(3) Chonburi	Chonburi, Chanthaburi, Trat, Rayong
NorthEast	(5) Nakhon Ratchasima	Nakhon Ratchasima, Buriram, Sa Kaeo
	(6) Khon Kaen	Khon Kaen, Kalasin, Chaiyaphum, Maha Sarakham, Roi Et, Loei, Sakon Nakhon, Nong Khai, Nong Bua Lamphu, Udon Thani
	(7) Ubon Ratchathani	Ubon Ratchathani, Nakhon Phanom, Mukdahan, Yasothon, Sisaket, Surin, Amnat Charoen
North	(8) Nakhon Sawan	Nakhon Sawan, Chainat, UThai Thani
	(9) Phitsanulok	Phitsanulok, Kamphaeng Phet, Tak, Phichit, Petchabun, Sukhothai, Uttaradit
	(10) Chiang Mai	Chiang Mai, Chiang Rai, Nan, Phrae, Phayao, Mae Hong Son, Lampang, Lamphun
South	(11) Nakhon Si Thammarat	Nakhon Si Thammarat, Krabi, Chumphon, Trang, Phatthalung, Surat Thani
	(12) Songkhla	Songkhla, Narathiwat, Pattani, Yala, Satun
	(13) Phuket	Phuket, Phang Nga, Ranong

The total travelling distance obtained with the re-allocation of the provinces to the existing NBC and RBCs is 1,599.22 km, about 180 km less than the current value of 1,781.90 km. Figure 5.2 shows the effects of reallocation by average distances travelled to each RBC, along with the volumes of blood requested at each RBC. It can be seen that the average distance travelled to RBC 10 at Chiang Mai increases slightly, while there is considerable reduction of the average distance to RBC 9 in Phitsanulok province. This is because hospitals in two provinces are re-allocated from Phitsanulok's RBC to Chiang Mai's RBC. There is also an increase in the average travelling distances to RBC 13 in Phuket province, but this is offset by a large decrease in average distance travelled to RBC11 in Nakhon Si Thammarat province. There is no change in allocation to RBCs located in three provinces: Lopburi, Ratchaburi, and Songkhla.

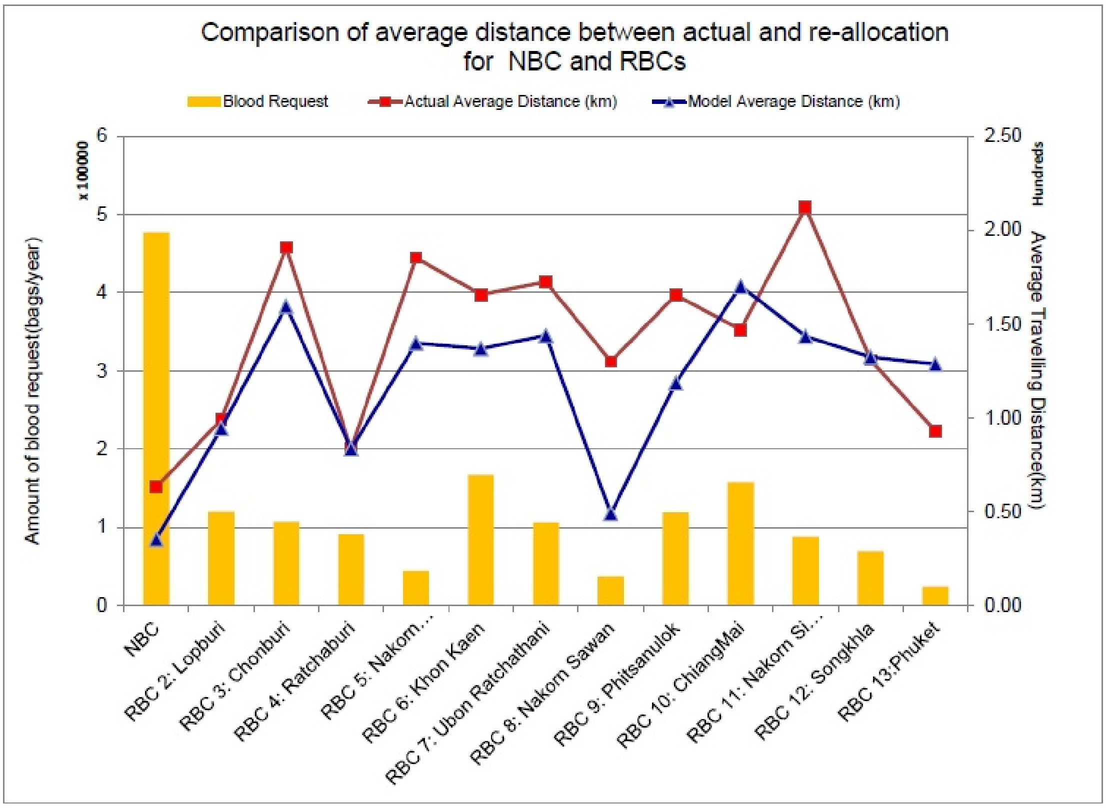


Figure 5.2: Comparison of average distance between actual and re-allocated hospitals and NBC and RBCs

5.1.2 Re-location of RBCs

In this section, we apply the p-median location model (See Section 3.2.1.1) to find the optimal locations for RBCs with the constraint of a maximum of twelve RBCs being opened. The 76 capital districts of each province are considered as candidate sites for RBCs, where suitably large numbers of potential blood donors are available. The location of the NBC remains unchanged. The demand-weighted average travel distance between the RBCs and hospitals is minimised. The assumption is made that demand is concentrated in the provincial capitals, as data are not available for individual hospitals throughout the country. This simplification is reasonable as, in most cases, the capital district is the most populous district of the province.

As shown in Figure 5.3, results indicate that five existing RBCs, which are represented with a red rectangular symbol, should be relocated. The map shows the five new recommended locations with blue star symbols. There are seven existing locations which stay as current: these are shown on the map with a black circular symbol.

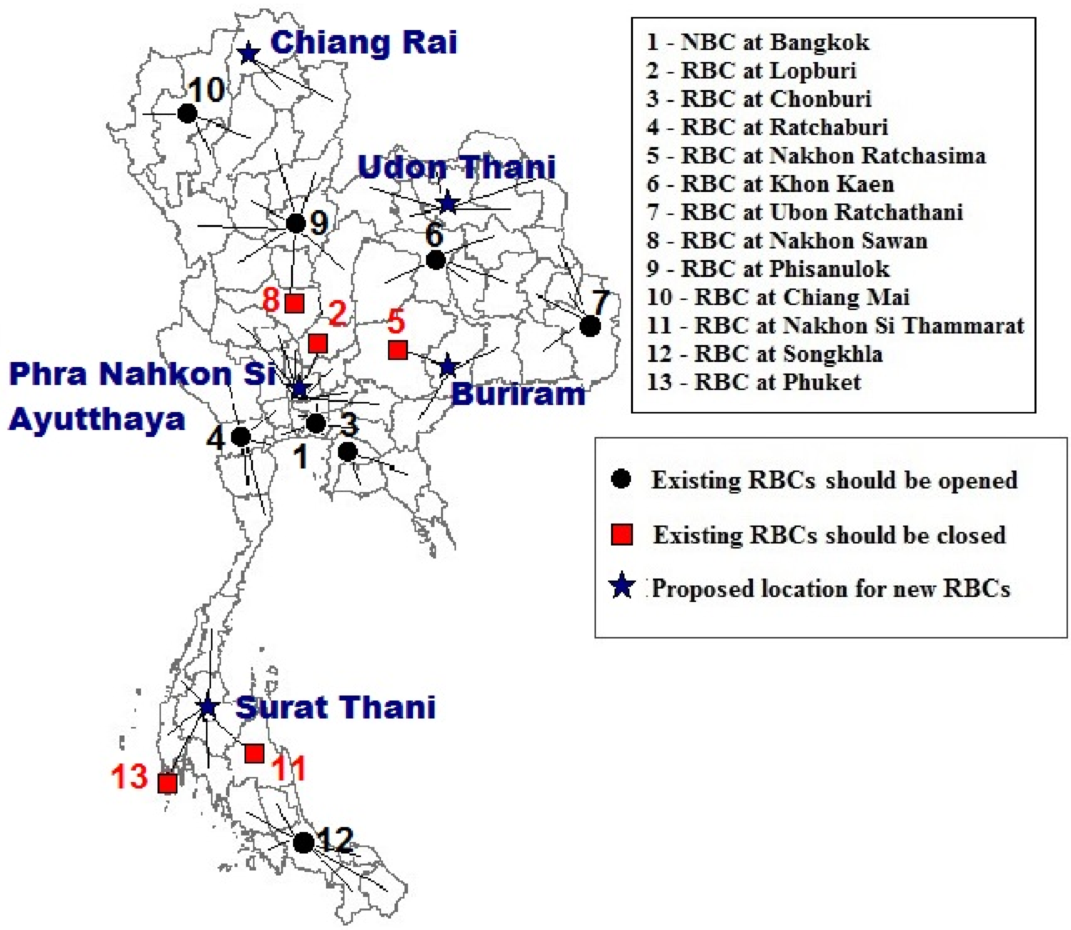


Figure 5.3: Map of results of re-location analysis for RBCs

Table 5.2: Current and proposed locations for the twelve Regional Blood Centres and the National Blood Centre

Existing RBC location		New RBC location
Should remain open	**Should be closed**	
(1) Bangkok	(2) Lopburi	Phra Nakhon Si Ayutthaya *
(3) Chonburi	(5) Nakhon Ratchasima	Buriram
(4) Ratchaburi	(8) Nakhon Sawan	Chiang Rai *
(6) Khon Kaen	(11) Nakhon Si Thammarat *	Surat Thani *
(7) Ubon Ratchathani	(13) Phuket *	Udon Thani *
(9) Phitsanulok		
(10) Chiang Mai		
(12) Songkhla		

(Note: * denotes agreement by NBC decision maker to location)

Further information about locations for RBCs suggested and in consideration can be seen in Table 5.2. Discussion with the NBC (Sakuldamrongpanich, 2010*a*) has found general agreement with the recommendations, although changes have not yet been made. Results highlight the unsuitable locations of both RBC 11 in Nakhon Si Thammarat province and RBC 13 in Phuket province, as these are not suitable for centralised location of blood distribution to hospitals: this closely corresponds to the opinion of the NBC. The RBC located in Nakhon Si Thammarat province should be changed to Surat Thani province; also Udon Thani is selected as a suitable RBC location. Phra Nakhon Si Ayutthaya was already planned by the NBC as an RBC location, while this analysis confirmed the NBC Deputy Director's opinion that Chiang Rai is a good location for blood distribution to the upper North region of the country. Table 5.2 indicates the new locations that have the agreement of the decision maker as being suitable. However, the location at Nakhon Ratchasima remains preferred to Buriram.

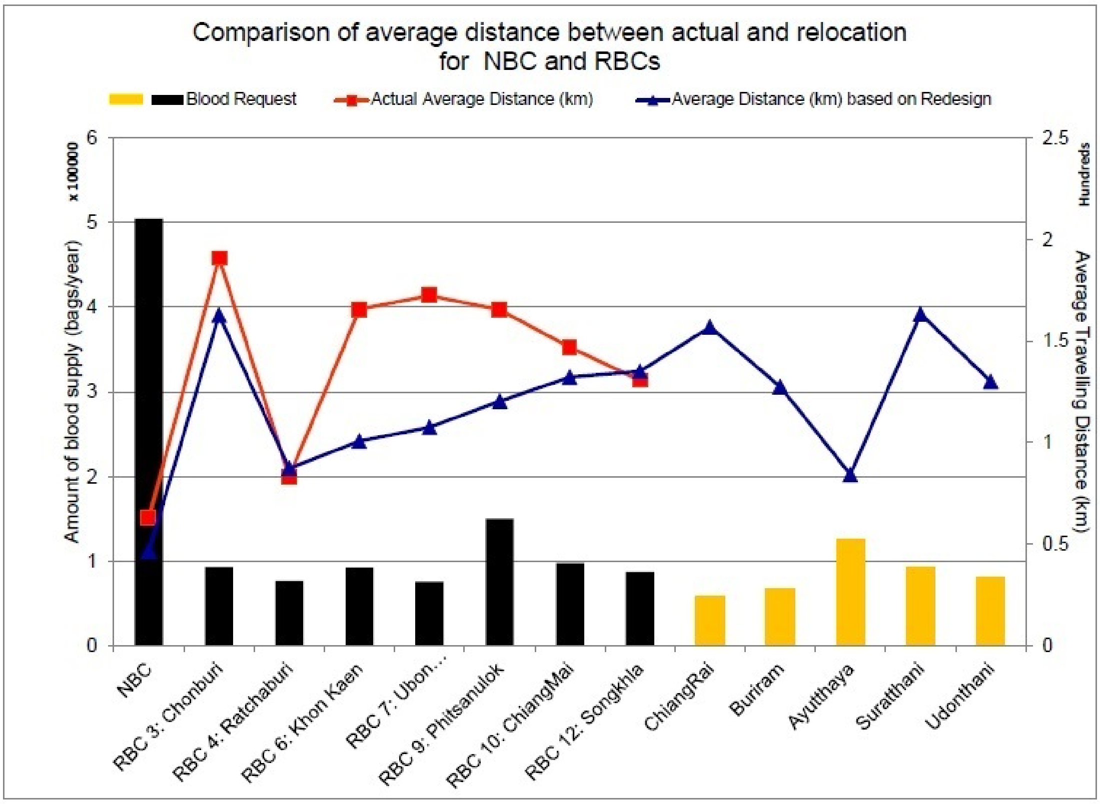


Figure 5.4: Comparison of average distance between demand and actual/ re-located NBC and RBCs

Average distances to RBCs with existing and redesigned locations are shown in Figure 5.4. The total average travelling distance (1,555.25 km) that would be obtained by relocation of the twelve RBCs is less than the actual travelling distance (1,781.90 km) by about 226 km. This represents an improvement on the total based on reallocation of provincial hospitals (see Section 5.1.1) to the nearest RBCs or the NBC (1,599.22 km) by about 44 km per delivery. This makes a considerable improvement in mountainous parts of the country, where difficult terrain currently necessitates flying in blood supplies from the NBC in Bangkok.

5.2 Location analysis for determining a suitable number of Regional Blood Centres

There are currently 13 blood service centres. However, the present situation is not desirable for service since hospitals must take a long time to collect blood from the RBCs, with resultant effects on quality of blood during transportation. Thus, the NBC is considering increasing the number of RBCs to improve efficiency in both economic and quality aspects. The question is, therefore, “How many RBCs should there be to cover the hospitals within a predefined distance?” and “Where should the RBCs be?”. The Maximal Covering model (see Section 3.2.1.2) is used to find answers to these questions. Experiments were conducted to determine the optimal number and locations for RBCs given different maximum service distances between RBCs and provincial capitals.

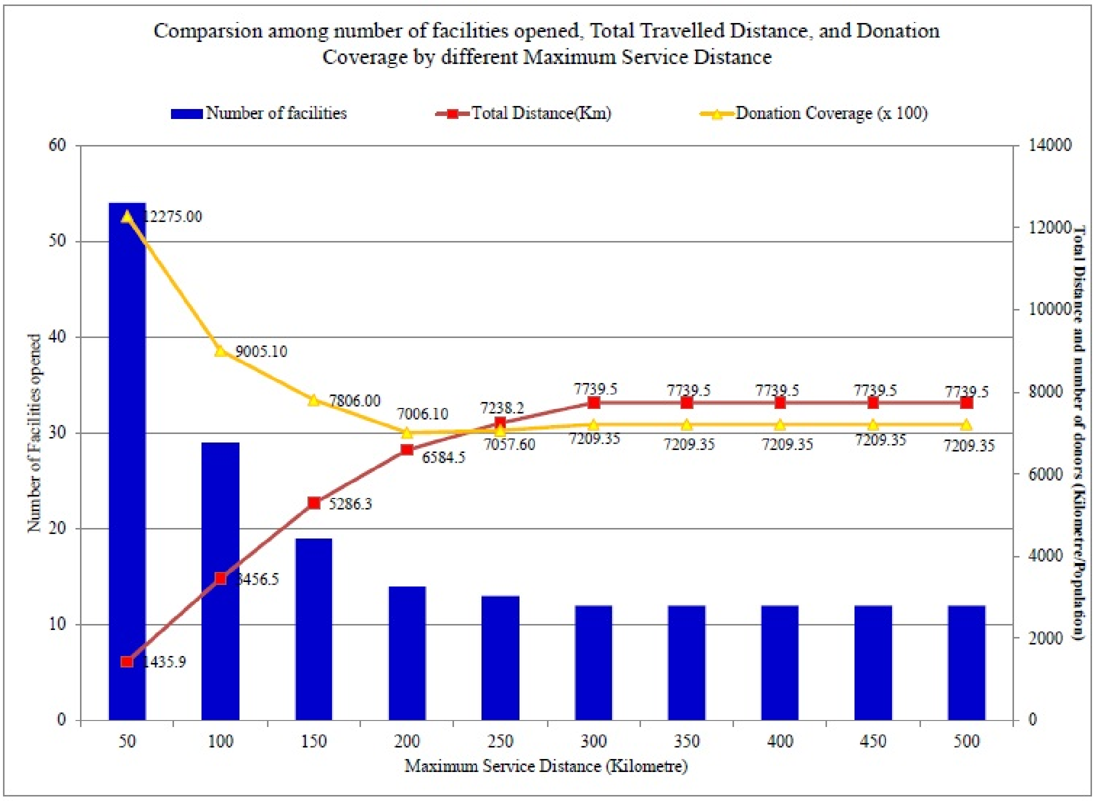


Figure 5.5: Comparison of results according to the various maximum service distance

Results of the experiments are shown in Figure 5.5. 54 locations for RBCs are recommended as the optimal number with a maximum service distance of approximately 50 kilometres, while 29 sites are needed for serving hospitals within 100 kilometres. Blood service centres should be opened in at least 14 locations to enable blood deliveries to be made from RBCs within a 4-hour time constraint (250 km). The lists of location sites needed for a range of maximum service distances are given in Table E.1 of Appendix E. Figure 5.5 also shows the reduction in total travel distance gained by increasing numbers of RBCs, and the increasing total numbers of donors within reach of an RBC.

5.3 Goal Programming Blood Centre Location-Allocation Problem (BCLAP) and Location-Routing Problem (BCLRP)

Location decisions may depend on a number of different criteria such as total costs (the fixed cost to establish facilities, the wage cost for staff, the transportation cost, and the inventory cost), response time, coverage of demand, access to the road network, safety and reliability, policy issues, and other factors which can be assessed by expert opinion. The Analytical Hierarchy Process (AHP) (Saaty, 1980) can be used by experts in an area to weigh the priorities of such influencing factors at potential locations. Since Goal Programming (GP) (Baumol, 1962) is a technique proposed for addressing multiple goals and conflicting goals, the weight scores obtained from AHP can be combined with GP models with multi-objectives in an integrated AHP methodology. An example of use of an integrated methodology is provided by Badri (1999) for a global location problem. Ho (2008) finds that integration of AHP with mathematical programming and other applications provides a better result than the stand-alone AHP.

An integrated AHP methodology was planned for this study, but the NBC decided not to proceed with nationwide relocation of RBCs and an AHP could not be implemented with local experts. This chapter therefore concludes with presentation of GP models applicable to location of RBCs using a test data set. Comparisons are made of results found with two GP models, based on the Location-Allocation Problem (LAP) and the Location-Routing Problem. This compares the current situation of hospitals collecting blood from RBCs to the proposed distribution system where RBCs deliver blood to hospitals.

Several objectives particular to the blood supply chains in Thailand are considered as potential targets for goal programming. Floods are disasters that have particularly disrupted transport and operations, as, for example, during the 2011 monsoon season in Thailand. Thus, avoidance of natural disasters is considered when building a new facility. Another important factor is government policy: different investments may be made in various locations for new health facilities. Furthermore, cooperation of people in local areas and the local Red Cross Society can support blood donor recruitment campaigns to achieve increasing amounts of donated blood. These issues are included in the two models.

In the following sections, we find optimal locations for new RBCs based on minimising deviations from targets for five objectives: for total blood supplied by RBCs, for total transportation distances, and for total scores on absence of risks of natural disaster, support from government funds, and cooperation of the local community. Scores for the latter three factors range between zero and one (one being the most desirable position). Existing RBCs have capacity limits of inventory because the buildings cannot be extended but there is no capacity constraint for building new RBCs.

5.3.1 Model assumptions

- Each objective function has different weights which can be set by expert judgement
- Scores for absence of risks of natural disaster, government funding and local cooperation can be supplied by expert judgement
- There are several potential sites for RBCs which provide blood for hospitals
- The number of potential RBCs and hospitals is known in advance
- The capacity for a pre-existing RBC is determined
- Each hospital can be supplied by only one RBC and one vehicle
- Each route starts and stops at the same RBC
- The capacity of each vehicle is predefined
- Potential blood supplies at each candidate RBC site are known, either from collections at the RBC or at an RBC branch at a hospital, or supplied by the NBC.

5.3.2 Notation

Parameter	**Description**
N	set of hospitals $\{1, \ldots, n\}$
M^e	set of existing sites for RBCs $\{n+1, \ldots, m^e\}$
M^p	set of potential sites for RBCs $\{m^e+1, \ldots, m^p\}$
M	set of sites for RBCs, $M = M^e \cup M^p$
K	set of vehicles
O	set of objectives
i,j	index of nodes (hospitals and potential sites for RBCs)
k	index of vehicles, $k \in K$
o	index of objectives, $o \in O$
b	budget allocated to construct healthcare facilities (in Thai Baht)

Parameter	Description
c_j	capacity of a pre-existing RBC (in units of blood) at site j, $j \in M^e$
d_{ij}	distance between node i and node j, $i \in N \cup M, j \in N \cup M$
f_j	fixed cost (a setup or upgrade cost) for an RBC at site j, $j \in M$
g_j	average quantity of blood supplied at RBC j, $j \in M$
m	maximum total travel distance in each route
n	the number of hospitals
q_i	average quantity of blood demanded at the i^{th} hospital (in units of blood), $i \in N$
Q_k	capacity of a vehicle k, $k \in K$
w_j^r	score of an RBC at site j for lack of natural disaster risks, $j \in M$
w_j^g	score of an RBC at site j for government funding, $j \in M$
w_j^c	score of an RBC at site j for cooperation of local communities, $j \in M$
α_o	penalty for objective o, $o \in O$
ϕ_o	target for objective o, $o \in O$

Decision variables

Variable	Description
δ_o^+	= over-achievement of the o^{th} objective, $o \in O$
δ_o^-	= under-achievement of the o^{th} objective, $o \in O$
s_{ik}	= auxiliary variable for sub-tour elimination constraints of the node at site i in the vehicle k, $i \in N$, $k \in K$
x_{ij}	$= \begin{cases} 1, & \text{if hospital } i \text{ is allocated to an RBC at the } j^{th} \text{ site}, i \in N,\ j \in M, \\ 0, & \text{otherwise.} \end{cases}$
y_j	$= \begin{cases} 1, & \text{if an RBC is open at the } j^{th} \text{ site}, \ j \in M, \\ 0, & \text{otherwise.} \end{cases}$
z_{ijk}	$= \begin{cases} 1, & \text{if the point } i \text{ precedes the point } j \text{ by the vehicle } k, i \in N \cup M, \\ & j \in N \cup M,\ k \in K, \\ 0, & \text{otherwise.} \end{cases}$

5.3.3 Model formulations

5.3.3.1 Objective function and constraints for Goal Programming Blood Centre Location-Allocation Problem (BCLAP)

This model finds optimal locations for RBCs and allocates hospitals to RBCs. Goal constraints target (1) the total blood supplied by RBCs, (2) the total factor for lack of risk of natural disaster, (3) the total factor for government funding, (4) the total local cooperativeness factor at candidate location sites and (5) total distance travelled. The latter assumes that hospitals must collect blood directly from the RBC to which they are assigned. The objective function (5.1) minimises the sum of the weighted over-achievement of the distance target plus the under-achievements of the other targets. The weights are normalised to avoid overweighting larger scale components (Li et al., 2009). The model is formulated as follows:

Minimise

$$\sum_{o=1}^{4} \frac{\alpha_o}{\phi_o}(\delta_o^-) + \frac{\alpha_5}{\phi_5}(\delta_5^+), \tag{5.1}$$

subject to

$$\sum_{j \in M} x_{ij} = 1, \quad \forall i \in N, \tag{5.2}$$

$$\sum_{j \in M} y_j g_j + \delta_1^- = \phi_1, \tag{5.3}$$

$$\sum_{j \in M} w_j^r y_j + \delta_2^- = \phi_2, \tag{5.4}$$

$$\sum_{j \in M} w_j^g y_j + \delta_3^- = \phi_3, \tag{5.5}$$

$$\sum_{j \in M} w_j^c y_j + \delta_4^- = \phi_4, \tag{5.6}$$

$$\sum_{j \in M} \sum_{i \in N} x_{ij}(d_{ij} + d_{ji}) - \delta_5^+ = \phi_5, \tag{5.7}$$

$$\sum_{i \in N} x_{ij} q_i \leq c_j, \quad \forall j \in M^e, \tag{5.8}$$

$$y_j = 1, \quad \forall j \in M^e, \tag{5.9}$$

$$x_{ij} - y_j \leq 0, \quad \forall i \in N, \forall j \in M, \tag{5.10}$$

$$\sum_{i \in N} x_{ij} - y_j \geq 0, \quad \forall j \in M, \tag{5.11}$$

$$\sum_{j \in M} f_j y_j \leq b, \tag{5.12}$$

$$x_{ij} \in \{0,1\}, \quad \forall i \in N, \quad \forall j \in M, \tag{5.13}$$

$$y_j \in \{0,1\}, \quad \forall j \in M, \tag{5.14}$$

$$\delta_o^+, \delta_o^- \geq 0, \quad \forall o \in O. \tag{5.15}$$

Hospitals and their demand are allocated to an RBC at site j by constraints (5.2). Constraint (5.34) finds the deviation from target of total supplied blood. Constraints (5.4), (5.5), and (5.6) are used to determine total deviation from target of the total scores in three factors: lack of natural disaster risks, government funding, and cooperation of local communities for an RBC at site j. Constraint (5.7) obtains the deviation from target of total distance travelled. Constraints (5.8) mandate that the quantity of blood supplied by a pre-existing RBC at site j^{th} hospital must not exceed the physical capacity of the RBC. Constraints (5.9) ensure that pre-existing RBCs are to be opened. Constraints (5.10) and (5.11) are used to force opening of an RBC at site j when any hospitals are allocated to that RBC. Constraint (5.12) ensures that the total fixed cost is within the budget allocated.

5.3.3.2 Objective function and constraints for Goal-Programming Blood Centre Location-Routing Problem (BCLRP)

This model finds optimal locations for RBCs and routes around hospitals allocated to RBCs. The model is based on the Location Routing Problem discussed in Chapter 3, Section 3.4. As for the LAP model, goal constraints target (1) the total supply of blood by RBCs, (2) the total factor for lack of risk of natural disaster, (3) total factor for government funding and (4) total local cooperativeness factor at candidate location sites and (5) total distance travelled. The objective function (5.16) minimises the sum of the weighted over-achievement of the distance target plus the under-achievements of the other targets. The mathematical model is formulated as follows:

Minimise

$$\sum_{o=1}^{4} \frac{\alpha_o}{\phi_o}(\delta_o^-) + \frac{\alpha_5}{\phi_5}(\delta_5^+), \tag{5.16}$$

subject to

$$\sum_{j \in N \cup M} \sum_{k \in K} z_{ijk} = 1, \quad \forall i \in N, \tag{5.17}$$

$$\sum_{i \in N} \sum_{j \in M} z_{jik} = 1, \quad \forall k \in K, \tag{5.18}$$

$$\sum_{i \in N} \sum_{k \in K} z_{jik} \leq 1, \quad \forall j \in M, \tag{5.19}$$

$$\sum_{i\in N} q_i \sum_{j\in N\cup M} z_{ijk} \le Q_k, \quad \forall k \in K, \tag{5.20}$$

$$\sum_{j\in N\cup M} z_{ijk} - \sum_{j\in N\cup M} z_{jik} = 0, \quad \forall i \in N, \quad \forall k \in K, \tag{5.21}$$

$$s_{ik} - s_{jk} + n z_{ijk} \le n-1, \quad \forall i \in N, \quad \forall j \in N, \quad \forall k \in K, \tag{5.22}$$

$$\sum_{i\in N} \sum_{j\in N\cup M} \sum_{k\in K} z_{ijk} = \sum_{i\in N} \sum_{j\in M} x_{ij}, \tag{5.23}$$

$$\sum_{l\in N\cup M} z_{ilk} + \sum_{l\in N\cup M} z_{jlk} \le 1 + x_{ij}, \quad \forall i \in N, \quad \forall j \in M, \quad \forall k \in K, \tag{5.24}$$

$$\sum_{j\in M} y_j g_j + \delta_1^- = \phi_1, \tag{5.25}$$

$$\sum_{j\in M} w_j^r y_j + \delta_2^- = \phi_2, \tag{5.26}$$

$$\sum_{j\in M} w_j^g y_j + \delta_3^- = \phi_3, \tag{5.27}$$

$$\sum_{j\in M} w_j^c y_j + \delta_4^- = \phi_4, \tag{5.28}$$

$$\sum_{i\in N\cup M} \sum_{j\in N\cup M} \sum_{k\in K} z_{ijk} d_{ij} - \delta_5^+ = \phi_5, \tag{5.29}$$

$$\sum_{i\in N} x_{ij} q_i \le c_j, \quad \forall j \in M^e, \tag{5.30}$$

$$\sum_{i\in N} \sum_{k\in K} z_{jik} - y_j = 0, \quad \forall j \in M, \tag{5.31}$$

$$y_j = 1, \quad \forall j \in M^e, \tag{5.32}$$

$$\sum_{j\in M} f_j y_j \le b, \tag{5.33}$$

$$\sum_{i\in N\cup M} \sum_{j\in N\cup M} z_{ijk} d_{ij} \le m, \quad \forall k \in K. \tag{5.34}$$

$$x_{ij} \in \{0,1\}, \quad \forall i \in N, \quad \forall j \in M, \tag{5.35}$$

$$y_j \in \{0,1\}, \quad \forall j \in M, \tag{5.36}$$

$$z_{ijk} \in \{0,1\}, \quad \forall i \in N\cup M, \quad \forall j \in N\cup M, \quad \forall k \in K, \tag{5.37}$$

$$v_{ik} \ge 0, \quad \forall i \in N, \quad \forall k \in K, \tag{5.38}$$

$$\delta_o^+, \delta_o^- \ge 0, \quad \forall o \in O. \tag{5.39}$$

$$s_{ik} \in \mathbb{I}^+, \quad \forall i \in N, \quad \forall k \in K. \tag{5.40}$$

Constraints (5.17), (5.18), and (5.19) make certain that each customer is allocated to exactly one vehicle, each route is served by at most one vehicle, and each route starts from one RBC. Constraints (5.20) ensure that the total amount of blood in each route does not exceed the capacity of a vehicle. Constraints (5.21) are the flow conservation constraint.

Constraints (5.22) are the sub-tour elimination constraint. Constraint (5.23) defines the relationship between variables x and z. Constraints (5.24) are used to define allocation of the hospital i to RBC j if there is a route from the RBC to the hospital. Constraint (5.25) finds the deviation from target of total supplied blood. Constraints (5.26), (5.27), and (5.28) are used to determine the total deviation from target in three factors: lack of natural disaster risks, government funding, and cooperation of local communities. Constraint (5.29) determines the deviation from target of the total travelling distance. Constraints (5.30) mandate that the quantity of blood supplied by a pre-existing RBC at site j must not exceed its physical capacity. Constraints (5.31) force opening of RBC j if there is a route from the RBC to any hospital. Constraints (5.32) are used to guarantee that the pre-existing RBCs are opened. Constraint (5.33) ensures that the total fixed cost is within the budget allocated. Constraints (5.34) enforces the maximum travel distance for each route.

5.4 Results and Discussion

Table 5.5: Test data for pre-defined input parameters for the model tests

Parameter	**Values**
Set of existing RBCs (M^e)	RBC 1
Set of potential sites (M^p)	Location 2, 3, 4, 5, 6, 7, 8
Set of hospitals (N)	Hospital 1, 2, 3, 4, 5, 6, 7, 8
Set of vehicles (K)	Vehicles 1,2, and 3
Pre-existing RBC (c_j)	RBC 1 with capacity 300 bags
Total budget (b)	400,000 Thai Baht
Maximum total travel distance in each route (m)	360 km

Table 5.6: Average blood demand of hospitals, average blood collected at RBCs, and fixed costs of RBC construction, by sites

Location	**Blood demand(bag)** (q_i)	**Blood collected(bags)** (g_j)	**Fixed cost(Thai Baht)** (f_j)
1	60	50	50,000
2	60	40	200,000
3	90	90	150,000
4	70	30	200,000
5	60	20	160,000
6	30	40	250,000
7	20	10	170,000
8	50	70	180,000

Table 5.7: Score of potential RBCs in three factors: lack of natural disaster risks, government funding, cooperation of community

Location	**Lack of disaster** (w_j^r)	**Government funding** (w_j^g)	**Cooperation of community** (w_j^c)
1	0.315	0.125	0.130
2	0.345	0.050	0.100
3	0.150	0.050	0.375
4	0.045	0.020	0.015
5	0.020	0.250	0.060
6	0.015	0.015	0.100
7	0.005	0.210	0.010
8	0.105	0.280	0.210
Total	1.000	1.000	1.000

Table 5.8: Target of objectives and penalties for goal constraints

Objective	**Target of objectives** (ϕ_o)	**Penalties for goal constraints** (α_o)
1	440	0.160
2	1	0.160
3	1	0.100
4	1	0.250
5	444.25	0.330

Table 5.9: Distance matrix

Distance	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1)	0	174	288	72	136	87	168	102
(2)	174	0	190	103	75	124	125	77
(3)	288	190	0	245	160	201	120	237
(4)	72	103	245	0	84	69	135	30
(5)	136	75	160	84	0	60	58	80
(6)	87	124	201	69	60	0	81	86
(7)	168	125	120	135	58	81	0	137
(8)	102	77	237	30	80	86	137	0

Table 5.10: Results of allocation with BCLRP and BCLAP in experiment 1

Hospital	**LAP**			**LRP**		
	RBC 1	**Location 3**	**Location 8**	**RBC 1**	**Location 3**	**Location 8**
1	✓			✓		
2			✓			✓
3		✓			✓	
4			✓			✓
5			✓			✓
6	✓					✓
7		✓			✓	
8			✓			✓

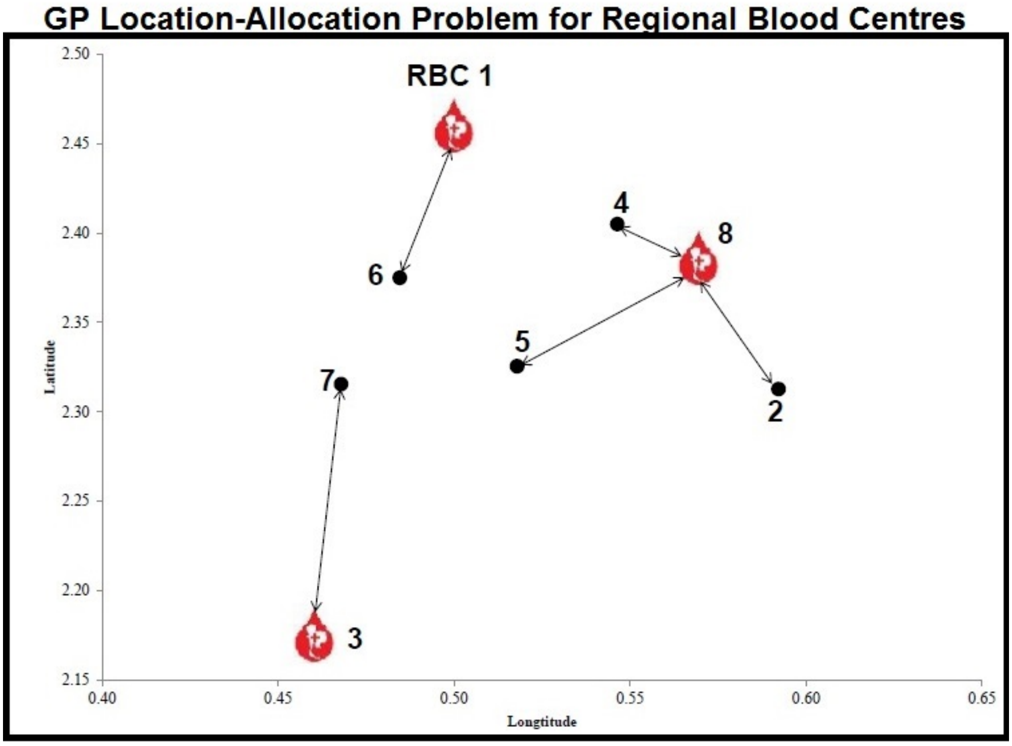


Figure 5.6: Result of allocation with BCLAP in experiment 1

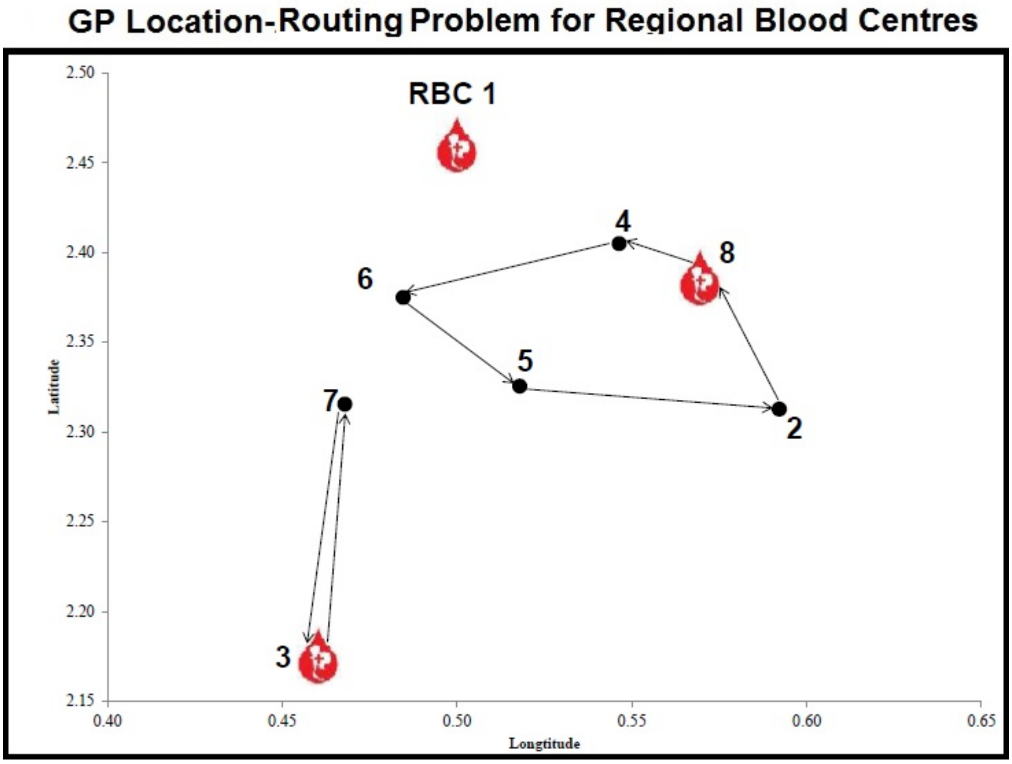


Figure 5.7: Result of routing with BCLRP in experiment 1

Table 5.11: Results of experiments on BCLAP model varying penalty scores

No	Penalty scores ($\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5$)	Goal values					Recommended locations
		Goal 1	Goal 2	Goal 3	Goal 4	Goal 5	
1	(0.160, 0.160, 0.100, 0.250, 0.330)	0.08364	0.06880	0.05450	0.07125	0.25386	Site 1,3, and 8
2	(0.200, 0.200, 0.200, 0.200, 0.200)	0.10455	0.08600	0.10900	0.05700	0.15385	Site 1,3, and 8
3	(0.320, 0.160, 0.180, 0.160, 0.180)	0.16727	0.06880	0.09810	0.04560	0.13847	Site 1,3, and 8
4	(0.150, 0.385, 0.150, 0.120, 0.195)	0.08864	0.07315	0.11625	0.04740	0.18337	Site 1,2, and 3
5	(0.130, 0.150, 0.340, 0.130, 0.250)	0.09159	0.08625	0.13090	0.08450	0.15068	Site 1,7, and 8
6	(0.130, 0.150, 0.400, 0.140, 0.180)	0.08864	0.08400	0.13800	0.08400	0.13037	Site 1,5, and 8
7	(0.170, 0.150, 0.220, 0.160, 0.300)	0.10818	0.07725	0.12650	0.06960	0.16595	Site 1,3, and 5
8	(0.140, 0.160, 0.140, 0.160, 0.400)	0.08909	0.08240	0.08050	0.06960	0.22127	Site 1,3, and 5

Table 5.12: Results of experiments on BCLRP model varying penalty scores

No	Penalty scores ($\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5$)	Goal values					Recommended locations
		Goal 1	Goal 2	Goal 3	Goal 4	Goal 5	
1	(0.160, 0.160, 0.100, 0.250, 0.330)	0.08364	0.06880	0.05450	0.07125	0.07930	Site 1,3, and 8
2	(0.200, 0.200, 0.200, 0.200, 0.200)	0.10455	0.08600	0.10900	0.05700	0.04806	Site 1,3, and 8
3	(0.320, 0.160, 0.180, 0.160, 0.180)	0.16727	0.06880	0.09810	0.04560	0.04325	Site 1,3, and 8
4	(0.150, 0.385, 0.150, 0.120, 0.195)	0.08864	0.07315	0.11625	0.04740	0.02381	Site 1,2, and 3
5	(0.100, 0.100, 0.460, 0.110, 0.230)	0.07045	0.05750	0.17710	0.07150	0.05527	Site 1,7, and 8
6	(0.120, 0.120, 0.540, 0.110, 0.110)	0.08182	0.06720	0.18630	0.06600	0.04797	Site 1,5, and 8
7	(0.170, 0.150, 0.190, 0.160, 0.330)	0.10818	0.07725	0.10925	0.06960	0.01541	Site 1,3, and 5
8	(0.140, 0.160, 0.140, 0.160, 0.400)	0.08909	0.08240	0.08050	0.06960	0.01868	Site 1,3, and 5

The Goal Programming models BCLAP and BCLRP were solved using A Modelling Language for Mathematical Programming (AMPL). Code is provided in Appendices F and G. The parameters used for runs are given in Table 5.5, 5.6, 5.7, 5.8 and distances between hospitals and RBCs are shown in Table 5.9.

The results of location, allocation and routing decisions of experiment 1 can be shown in Table 5.10 and Figures 5.6 and 5.7, for the BCLAP and BCLRP models. With both models, sites 3 and 8 are recommended to be opened as new RBCs according to the given penalty scores ($\alpha_1 = 0.160, \alpha_2 = 0.160, \alpha_3 = 0.100, \alpha_4 = 0.250, \alpha_5 = 0.330$), for the objectives for blood supplied, safety from natural disasters, government policy, local cooperation and total distance respectively. Figure 5.8 shows a comparison of the three penalty scores ($\alpha_2, \alpha_3, \alpha_4$) and weights ($w_i^r, w_i^g, w_i^c$) of different candidate locations in three of the objectives: safety from natural disasters, government policy and cooperation of local community. Location 2 has the highest weight scores of the first objective, location 8 for the second objective, and location 3 for the third objective respectively. Additionally, the highest and lowest average amounts of blood are collected at locations 3 and 7 respectively. In this experiment, goals 1, 2, 3 and 4 are under-achieved and goal

5 is over-achieved. The total travel distance is reduced with BCLRP in comparison to BCLAP, in other words routing of blood deliveries is shown to save travel in comparison to direct collection of blood.

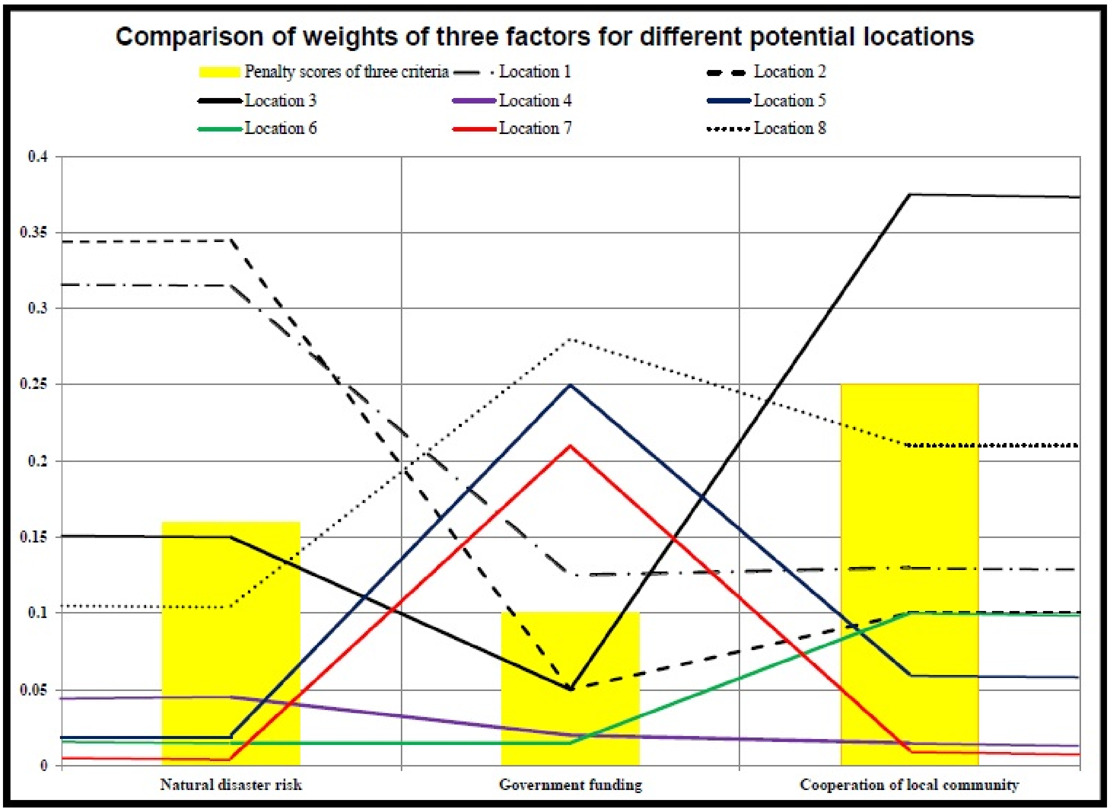


Figure 5.8: Comparison of weights of three factors for the different potential locations

Further experiments were conducted to determine the effects of different penalty scores on results, see Tables 5.11 and 5.12. With equal scores for all penalties (experiment 2), sites 1, 3 and 8 are recommended for both BCLAP and BCLRP, as in experiment 1. Experiment 3 with a high score for objective 1 (blood supply) gives the same results. It can be observed with experiment 4 that location 2 is recommended instead of location 8 when the penalty score in the second objective increases (location 8 has highest weight for the second objective). Moreover, in experiment 5, locations 7 and 8 are recommended to be open when the penalty score in the third objective increases (displacing location 3 has highest weight for third factor). It was necessary to increase the penalty score for objective 3 by different amounts for BCLAP and BCLRP (0.340 and 0.460 respectively) to achieve this affect. However, location 5 and 8 are suggested when the penalty score of the third objective increases further in experiment 6 (0.400 and 0.540 for BCLAP and BCLRP) while the penalty score of the final objective decreases as well. Finally, location 3 and 5 are suggested for RBCs when the penalty score of the last objective is much increased (experiments 7 and 8).

Some general observations can be made concerning these experiments. It should be noted that, in the test data, location 6 is the most expensive fixed cost for building a new RBC: this site is not a recommended location in any experiment. Similarly, site 4 is not recommended as it scores low on objectives 2, 3 and 4. Overall, the BCLRP model gives considerably lower deviation values than BCLAP in objective 5 (goal value 5, total distance) in all experiments because of total travelling distance closer to the target. In all experiments, total distance travelled with BCLRP is lower than BCLAP, indicating travel cost savings with the delivery routes constructed.

5.5 Summary and Conclusion

It was explained in Chapter 2 that some current RBC locations may not be the best for distribution of blood to hospitals by the TRCS in all provinces of Thailand. We have demonstrated in this chapter the efficiencies that can be gained firstly by reallocation of hospitals in provinces to existing RBC locations, and secondly by relocation of the current number of RBCs to different provinces, using p-median modelling. The results of the latter suggest a number of new RBC locations which have confirmed possible future TRCS policies. Furthermore, results of maximal covering modelling demonstrate that two further RBCs are needed to cover hospitals within a 4-hour time constraint. This study proposes goal programming models for the Blood Centre Location-Allocation Problem (BCLAP) and Blood Centre Location-Routing Problem (BCLRP) of blood centres. Goal programming models are particularly suited to taking into account weightings that can be accorded to different factors to be considered when siting regional blood centres. Such weighting could be set by experts in the area, as part of an integration of Analytical Hierarchy Process (AHP) with Goal Programming. Test results demonstrate that supplier-managed routing of blood deliveries to hospitals can cut transportation costs in comparison to collection of blood directly by hospitals. Moreover, supplier deliveries also reduce the traffic problem of multiple vehicles arriving in the vicinity of blood centres.

As the TRCS is currently unable to implement plans to build and run more fully-functioning RBCs, the study continues in Chapter 6 with modelling to address the problem of location of low-cost extensions to the current network of RBCs.

Chapter 6

Nationwide Location of Low-cost blood collection and distribution centres

In this chapter, optimal locations are found for low-cost blood service facilities. Such facilities, as highlighted in Section 2.5, are part of the long-term plan of the TRCS to extend the existing blood supply chain network. The costs of building such collection and distribution centres are much lower than those of building new full-function blood centres with installation of expensive blood testing and screening equipment (as considered in Chapter 5). Two types of low-cost facility are under consideration: the first (termed a Type 1 facility) consists of a donation room only. The second, more expensive facility (termed a Type 2 facility), combines a donation room with a distribution centre. The foundation of Type 1 fixed donation rooms is proposed to facilitate easy access for donors who may be unaware of the timing and place of bloodmobile sessions. Type 2 facilities with distribution centres are proposed to improve the logistics system. Hospitals in some provinces suffer significant costs in collecting blood from remote RBCs or the NBC. Lengthy transportation may also have an effect on quality of blood products received. Both Type 1 and Type 2 facilities would be allocated to an RBC or the NBC for testing of blood in a timely manner.

Locations for these two types of low-cost blood service facilities and optimal numbers for each type of facility need to be determined under the budgetary constraints of the TRCS. Figure 6.1 shows distances travelled by blood samples and blood collected at each type of facility. For Type 1 facilities, being without distribution centres, costs must be considered of transporting the blood collected to RBCs for testing and of distribution from RBCs to hospitals. From Type 2 facilities, including distribution capabilities, costs

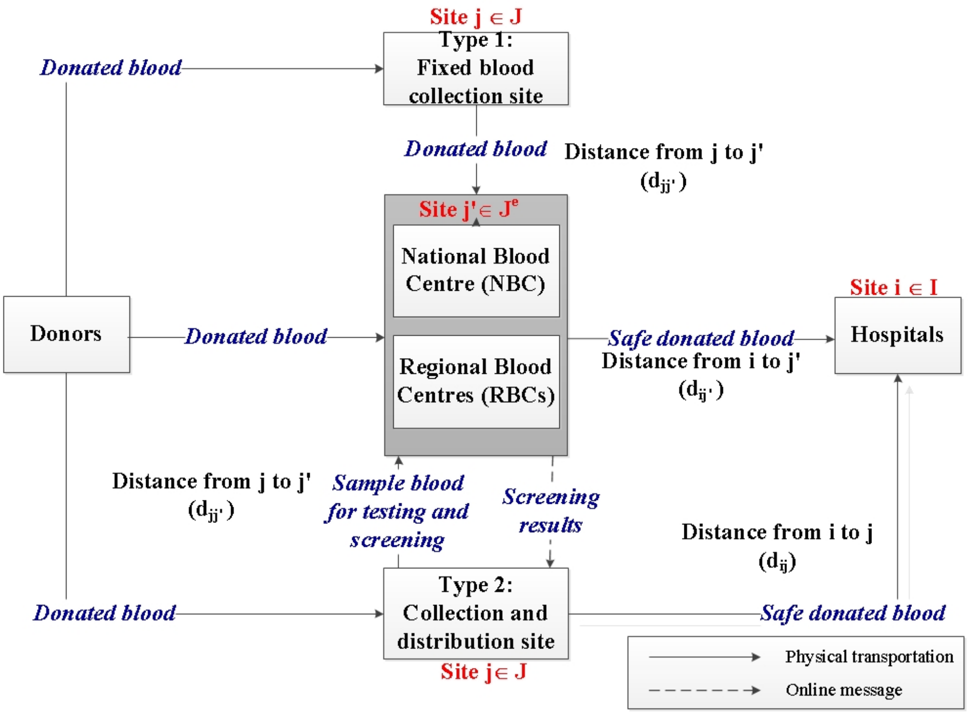


Figure 6.1: Proposed blood supply chain with two new types of blood service facilities

are incurred transporting samples of blood to RBCs for safety checks as well as costs of distribution of blood collected from the Type 2 facility directly to hospitals.

Budgetary constraints on development of both types of low-cost facility have to take into account land costs, building costs and equipment costs. Land costs vary throughout the provinces of Thailand. Building costs include labour costs, again varying throughout Thailand. The equipment costs for a Type 2 facility, with equipment for preparing blood for distribution, are more expensive than for Type 1 donation rooms alone.

6.1 Formulation of Facility Location Problem for Donation Rooms and Distribution Sites Facility

6.1.1 Model specification

The essence of the logistics problem of locating the low-cost collection and delivery centres is illustrated in Figure 6.1. Donors give blood either at one of the two types of blood service facilities proposed or at the NBC or RBCs. Transportation of whole blood and blood products is illustrated: all blood collected at a Type 1 facility goes straight to an allocated RBC. On the other hand, only samples of blood collected at Type 2 facilities are sent to an RBC and results of screening and testing are reported online. After testing, safe blood products are distributed to demand points at hospitals.

The capital of each province is considered both as a demand point and as a candidate site for both types of low-cost facilities, unless the capital is already an RBC location. Locations for both types of blood service facilities are chosen according to a weighted sum of three criteria, of which the first is the estimated sum of donations at opened sites. Secondly, total distances are summed from Type 1 and 2 facilities to an allocated RBC, representing transport of samples. Thirdly, total distances from RBCs or Type 2 facilities to hospital demand points are calculated, weighted by estimated quantity of blood products transported. Criteria weights are supplied by the decision maker.

The model makes the following assumptions: that donations at all candidate facility sites can be estimated for the planned time period, that demand from hospitals can similarly be estimated, that a total budget for establishing the new facilities is known, and that the decision maker can weigh the relative importance of improving supply against improving transportation costs. Transportation costs are the same for both whole blood bags and blood samples since the same vehicles are used. Vehicle capacities are not considered in this model.

6.1.2 Mathematical model

Notation

Parameter	Description
I	set of demand sites
J	set of candidate sites for type 1 and type 2 facilities
J^e	set of sites of RBCs (including the NBC)
b	budget allocated for establishing blood service facilities
$d_{ij'}$	distance between the i^{th} hospital and the j'^{th} RBC site, $i \in I,\ j' \in J^e$
$d_{jj'}$	distance between the j^{th} facility site and the j'^{th} RBC site, $j \in J,\ j' \in J^e$
d_{ij}	distance between the j^{th} facility site and the i^{th} hospital, $i \in I,\ j \in J$
e^1_j , e^2_j	equipment costs for Type 1 and 2 facilities at site $j, j \in J$
f^1_j , f^2_j	construction costs for Type 1 and 2 facilities at site $j, j \in J$
g_j	annual expected amount of blood collected at the j^{th} donation room in units of blood, $j \in J$
l^1_j , l^2_j	land costs for Type 1 and 2 facilities at site $j, j \in J$
m	maximum travel distance between a Type 2 facility and the regional blood centre

Parameter	Description
q_i	average quantity of blood usage at the i^{th} hospital in units of blood,$i \in I$
w_1,w_2,w_3	weight score for the 1st, 2nd and 3rd objective

Decision variables

Variable	Description
$x^1_{ij'}$	$= \begin{cases} 1, & \text{if the } i^{th} \text{ hospital is is allocated to the } j'^{th} \text{ RBC, } i \in I,\ j' \in J^e, \\ 0, & \text{otherwise} \end{cases}$
x^2_{ij}	$= \begin{cases} 1, & \text{if the } i^{th} \text{ hospital is allocated to a type 2 facility at the } j^{th} \text{ site,} \\ & i \in I,\ j \in J, \\ 0, & \text{otherwise} \end{cases}$
y^1_j	$= \begin{cases} 1, & \text{if a type 1 facility is opened at the } j^{th} \text{ site, } j \in J, \\ 0, & \text{otherwise} \end{cases}$
y^2_j	$= \begin{cases} 1, & \text{if a type 2 facility is opened at the } j^{th} \text{ site, } j \in J, \\ 0, & \text{otherwise} \end{cases}$
$z^1_{jj'}$	$= \begin{cases} 1, & \text{if a type 1 facility at the } j^{th} \text{ site is allocated to the } j'^{th} \text{ RBC,} \\ & j \in J,\ j' \in J^e, \\ 0, & \text{otherwise} \end{cases}$
$z^2_{jj'}$	$= \begin{cases} 1, & \text{if a type 2 facility at the } j^{th} \text{ site is allocated to the } j'^{th} \text{ RBC,} \\ & j \in J,\ j' \in J^e, \\ 0, & \text{otherwise} \end{cases}$

Model formulation

The objective function (6.1) minimises the weighted sum of three components. The first component is the total travel distance from the two types of blood facilities to allocated RBCs. The second component is the demand-weighted distance from Type 2 facility or RBCs to the allocated demand site; this component is analogous to the p-median model discussed in Chapter 3, Section 3.2.1.1. The final component is the expected sum of blood donated during the planning period. It should be noted that we do not weight the first component according to the amounts of blood transported to the RBCs or numbers of samples, which are small in volume. Both these types of transport require a vehicle, and are therefore given equal weighting.

Minimise

$$w_1 \left(\sum_{j \in J} \sum_{j' \in J^e} d_{jj'} (z^1_{jj'} + z^2_{jj'}) \right) + w_2 \left(\sum_{i \in I} \sum_{j' \in J^e} q_i (d_{ij'} x^1_{ij'} + d_{ij} x^2_{ij}) \right) - w_3 \left(\sum_{j \in J} g_j (y^1_j + y^2_j) \right) \tag{6.1}$$

subject to

$$\sum_{j' \in J^e} x^1_{ij'} + \sum_{j \in J} x^2_{ij} = 1, \quad \forall i \in I, \tag{6.2}$$

$$\sum_{j' \in J^e} z^1_{jj'} = y^1_j, \quad \forall j \in J, \tag{6.3}$$

$$\sum_{j' \in J^e} z^2_{jj'} = y^2_j, \quad \forall j \in J, \tag{6.4}$$

$$x^2_{ij} \leq y^2_j, \quad \forall i \in I, \quad \forall j \in J, \tag{6.5}$$

$$y^1_j + y^2_j \leq 1, \quad \forall j \in J, \tag{6.6}$$

$$z^1_{jj'} \left(\frac{d_{jj'}}{90} \right) \leq 4, \quad \forall j \in J, \quad \forall j' \in J^e, \tag{6.7}$$

$$z^2_{jj'} d_{jj'} \leq m, \quad \forall j \in J, \quad \forall j' \in J^e, \tag{6.8}$$

$$\sum_{j \in J} (e^1_j + f^1_j + l^1_j) y^1_j + \sum_{j \in J} (e^2_j + f^2_j + l^2_j) y^2_j \leq b, \tag{6.9}$$

$$x^1_{ij'}, x^2_{ij} \in \{0, 1\}, \quad \forall i \in I, \quad \forall j \in J, \quad \forall j' \in J^e, \tag{6.10}$$

$$y^1_j, y^2_j \in \{0, 1\}, \quad \forall j \in J, \tag{6.11}$$

$$z^1_{jj'}, z^2_{jj'} \in \{0, 1\}, \quad \forall j \in J, \quad \forall j' \in J^e. \tag{6.12}$$

Constraints (6.2) ensure that each hospital is allocated to exactly one RBC or one distribution centre. Constraints (6.3) and (6.4) allocate an open Type 1 or 2 facility j to exactly one RBC j'. Constraints (6.5) ensure that hospital i is allocated only to an open Type 2 facility. Type 1 and Type 2 facilities cannot be opened at the same site via constraints (6.6). If a Type 1 facility i is allocated to RBC j', Constraints (6.7) impose a maximum travel time of 4 hours on blood transported between the sites, assuming 90 kph speed of travel. Constraints (6.8) define the maximum travel distance from a Type 2 facility j to the regional blood centre, j', to which it is allocated. Constraint (6.9) defines the budgetary constraint.

6.2 Data used and results

6.2.1 Data sources

As indicated in Chapter 4, data for runs of this model are obtained from the annual reports for years 1999 to 2009 of the NBC (NBC, 2009). Capitals of Thailand's 76 provinces were used as candidate sites for Type 1 or 2 facilities, unless RBCs or the NBC were already located there. From the available NBC data, it can be observed that it is from the provincial capitals that most donations were received by the TRCS. Expected donations at each candidate site were calculated from the quantities given by existing donors who gave blood to local hospitals in that area if there was no RBC in the province.

The approximation was made that demand is concentrated in the capital of each province, since more detailed data were not available regarding demand from every hospital in every province. All hospitals in one province are therefore assumed to be allocated to one distribution centre or RBC. As described in Chapter 4, Google Earth and GIS software ArcGIS version 10 were employed to compute distances among various nodes based on the national road network, as defined by a geographic data set of Thailand Transport Portal, Ministry of Transport in Thailand.

Costs for investment in facilities can be divided into three parts. Firstly, costs of land are different across the provinces, ranging from approximately 65,000 to 13,000,000 Thai Baht per square feet (see Appendix B.1). These are assessed by the Department of Land, Ministry of Interior. Secondly, the costs of equipment include beds for blood donation. In addition, Type 2 facilities must have refrigerators for storing blood at low temperatures to control its quality and blood cell separator machines for preparing blood and blood products for distribution. The costs for Type 2 facility equipment are seven times greater than the costs for Type 1. Lastly, the costs of construction vary depending on local labour costs in different areas, including the size of building. Type 2 facilities need more rooms available than Type 1 facilities.

We used equally weighted objective components after discussion with the National Blood Centre. The actual weights used were normalised according to the magnitude of the objectives.

6.2.2 Graphic User Interface

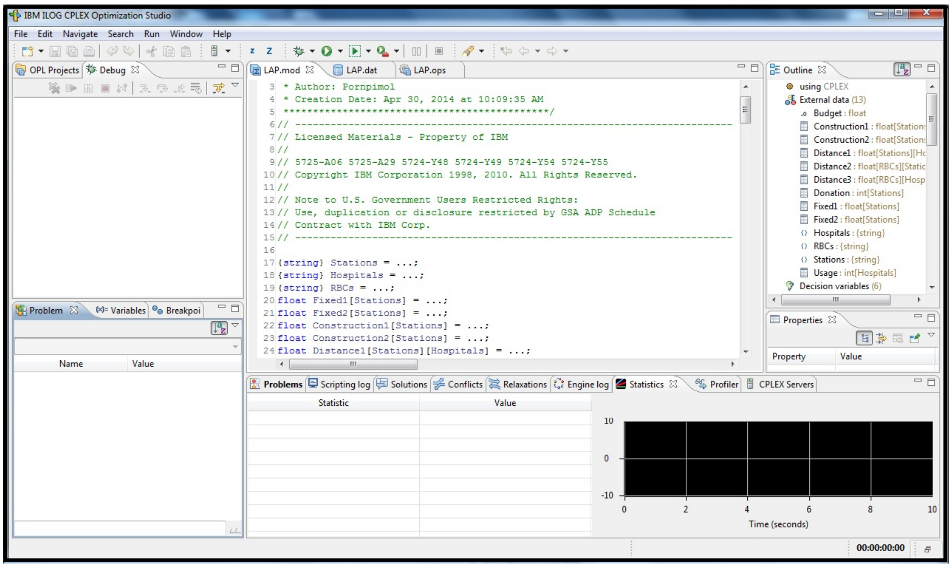


Figure 6.2: IBM ILOG CPLEX Window

The proposed model was solved using IBM ILOG CPLEX academic version 12.2 on 2.26 GHz Intel Core 2 Duo CPU processor running on a Windows 7 operating system. The CPLEX window is shown in Figure 6.2. The optimal solution is obtained with a total computing time of approximately 2.34 seconds. Statistical values from implementation are displayed in Figure 6.3.

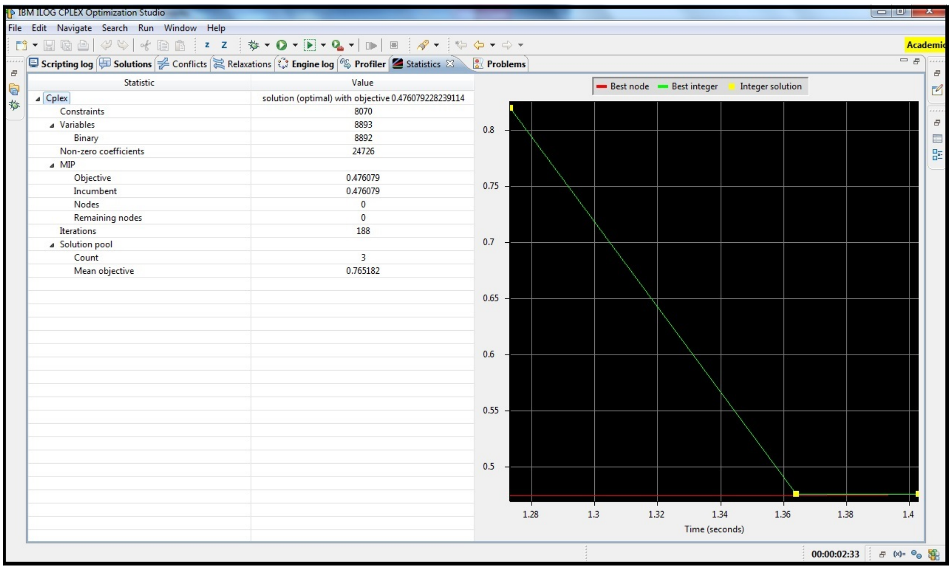


Figure 6.3: Computing Time and Statistics Result

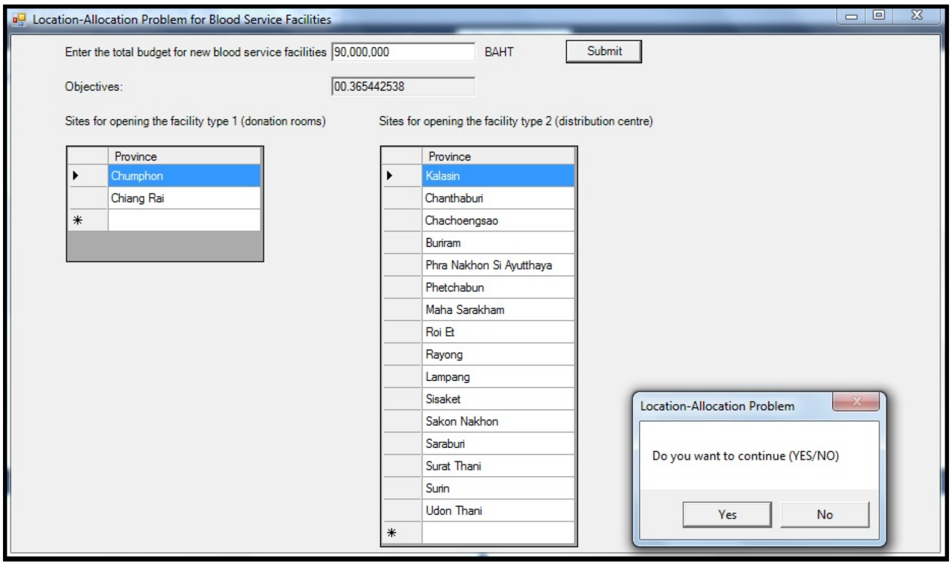


Figure 6.4: User interface based on Window Application for location-allocation model for low-cost blood service facilities

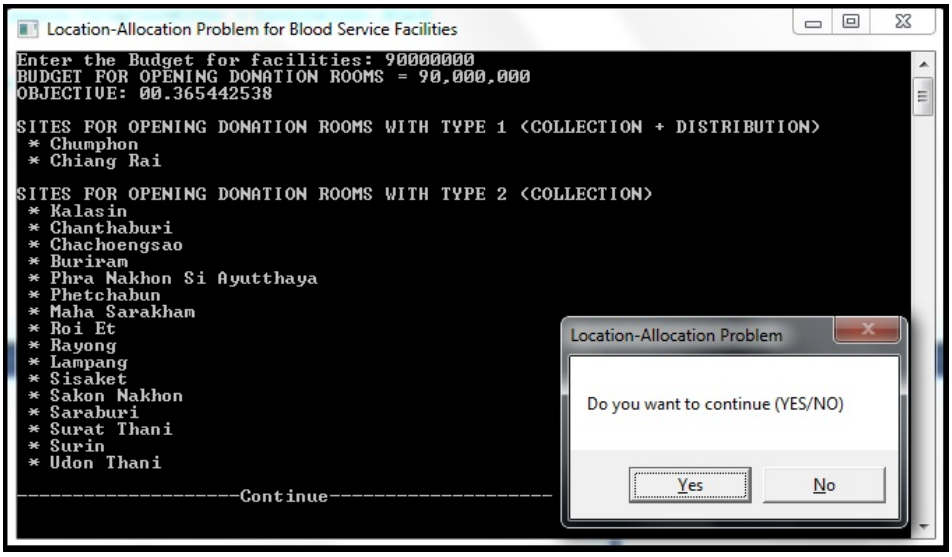


Figure 6.5: User interface based on Console Application for location-allocation model for low-cost blood service facilities

The ILOG OPL program is embedded in Visual Basic.Net as User Interface based on Window Application shown in Figure 6.4 and based on Console Application in Figure 6.5 (see ILOG codes in Appendix H and Appendix I). Decision makers can obtain different results by changing a budget value as a parameter in the application program.

6.2.3 Results: Recommended locations and insights obtained

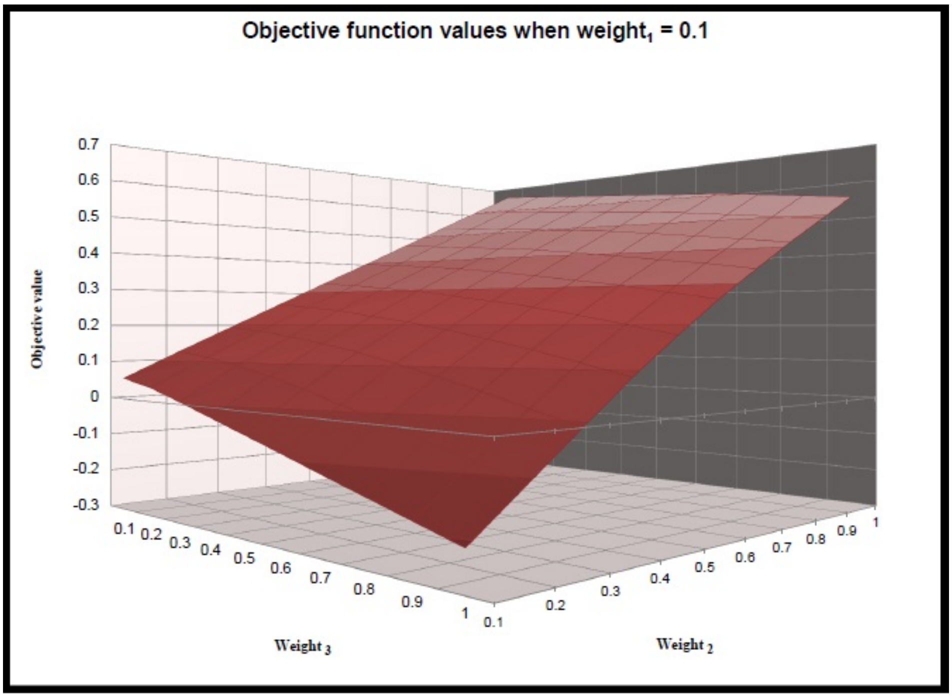


Figure 6.6: Comparing objectives on different values of weight 2 (w_2) and weight 3 (w_3) when weight 1 (w_1) = 0.1

In this section, we present the results based on the binary integer programming model implemented on the real world data described. As expected, experiments on different values of weights show that increasing weight 1 (w_1) and weight 2 (w_2) and decreasing weight 3 (w_3) of the objective function gives the higher objective values, with opening of distribution centres. This is illustrated in Figure 6.6 when weight 1 (w_1) is equal to 0.1. It was found when weight 1 was equal to 0.1, that a type 2 facility will be proposed when weight 3 is less than 0.6 or weight 2 is greater than 0.4.

We describe experimental results for a budget of 90 million Thai Baht with weights for three objective components equal to 1. In the upper North region, illustrated in Figure 6.7, an RBC is currently located in Chiang Mai province. All hospitals in Mae Hong Son, Lamphun, Lampang, and Phrae provinces can obtain blood from the Chiang Mai RBC. Chiang Rai province is suggested as a suitable site for a Type 2 facility for hospitals in Phayao and Nan provinces. Furthermore, a donation room should be established in Lampang, providing 2.74 - 2.94 blood bag donation rate per 100 head of population (according to population figures derived from ArcGIS). The results for the other regions are shown in Figures 6.8, 6.9, 6.10, 6.11, 6.12, 6.13 and 6.14.

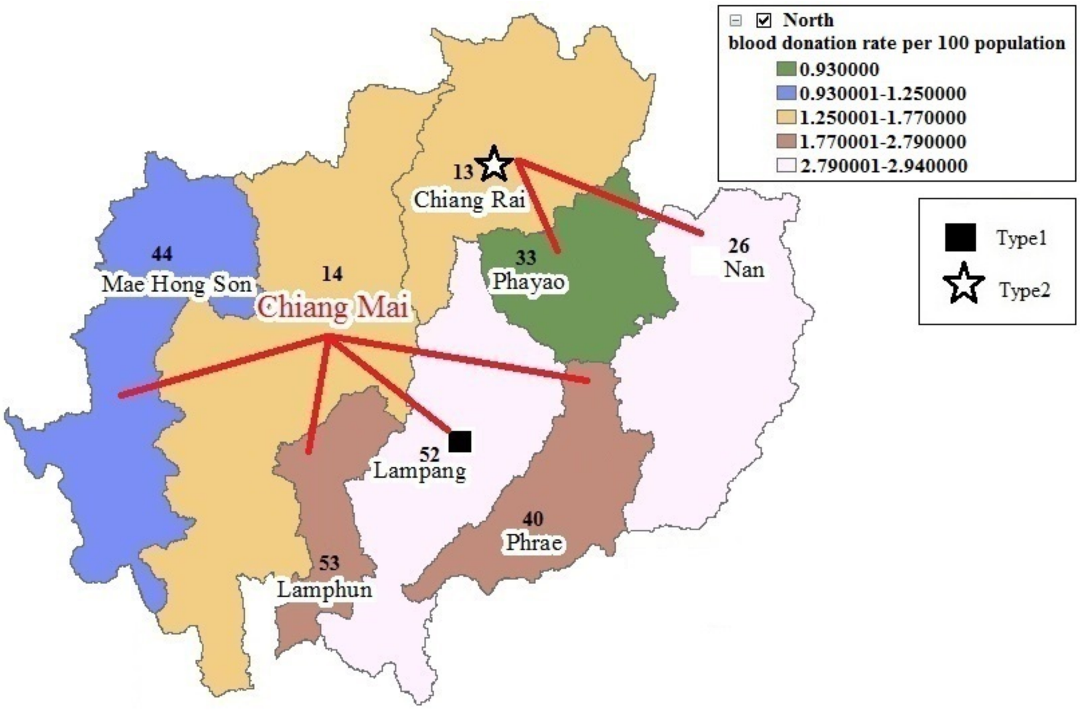


Figure 6.7: Results of locations for type 1 and 2 facilities in the upper North Region

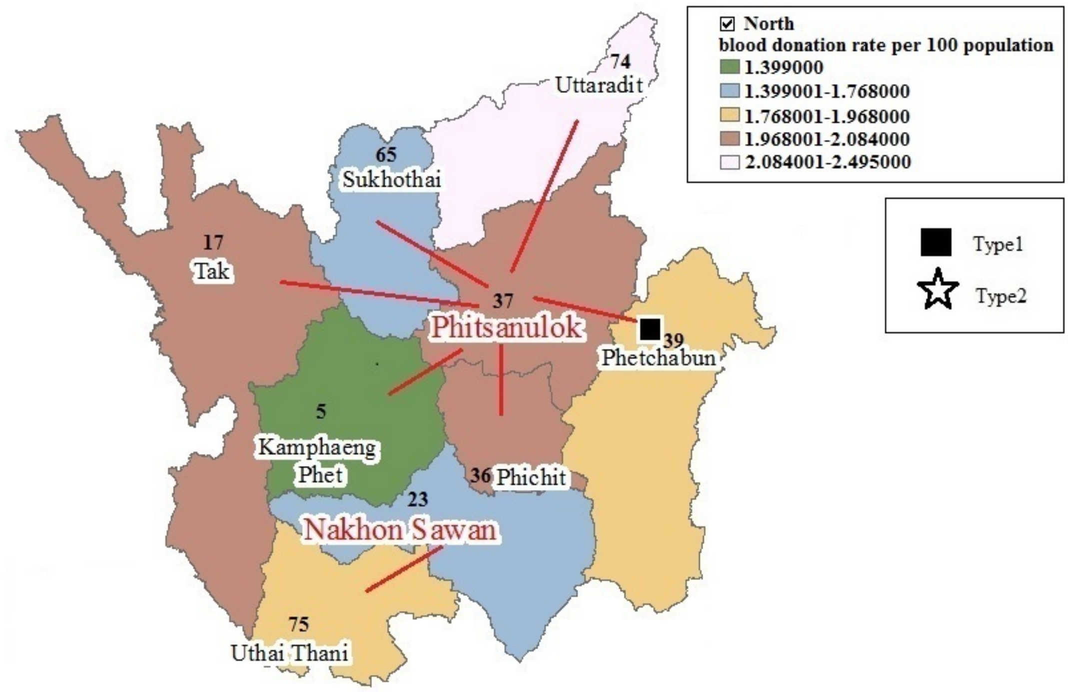


Figure 6.8: Results of locations for type 1 and 2 facilities in the lower North Region

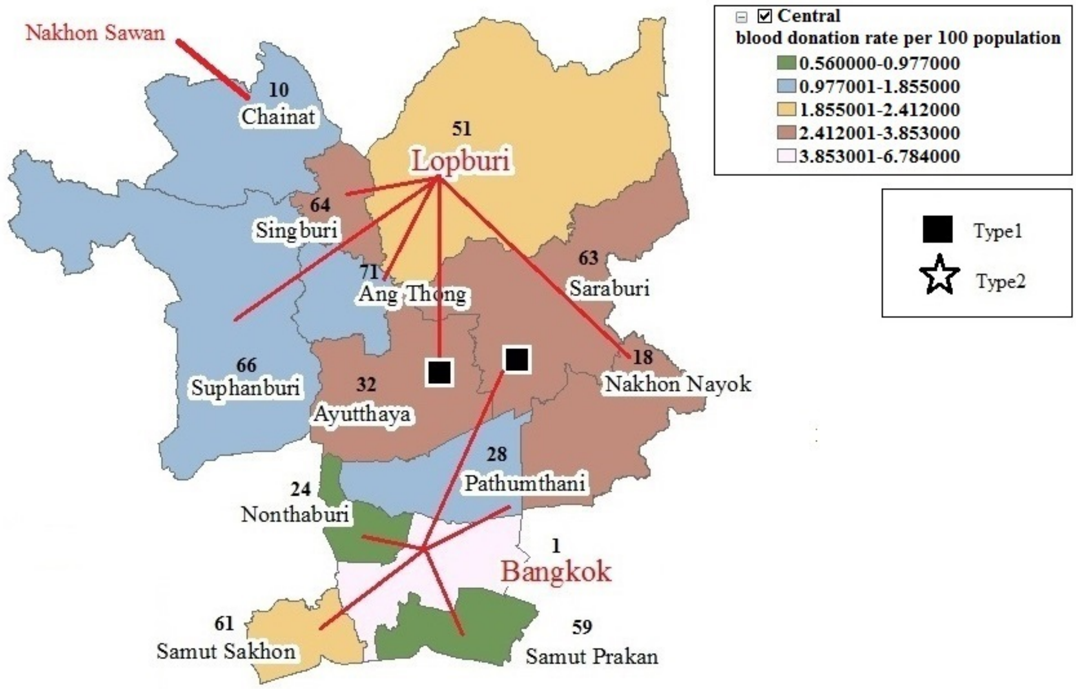


Figure 6.9: Results of locations for type 1 and 2 facilities in the upper Central Region

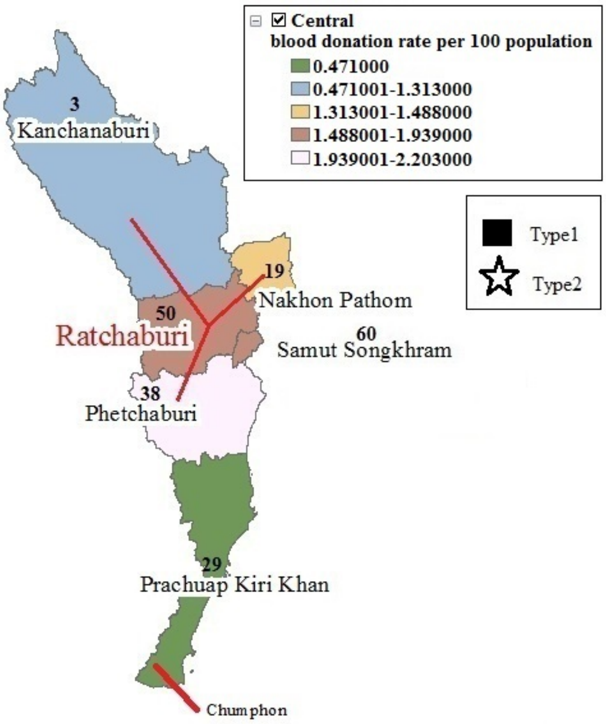


Figure 6.10: Results of locations for type 1 and 2 facilities in the lower Central Region

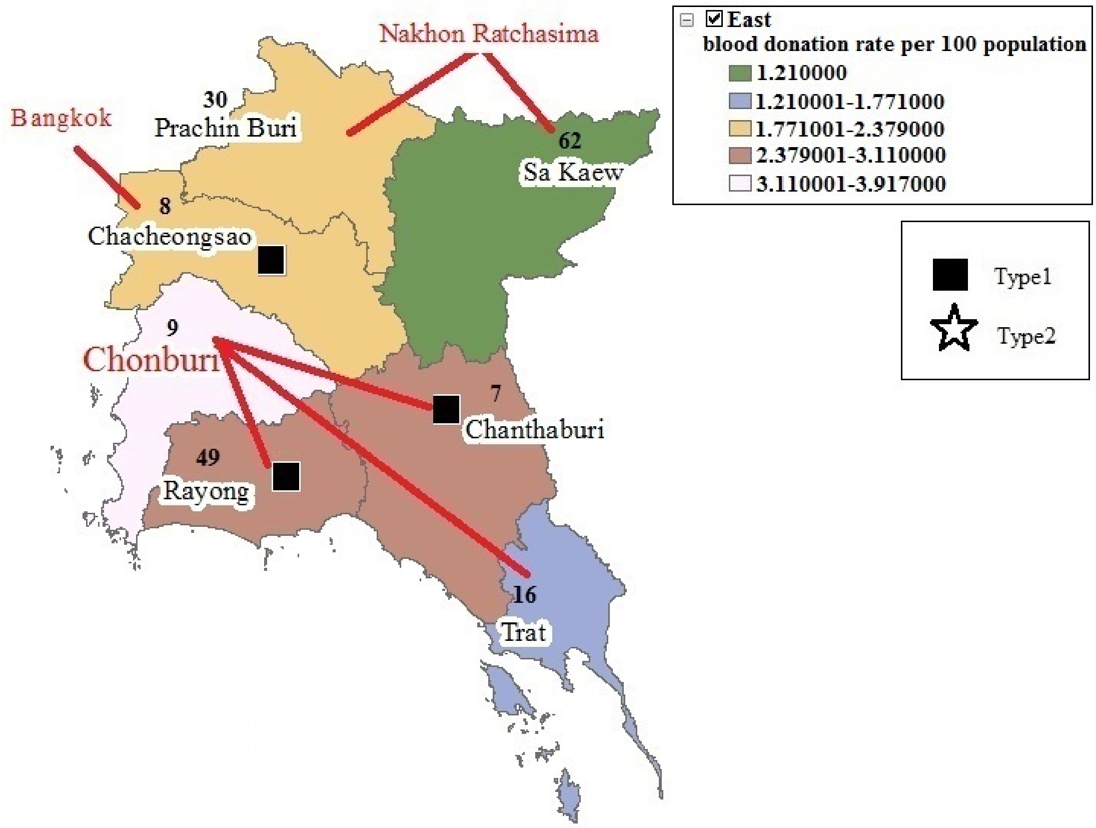


Figure 6.11: Results of locations for type 1 and 2 facilities in the East Region

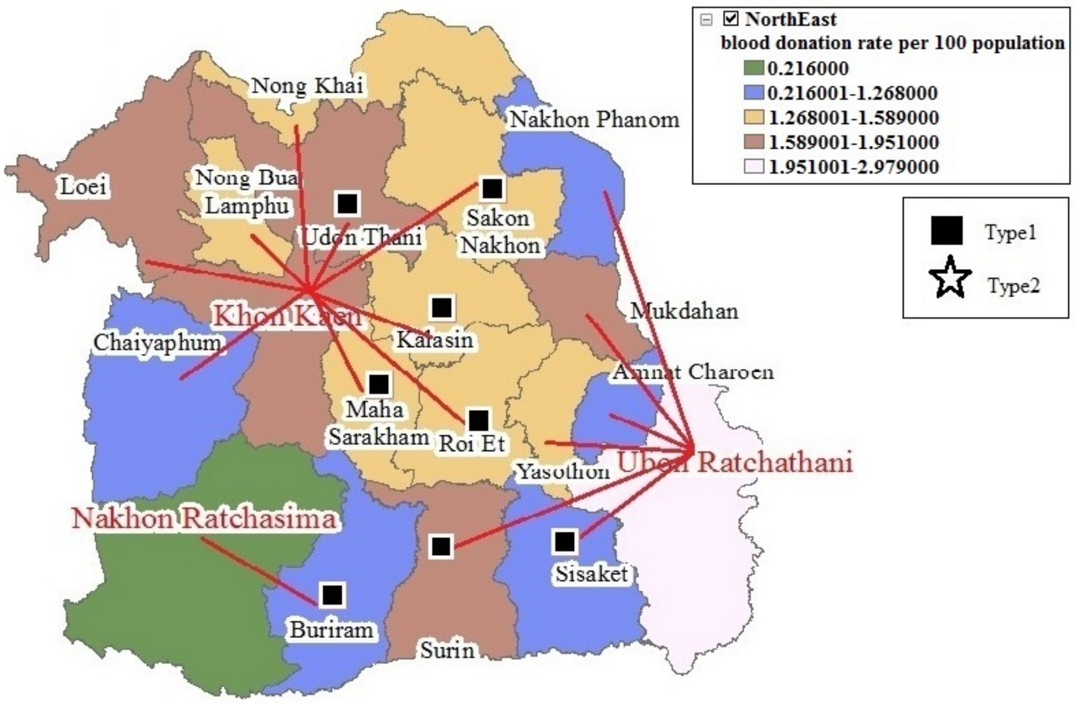


Figure 6.12: Results of locations for type 1 and 2 facilities in the Northeast Region

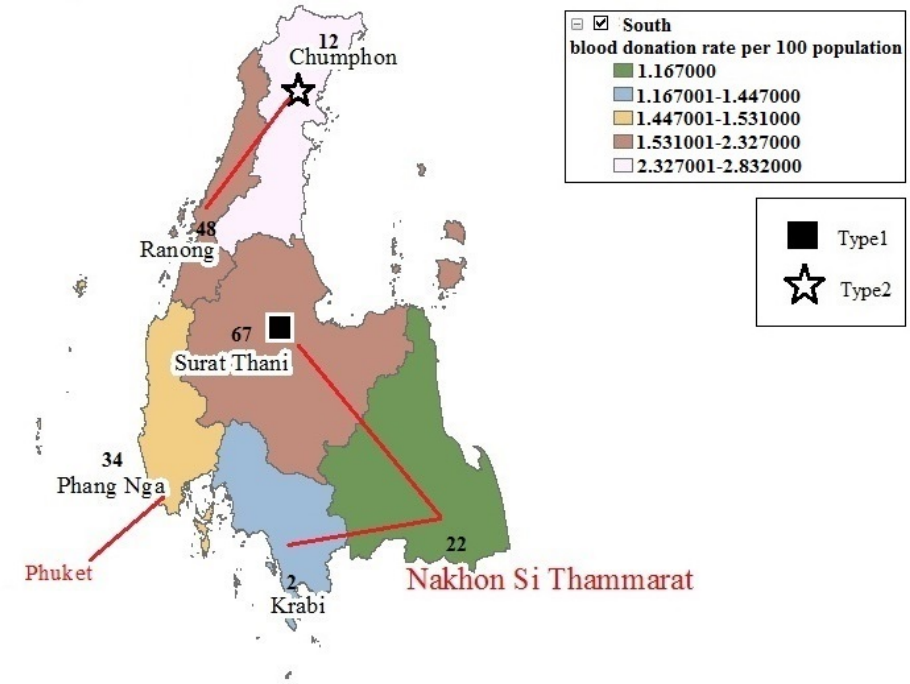


Figure 6.13: Results of locations for type 1 and 2 facilities in the upper South Region

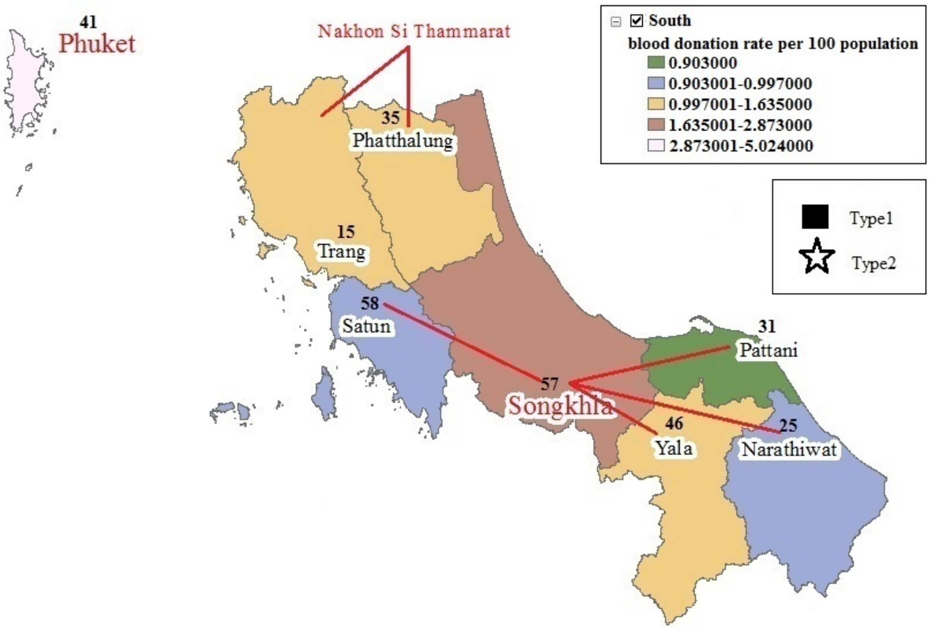


Figure 6.14: Results of locations for type 1 and 2 facilities in the lower South Region

Different colours in Figures 6.7,6.8, 6.9, 6.10, 6.11, 6.12, 6.13 and 6.14 represent blood donation rates per 100 population in a province. Bangkok has the highest blood donation rate (see Figure 6.9). Some regions have no recommended new facility because there is already a good blood service, with a high number of donors and a central location for blood distribution. For example, this applies in Ratchaburi province in the lower Central Region and Songkhla province in lower South Region. However, the number of facilities suggested for opening depends on the budget assumed to be available nationally for healthcare facilities. Detailed results are shown in Appendix J.

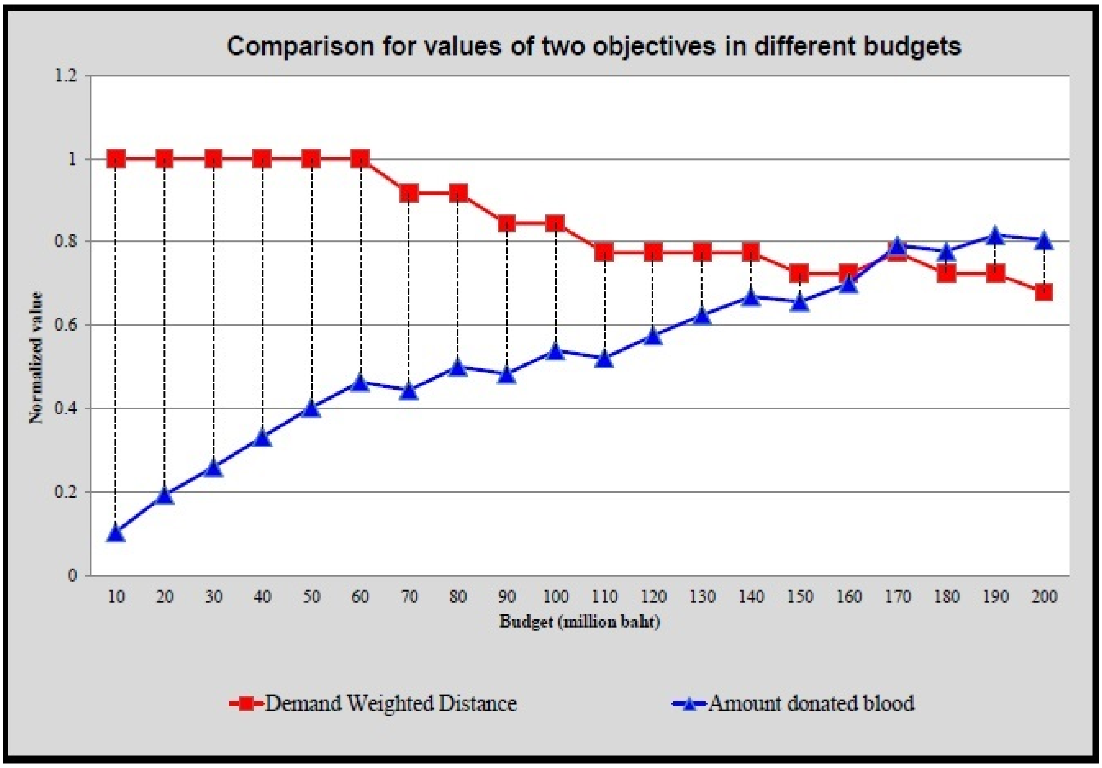


Figure 6.15: Comparing objectives: the demand weighted distance and the donor coverage

Runs were made for budgets from 10 to 200 million Thai Baht with contrastingly decreasing costs of transporting blood to hospitals and increasing quantities of blood collected from donors (see Figure 6.15). For lower budgets, up to 70 million Thai Baht, only the less costly Type 1 facilities are located, with rooms for donations only. At higher budgets, the more costly Type 2 facilities can also be afforded, with rooms for both donations and distribution. There is a steady decline in the logistics and transportation costs with the opening of a new distribution site.

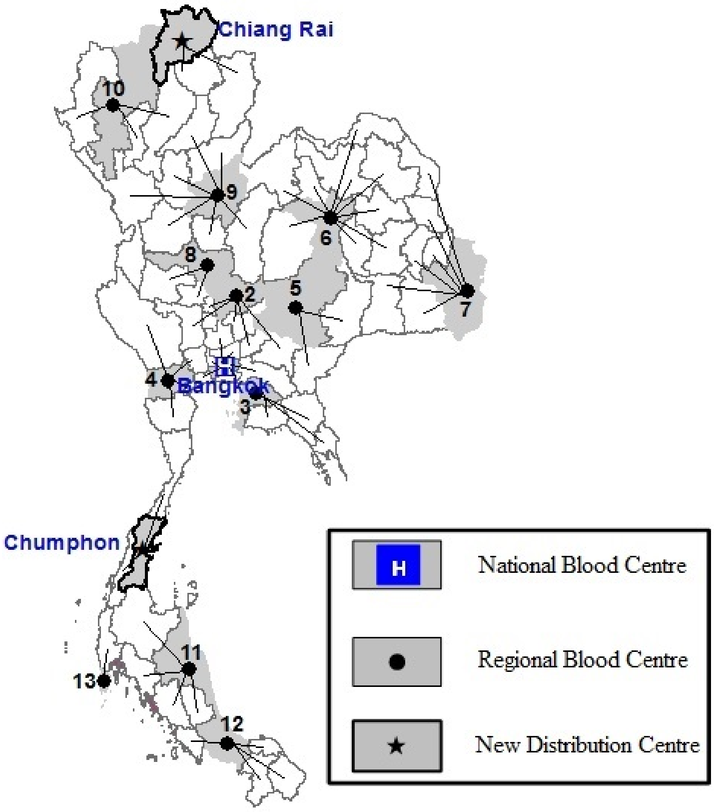


Figure 6.16: Locations recommended as distribution sites

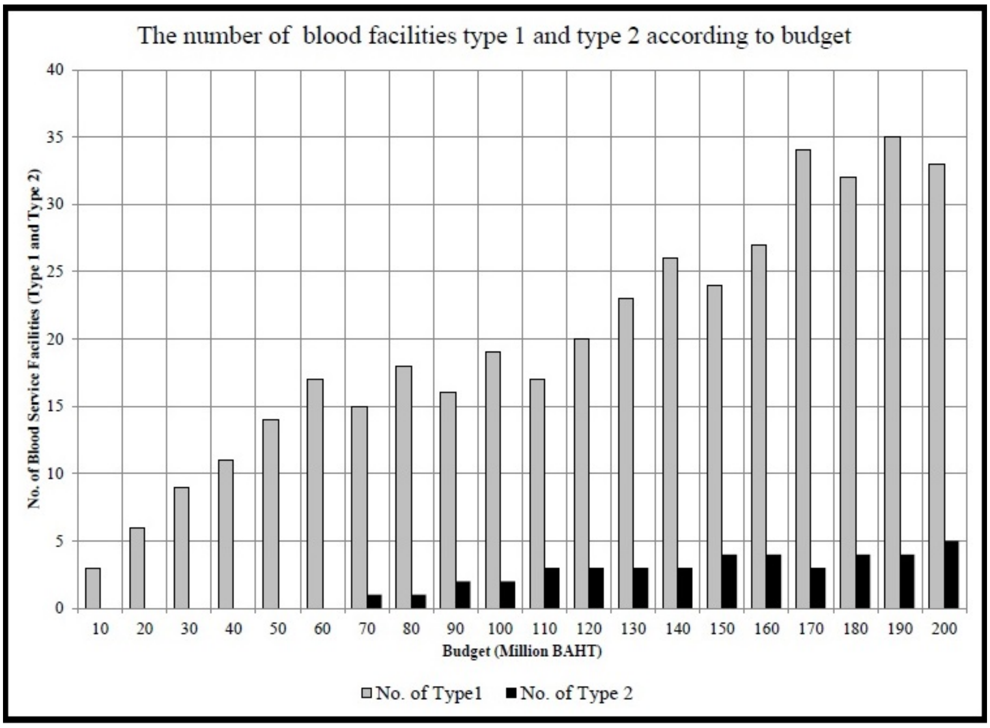


Figure 6.17: Comparison of numbers of Type 1 and Type 2 blood facilities at various budgets

Table 6.3: Comparison of distances for blood distribution to 1000 hospitals from the blood service facilities (unit: kilometre)

Blood Service Facility	Based on current situation				Based on solution proposed			
	Min.	**Max.**	**Avg.**	**Std.**	**Min.**	**Max.**	**Avg.**	**Std.**
NBC: Bangkok	0.61	115.74	25.86	24.12	0.61	162.33	32.91	34.60
RBC 2: Lopburi	10.27	140.15	60.06	40.74	5.00	187.04	65.80	42.27
RBC 3: Chonburi	11.87	277.86	107.20	50.03	11.87	277.86	106.88	51.28
RBC 4: Ratchaburi	0.69	315.47	82.25	68.03	0.69	291.79	66.36	50.58
RBC 5: Nakorn Ratchasima	26.21	309.35	143.36	75.28	26.21	235.43	95.48	53.99
RBC 6: Khon Kaen	13.99	299.29	174.72	80.87	13.99	315.32	177.28	79.47
RBC 7: Ubon Ratchathani	23.00	315.96	179.53	81.80	23.00	315.96	179.53	81.80
RBC 8: Nakorn Sawan	28.89	381.13	140.23	88.95	28.89	155.47	74.46	32.64
RBC 9: Phitsanulok	2.24	370.34	139.45	98.71	2.24	315.76	117.90	63.26
RBC 10: Chiang Mai	32.26	289.28	116.45	56.71	32.26	289.28	110.81	60.04
RBC 11: Nakorn Si Thammarat	1.41	372.93	159.61	96.25	1.41	209.25	110.82	50.02
RBC 12: Songkhla	12.31	247.02	114.11	68.98	12.31	247.02	114.11	68.98
RBC 13: Phuket	5.38	18.74	14.48	4.68	5.38	114.50	41.58	36.56
DC: Chiang Rai					11.15	289.74	120.80	84.99
DC: Chumphon					11.82	263.66	97.15	74.61
Overall average	-	-	112.10	-	-	-	100.79	-

(NBC: National Blood Centre, RBC: Regional Blood Centre DC: Distribution Centre)

One site in the North region, Chiang Rai province, and one site in the South region, Chumphon province, is recommended for Type 2 facilities with distribution centres, when budgets are higher than 90 million Thai Baht. Demand from several provinces is re-allocated to receive blood from the new distribution sites. Hospitals in Chiang Rai, Nan and Phayao provinces are assigned to the distribution site at Chiang Rai province located in the north of the country, while the distribution site at Chumphon province in the South region supports hospitals located in Chumphon, Ranong, and Prachuap Khiri Khan provinces, as illustrated in Figure 6.16. Figure 6.17 shows the numbers of Type 1 and Type 2 facilities sited according to a range of budget from 10 to 200 million Thai Baht.

Demand for blood products was assumed in model runs to be aggregated in the 76 provincial capitals. To determine the effects of this approximation, the actual locations of more than 1,000 hospitals were used in subsequent testing of results to compare current distances travelled to RBCs with distances to RBCs and the recommended Type 2 distribution facilities. Table 6.3 shows minimum, maximum, average, and standard deviations of actual travel distances obtained by allocating 1,000 hospitals to the blood service centres. Results based on the proposed model show a considerable improvement, with the overall average travelling distance from hospitals to RBCs or Type 2 distribution centres (DCs) being reduced from 112 km to 101 km. In most cases the average distance travelled from hospitals to individual RBCs is decreased by the new proposal. However, there are small increases to some RBCs and the NBC due to re-allocation of hospitals to even out travelling.

6.3 Discussion

The results of running different scenarios have been discussed with the NBC. The NBC's current plans for building blood distribution centres, based on working experience, propose siting a facility at Chiang Rai province, one of the sites recommended from the model results. It is evident that two provinces, Nan and Phayao provinces, are currently far from the nearest RBC in Chiang Mai province. By re-allocating the demand from these provinces to Chiang Rai, transportation time for blood products to hospitals in these provinces can be reduced significantly. The results thus obtained from the model closely correspond to the decision maker's opinion.

6.4 Summary and Conclusion

Shortage of supply of safe blood products is a severe problem in many developing countries such as Thailand. Increasing the number of blood services for collecting blood from donors in the provinces is expected to help increase the amount of donated blood. In such regions, funds are limited for development of technologically advanced centres for blood screening and testing. However, low-cost solutions can be found that extend the reach of a network of existing blood centres. Increasing the number of blood services for collecting blood from donors in the provinces is expected to help increase the amount of donated blood. This research demonstrates the possibilities of improving the supply of blood products while also reducing transportation costs within available budgets.

Binary Integer programming is proposed for this novel location-allocation problem based on contrasting objectives of improving supply while reducing transportation costs. Budgetary constraints take into account the full range of costs of construction of two types of facility, either donation room only or donation room with distribution centre.

Chapter 7

Fixed Routes for Blood Distribution

This thesis now turns to the case study of blood distribution in the upper North Region introduced in Chapter 2, Section 2.6. The case study design is influenced by the descriptive data analysis described in Chapter 4, Section 4.3. The problems of blood supply and distribution throughout Thailand were discussed in Section 2.5. Supplier-managed supply is proposed by the TRCS to improve the blood supply chain, both in terms of quality and efficiency. Thus, planning of schedules and routing for blood delivery is the focus of this chapter, considering regular, fixed routes out of the RBC at Chiang Mai to hospitals throughout the upper North region. We present algorithms for determining the shortest possible fixed routes for blood delivery, according to several policies applicable to situations of both sufficient and insufficient supplies of blood.

Firstly in this chapter, a basic policy of six-day delivery is described, with all hospitals visited once during the six-day planning period. After geographical clustering of hospitals into six groups, each group is visited on exactly one of the delivery days, using a minimum number of vehicles. A comparison is made between use of an improved version of the Clarke and Wright Savings algorithm (Laporte et al., 2000; Ferreira and Pureza, 2012; Straka et al., 2013) with local search and use of an improved version of the GRASP algorithm. Secondly, a policy of delivery on a reduced number of days (three days) is proposed, to save transportation costs, with investigation of routing to hub hospitals and other selected hospitals only. Finally, for insufficient blood supplies, we propose a multi-frequency plan of delivery.

7.1 Fixed Routes for Six-day Blood Distribution with Clarke and Wright Savings algorithm and Local Search

We compare several methods for developing a basic routing plan from the RBC to hospitals in the upper North region to improve blood supply and logistics. Fixed routes are developed for six-day blood distribution: hospitals in the routes are visited on one day only. The amount of blood allocated to hospitals is assumed to be constant, as is appropriate in situations of sufficient supply. Each route must be not over the maximum driving distance of 720 km, which represents a maximum of 8 hours driving at 90 kph (as explained in Section 4.2.). One vehicle with a capacity constraint covers each route.

Table 7.1: Clusters of hospitals in the upper North region of Thailand

Cluster no.	**Number of hospitals**
1	10
2	26
3	43
4	9
5	13
6	11
Total	112

All hospitals are first clustered by their geographic locations into six groups, according to the number of working days for delivery. Each cluster is served exactly one day per week. The number of hospitals is different in each cluster, as shown in Table 7.1. K-Means Clustering in Minitab software is used to divide the hospitals into the six groups.

7.1.1 Capacitated Vehicle Routing Model

Notation and a formulation follow for a Capacitated Vehicle Routing Model (based on that given in Chapter 3, Section 3.3.1) to determine minimal distance vehicle routes from the RBC to hospitals in a cluster using a given maximum number of vehicles. The model is implemented in CPLEX: see Section 7.3 for results and comparisons with heuristic methods. It was not possible to obtain optimal results for all clusters using this model.

Notation

Parameter	Description
I	set of sites of hospitals and the RBC
J	set of sites of hospitals
K	set of vehicles
Q_k	vehicle capacity of route k, $k \in K$
d_{ij}	distance between the i^{th} node and the j^{th} node, $i \in I$, $j \in I$
m	maximum total travel distance in each route
n	number of hospitals
q_i	the quantity of blood requested by the hospital at site $i, i \in J$

Decision variables

Variable	Description
s_{ik}	= auxiliary variable for sub-tour elimination constraints of the node at site i in the vehicle $k, i \in J, k \in K$
x_{ijk}	$= \begin{cases} 1, & \text{if the } i^{th} \text{ node precedes the } j^{th} \text{ node with the } k^{th} \text{ vehicle, } i \in I, \\ & j \in I,\ k \in K, \\ 0, & \text{otherwise.} \end{cases}$

Objective function and constraints

The objective function (7.1) minimises the total travelling distance. The formulation is as follows:
Minimise

$$\sum_{i \in I} \sum_{j \in I} \sum_{k \in K} x_{ijk} d_{ij}, \tag{7.1}$$

subject to

$$\sum_{j \in J} x_{0jk} = 1, \quad \forall k \in K, \tag{7.2}$$

$$\sum_{j \in J} x_{j0k} = 1, \quad \forall k \in K, \tag{7.3}$$

$$\sum_{j \in J} x_{ijk} - \sum_{j \in J} x_{jik} = 0, \quad \forall i \in I, \quad \forall k \in K, \tag{7.4}$$

$$s_{ik} - s_{lk} + n x_{ilk} \leq n - 1, \quad \forall i \in J, \quad \forall l \in J, \quad \forall k \in K, \tag{7.5}$$

$$\sum_{i \in I} \sum_{k \in K} x_{ijk} = 1, \quad \forall j \in J, \tag{7.6}$$

$$\sum_{i \in I} \sum_{j \in I} x_{ijk} q_i \leq Q_k, \quad \forall k \in K, \tag{7.7}$$

$$\sum_{i \in I} \sum_{j \in I} x_{ijk} d_{ij} \leq m, \quad \forall k \in K, \tag{7.8}$$

$$x_{ijk} \in \{0, 1\}, \quad \forall i \in I, \quad \forall j \in I, \quad \forall k \in K, \tag{7.9}$$

$$s_{ik} \in \mathbb{I}^{+}, \quad \forall i \in J, \quad \forall k \in K. \tag{7.10}$$

Constraints (7.2) and (7.3) ensure that the route starts and ends at the RBC. Constraints (7.4) are flow balance constraints. Constraints (7.5) are the sub-tour elimination constraints. Constraints (7.6) ensure that the hospitals are assigned to exactly one route. Constraints (7.7) enforce the capacity of the vehicles. Constraints (7.8) enforce the maximum travel distance on each route.

7.1.2 The Clarke and Wright Savings Algorithm

The Clarke and Wright (C&W) Savings Algorithm (Clarke and Wright, 1964) is a method used to construct vehicle routes by merging feasible routes based on the distance saved. The algorithm has a tendency to offer good routes in the early iterations but perhaps less appropriate routes later on (Laporte and Semet, 2002). This algorithm is also suitable for the problem in which the number of vehicles is considered as a decision variable, with a maximum number of vehicles defined. There are two versions: sequential and parallel (Chrisofides et al., 1979). In the sequential version exactly one route is built at a time, while in the parallel version more than one route may be built at a time. The parallel version of the savings method is claimed to frequently provide better results than the sequential algorithm (Cordeau et al., 2002). However, Rand (2009) argues that the parallel versions are not always better than the sequential versions, since optimality is not achieved. Segerstedt (2014) provides further evidence of an example of a sequential version producing better results than a parallel one. We therefore propose an improved version: we use both sequential and parallel versions to find solutions, and improve the better result using local search.

The process of the algorithm is described in Table 7.4 and 7.5. For the sequential version, savings costs of each pair of nodes are calculated and are stored in the node list sorted from low to high values. Any pair of nodes which cannot be assigned to the route is added to the unassigned list. The unassigned list is used to consider nodes inserted into the route. However, nodes in the node list are considered after there is no node in the unassigned list. The parallel version may combine two route lists to reduce the number of vehicles used and the total travelling distance must not exceed the given maximum distance.

An overview of the procedure for sequential and parallel versions of the algorithm is as follows:

1. Calculate the distance saving, $s_{ij} = d_{i0} + d_{0j} - d_{ij}$ for every pair of nodes (i, j), where $i, j \in \{1, \ldots, n\}$, $i \neq j$, and where d_{i0} is the distance from i to the RBC, d_{0j} is the distance from the RBC to j, and d_{ij} is the distance from i to j. The saving s_{ij} represents the gain from linking nodes i and j together, representing travel from the depot to i, from i to j, and back to the depot. The saving thus avoids going from i directly back to the depot, and from the depot to j, but involves travel from i to j. The savings values are listed in decreasing order.

2. Starting at the top of the savings list, execute the following:

   - For the Sequential version
     - Consider in turn each route $(0, i, \ldots, j, 0)$
     - Consider all other nodes that can be added to route $(0, i, \ldots, j, 0)$. Determine the best saving that can feasibly be made in merging another node into the current route
     - Implement the merge and repeat this operation with the current route
     - If no feasible merge exists, consider the next route and reapply the same operations
     - Stop when there are no nodes unassigned to the routes
   - For the Parallel version
     - Given the saving, determine whether there exist two routes that can feasibility be merged
     - Combine these two routes by deleting $(0, i)$ and $(j, 0)$ and introducing (i, j)

Table 7.4: Clarke and Wright Sequential Savings Algorithm

Clarke and Wright Sequential Savings Algorithm
01. Form a list L containing pairs (i, j), where i and j are nodes, listed in non-increasing order of saving s_{ij}
02. Set U to be the set of unassigned nodes
03. Set $k = 1$
04. Select the first pair (i, j) in list L
05. Initialise the route r_k for vehicle k by including arc (i, j)
06. Set $u = i, v = j$
07. Set $U = U \backslash \{i, j\}$

Continued on next page

Table 7.4: Clarke and Wright Sequential Savings Algorithm

Clarke and Wright Sequential Savings Algorithm
08. Remove (i, j) from list L
09. Set $D = d_{ij}$
10. Set $q = q_i + q_j$
11. Do while $U \neq \emptyset$
12. Select the largest saving (v, v') for $v' \in U$ from list L such that $q + q_{v'} \leq Q$ and $D + d_{vv'} + d_{0u} + d_{v'0} \leq m$
13. Select the largest saving (u', u) for $u' \in U$ from list L such that $q + q_{u'} \leq Q$ and $D + d_{u'u} + d_{0u'} + d_{v0} \leq m$
14. If v' exists and u' does not or if v' and u' exist and $S_{vv'} \geq S_{u'u}$ then
15. Add (v, v') to the end of route r_k
16. Set $U = U \backslash \{v'\}$
17. Remove (v, v') from list L
18. Set $D = D + d_{vv'}$
19. Set $q = q + q_{v'}$
20. Set $v = v'$
21. Else if u' exists and v' does not or if v' and u' exist and $S_{uu'} \geq S_{v'v}$ then
22. Add (u, u') to the beginning of route r_k
23. Set $U = U \backslash \{u'\}$
24. Remove (u', u) from list L
25. Set $D = D + d_{u'u}$
26. Set $q = q + q_{u'}$
27. Set $u = u'$
28. Else
29. Set $k = k + 1$
30. Create list L from node in set U
31. End If
32. Loop

Table 7.5: Clarke and Wright Parallel Savings Algorithm

Clarke and Wright Parallel Savings Algorithm
01. Form a list L containing pairs (i, j), where i and j are nodes, listed in non-increasing order of saving s_{ij}
02. Build the initial routes for $i \in I$ as follows: $r_i = (0, i, 0)$ with quantity q_i and distance $D_i = d_{0i} + d_{i0}$

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Table 7.5: Clarke and Wright Parallel Savings Algorithm

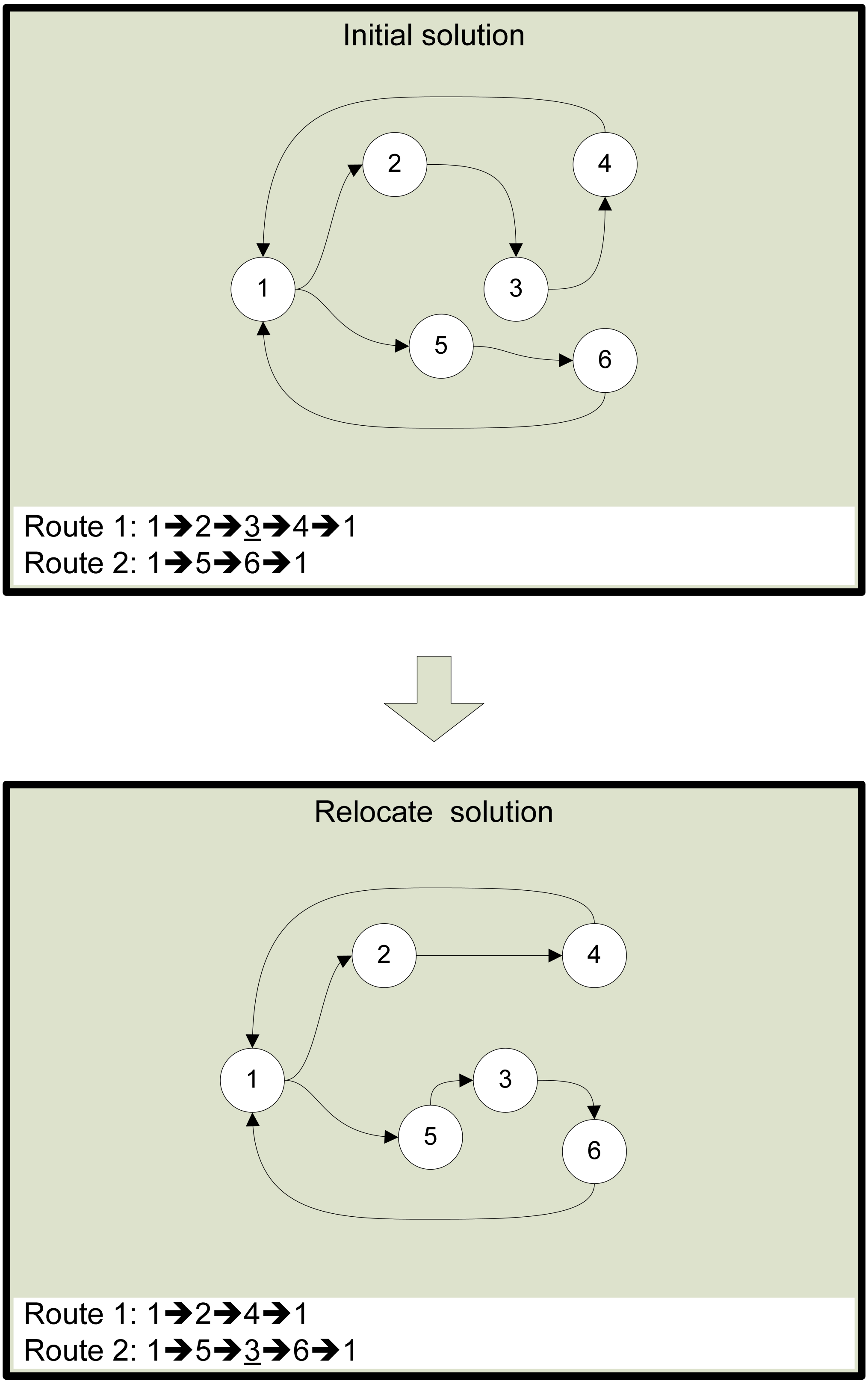
Clarke and Wright Parallel Savings Algorithm
03. Do while there are no more savings to consider
04. Select the largest saving (i, j) from list L
05. Set $r_{i'}$ be the route containing i
06. Set $r_{j'}$ be the route containing j
07. If $q_{i'} + q_{j'} \leq Q$ and $D_{i'} + D_{j'} + d_{ij} - d_{0i} - d_{0j} \leq m$ then
08. Enlarge $r_{i'}$ by adding link (i, j), remove the link of $r_{j'}$, and links $(i, 0)$ and $(j, 0)$
09. Delete route $r_{j'}$
10. Update $q_{i'} = q_{i'} + q_{j'}$
11. Update $D_{i'} = D_{i'} + D_{j'} + d_{ij} - d_{0i} - d_{0j}$
12. End if
13. Remove savings $s_{ih}, s_{jh}, s_{hi}, s_{hj}$ from list $L, \forall h \in N$
14. Loop

7.1.3 Construction phase

Hospital nodes that are close together are grouped using the K-Means clustering technique. Both the C&W Sequential Savings Algorithm and C&W Parallel Savings Algorithm are used to find solutions for each cluster: solutions are compared and the best is used as the initial solution for the improvement phase.

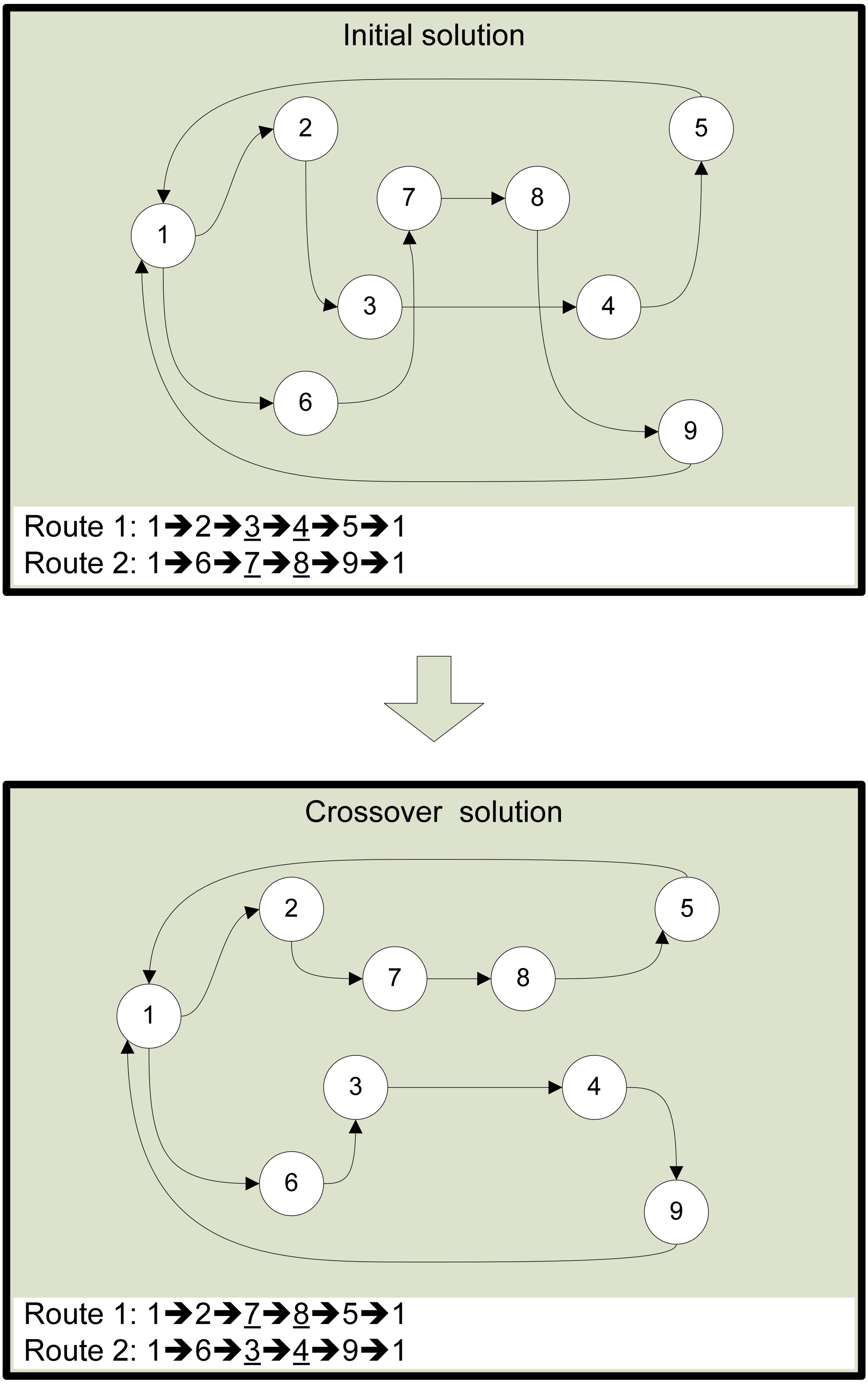
7.1.4 Improvement phase

Improvements on the initial solution are made using four movements of neighbourhood (See Figure 7.1), in the following order: Relocation (Savelsbergh, 1992), Crossover (Savelsbergh, 1992), Exchange (Savelsbergh, 1992), and 2-opt (Croes, 1958). The Relocate operator is used to search for different positions on different routes for each demand node, while the Crossover operator carries out more than one swap at a time. The Exchange operator swaps two demand nodes in the route. The 2-opt operator replaces two arcs with two other arcs. Two of these, Relocation and Crossover are inter-route movements and the next pair, Exchange and 2-opt are intra-route movements that improve the routes obtained by the inter-route movements. If the new solution is better than the original solution, the current solution is updated. The lowest-cost-best first search is applied to explore nodes in the routes with the minimum cost.



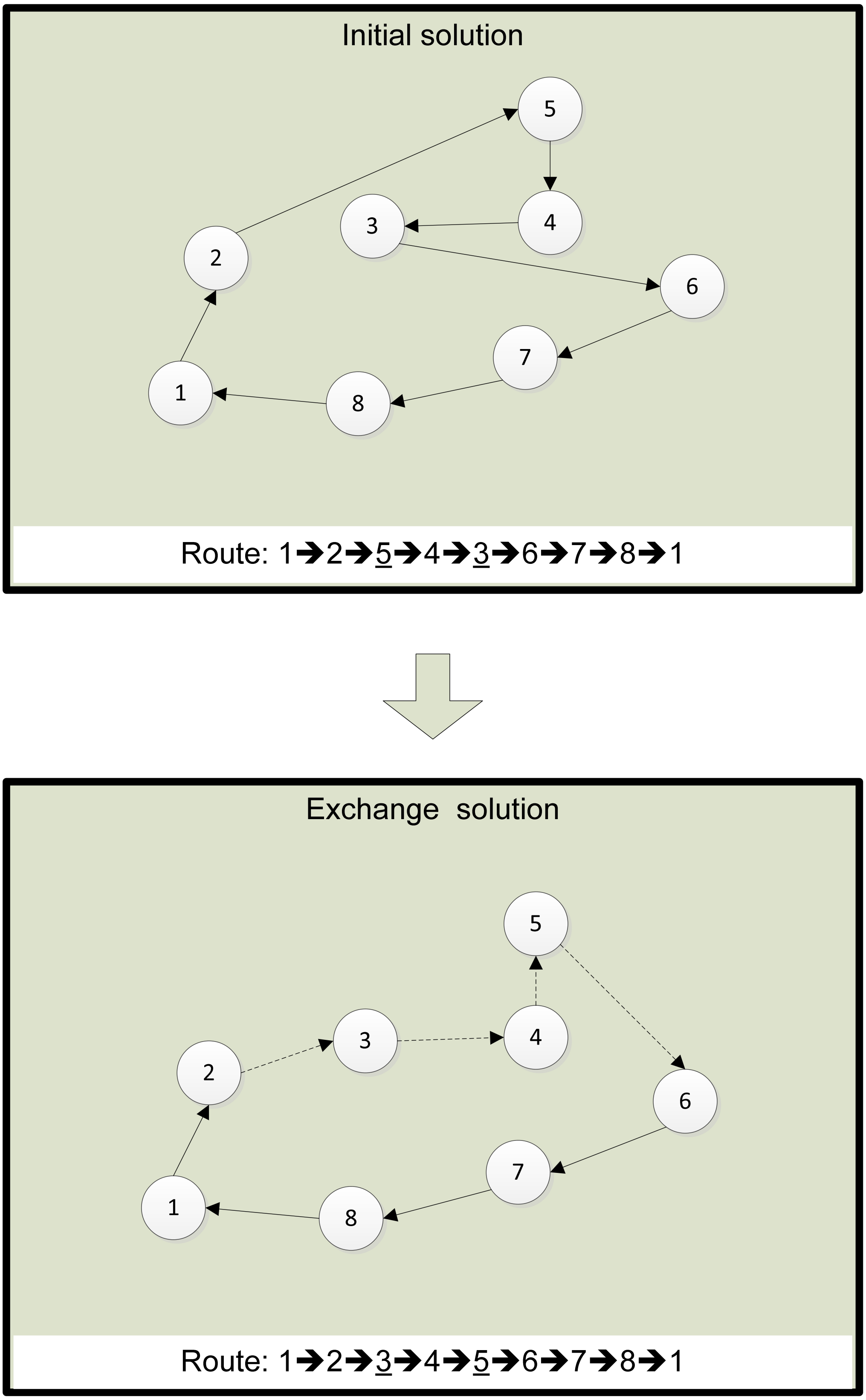
(a) Example of Relocate operator

Figure 7.1: Local Search Operators: Relocate



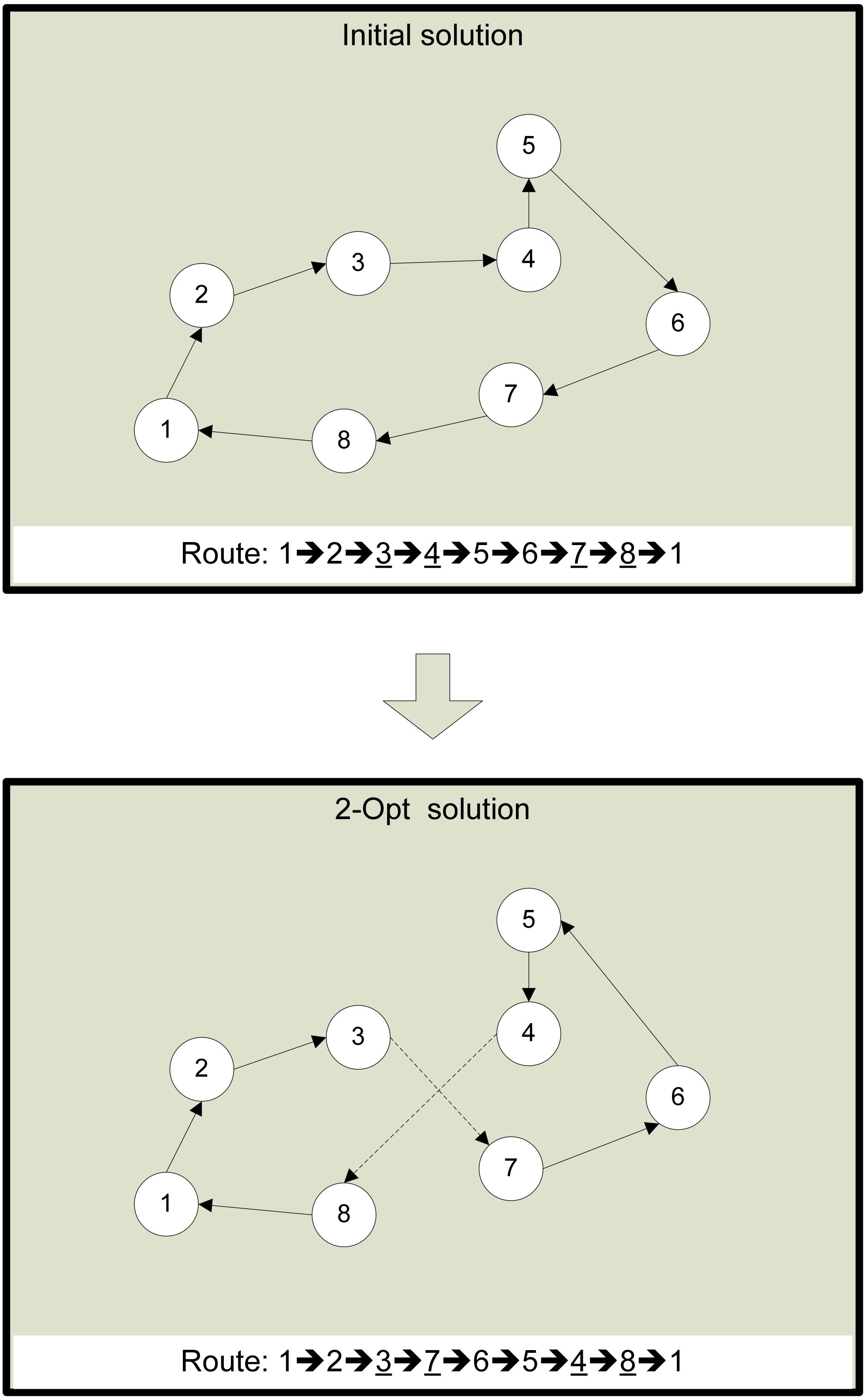
(b) Example of Crossover operator

Figure 7.1: Local Search Operators: Crossover



(c) Example of Exchange operator

Figure 7.1: Local Search Operators: Exchange



(d) Example of 2-Opt operator

Figure 7.1: Local Search Operators: 2-Opt

7.2 Fixed Routes for Six-Day Blood Distribution using the GRASP algorithm

GRASP stands for Greedy Randomized Adaptive Search Procedure; it was first introduced by Feo and Resende (1989). We test this version (Version 1) and a proposed modification of the original version with randomised selection of node positions (Version 2). It is an iterative process with a multi-start procedure used to generate a variety of solutions. Each iteration can be divided into two phases (see Table 7.6): 1) Construction phase 2) Local Search.

Table 7.6: Overview of the GRASP algorithm

Overview of the GRASP algorithm
01. Set $f^* = \infty$
02. Set $S^* = \emptyset$
03. For $\gamma = 1$ to Max Iterations
04. Set S_1 = solutions obtained by Greedy Randomised Construction
05. Set S = Local Search(S_1)
06. if $f(S) < f^*$ then
07. Set $S^* = S$
08. Set $f^* = f(S)$
09. end if
10. Next

Table 7.7: GRASP algorithm: Construction phase (Version 1)

Construction phase (Version 1)
01. Set $U = N$ to be the list of unassigned nodes
02. Set $k = 1$
03. Do while $U \neq \emptyset$
04. If no nodes are assigned to route k then
05. Set $u' \in U$ to be the unassigned node that is nearest to node 0
06. Initialise route k by including node u'
07. Set $i = u', j = u'$ and $U = U \backslash \{u'\}$
08. Set $\mu = 0$ and $q = q_{u'}$
09. End if
10. Form a candidate list CL containing all pairs (u, i) and (j, u) for $u \in U$
11. Form a restricted candidate list RCL from CL by removing those entries (u, i) with $s_{ui} \leq \alpha s_{\min} + (1-\alpha)s_{\max}$ and those entries (j, u) with $s_{ju} \leq \alpha s_{\min} + (1-\alpha)s_{\max}$ where $s_{\min} = \min_{v \in U}\{\min\{s_{vi}, s_{jv}\}\}$ and $s_{\max} = \max_{v \in U}\{\max\{s_{vi}, s_{jv}\}\}$

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Table 7.7: GRASP algorithm: Construction phase (Version 1)

Construction phase (Version 1)
12. Randomly select (u, i) or (j, u) from RCL, and set $h = i$ if (u, i) is selected and $h = j$ if (j, u) is selected
13. If $\mu + d_{hu} > m$ or $q + q_u > Q$ then
14. Set $k = k + 1$
15. Else
16. Set $\mu = \mu + d_{hu}, q = q + q_u$ and $U = U \backslash \{u\}$
17. If $h = i$, include arc (u, i) in route k and set $i = u$
18. If $h = j$, include arc (j, u) in route k and set $j = u$
19. End if
20. Loop

Table 7.8: GRASP algorithm: Construction phase (Version 2)

Construction phase (Version 2)
01. Set $U = N$ to be the list of unassigned nodes
02. Set $k = 1$
03. Do while $U \neq \emptyset$
04. If no nodes are assigned to route k then
05. Set $u' \in U$ to be the unassigned node that is nearest to node 0
06. Initialise route k by including node u'
07. Set $i = u', j = u'$ and $U = U \backslash \{u'\}$
08. Set $\mu = 0$ and $q = q_{u'}$
09. End if
10. Randomly select $h \in \{i, j\}$
11. Form a candidate list CL containing all pairs (h, u) for $u \in U$
12. Form a restricted candidate list RCL from CL by removing those entries (h, u) with $s_{hu} \leq \alpha s_{\min} + (1 - \alpha) s_{\max}$, where $s_{\min} = \min_{v \in U} s_{hv}$ and $s_{\max} = \max_{v \in U} s_{hv}$
13. Randomly select (h, u) from RCL
14. If $\mu + d_{hu} > m$ or $q + q_u > Q$ then
15. Set $k = k + 1$
16. Else
17. Set $\mu = \mu + d_{hu}, q = q + q_u$ and $U = U \backslash \{u\}$
18. If $h = i$, include arc (u, i) in route k and set $i = u$
19. If $h = j$, include arc (j, u) in route k and set $j = u$
20. End if

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Table 7.8: GRASP algorithm: Construction phase (Version 2)

Construction phase (Version 2)
21. Loop

In the construction phase, the elements that are not included in the current partial solution are ordered by their greedy function value, in non-increasing order, in a list called the restricted candidate list (RCL). Next, one element from the list is randomly chosen and added into the partial solution. The size of the RCL is defined by a parameter $\alpha, 0 \leq \alpha \leq 1$ (or $0 \leq \alpha \leq 100\%$). The RCL contains the pairs of nodes which have savings values greater than $\alpha f_{min} + (1-\alpha) f_{max}$, where f_{min}, f_{max} denote the minimum and maximum savings values in the candidate list (CL) respectively. The construction process stops when a feasible solution is reached. In the second phase, the local search operators are used to improve the initial solution in order to obtain a better solution at each iteration. The same movements of neighbourhood are used as with the C&W algorithm, see Section 7.1.4. Our second version of the GRASP algorithm differs from the original version in that the positions in which nodes are added to routes (head or tail) are randomly selected. The pseudo code for GRASP versions 1 and 2 is shown in Tables 7.7 and 7.8.

7.3 Results for fixed routes with six-day deliveries

This section gives results of constructing fixed routes for six-day blood distribution using all three methods applied: the CPLEX model, the improved Clarke and Wright Savings algorithm, and the GRASP algorithm.

7.3.1 Results with Clarke and Wright Savings algorithm and Local Search

Table 7.9 gives the results obtained for fixed route six-day blood distribution using both versions of the C&W Saving algorithm combined with local search. These results are compared with optimal solutions found using ILOG CPLEX Software where these could be obtained: for two clusters (2 and 3) with large numbers of hospital nodes, optimality could not be reached because of running out of memory. A total travelling distance per week of approximately 6,440 kilometres is obtained using the improved C&W method. CPU times are also provided for the improved method. The Improved Sequential Saving algorithm mostly gives reduced total travel distance compared with the Parallel method. The C&W Parallel Savings algorithm generally produces more routes and needs more vehicles than the Sequential method and so gives worse solutions for clusters 1, 2 and 3, in which hospitals are generally close together. However the Parallel Savings version provides the best solutions in clusters 4, 5, and 6, in which the hospitals are generally far apart from each other. For these clusters, the same numbers of routes were produced by both methods, and the Parallel method produces better links between nodes. The initial solution is subsequently improved upon using the local search approach. The maximum number of vehicles needed for each days transportation is two.

Table 7.9: Results for fixed-route blood distribution to hospitals based on the improved Clarke and Wright Savings algorithm

Fixed routes: total travelling distances (km.)						
Cluster no.	**Optimal**	**Upper bound**	**Sequential Savings**	**Parallel Savings**	**Improved Solution**	**CPU time (Seconds)**
1	1,159.19	1,329.77	1,159.19	1,166.58	1,159.19	0.819
2	-	1,315.05	1,130.35	1,171.49	1,104.87	2.793
3	-	834.64	604.45	777.78	586.32	4.525
4	1,131.59	1,309.90	1,131.63	1,131.63	1,131.63	0.754
5	1,176.57	1,227.87	1,221.00	1,202.12	1,198.99	0.959
6	1,258.32	1,323.19	1,312.55	1,273.19	1,258.87	0.825
Total	-	7,340.42	6,559.18	6,722.79	6,439.87	-

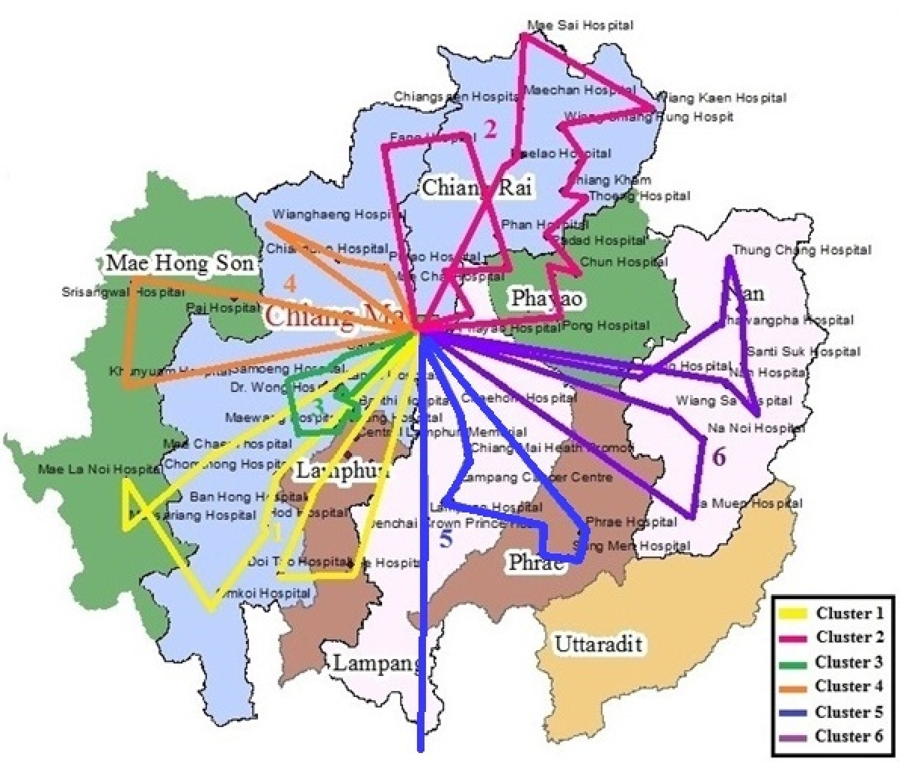


Figure 7.2: Results of routing for six clusters based on the improved Clarke and Wright saving algorithm

The routes for each cluster are illustrated in Figure 7.2, with different coloured routes for each cluster. All clusters except cluster 3 are served by two vehicles: cluster 3 contains hospitals only in Chiang Mai province, close to the RBC. Route crossovers can be observed within the route for cluster 6 and between the two routes for cluster 2, where non-optimal solutions were found.

7.3.2 Results with GRASP

Table 7.10: Comparison of results for fixed-route blood distribution to hospitals

Fixed routes: total travelling distances (km.)						
Cluster no.	Optimal	C&W	GRASP version 1	CPU time (Seconds)	GRASP version 2	CPU time (Seconds)
1	1,159.19	1,159.19	1,159.19	0.663	1,159.19	0.562
2	-	1,104.87	1,126.62	2.541	1,098.85	2.492
3	-	586.32	601.17	4.363	454.17	4.178
4	1,131.59	1,131.63	1,131.59	0.507	1,131.59	0.412
5	1,176.57	1,198.99	1,178.70	0.843	1,189.16	0.769
6	1,258.32	1,258.87	1,258.32	0.771	1,258.32	0.718
Total	-	6,439.87	6,455.59	-	6,291.28	-

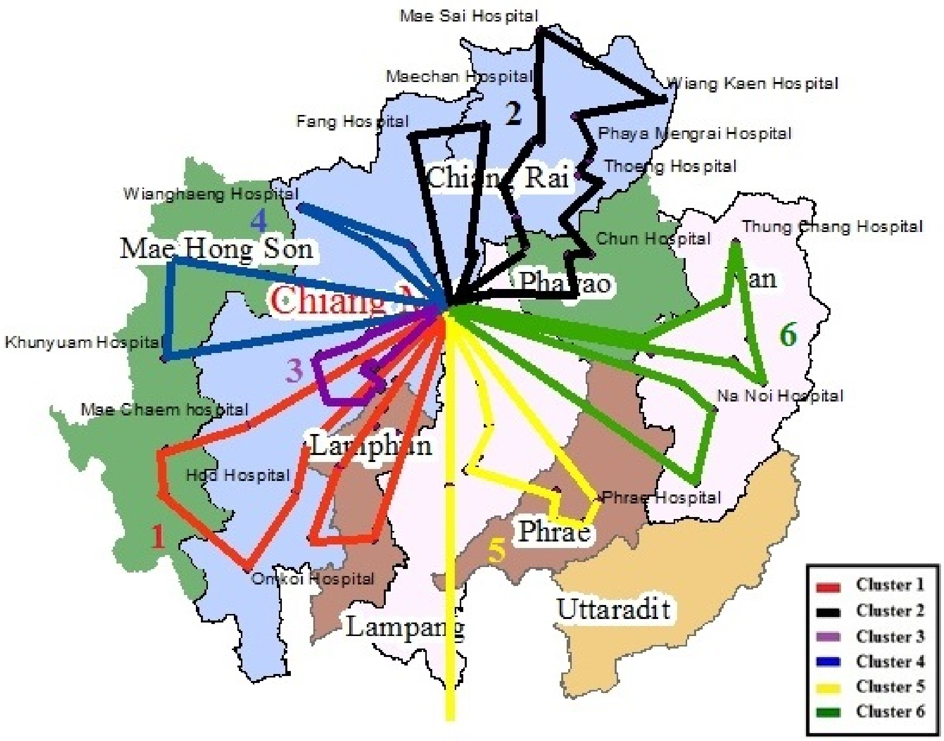


Figure 7.3: Results of routing for six clusters based on GRASP algorithm (Version 2)

Table 7.11: Results from GRASP version 1

No. of iterations	α	Cluster1	Cluster2	Cluster3	Cluster4	Cluster5	Cluster6
10	0	1166.29	1258.09	605.47	1294.97	1185.31	**1258.32**
	10	1159.24	**1126.62**	769.09	1294.97	1183.06	**1258.32**
	20	**1159.19**	1357.67	767.20	1294.93	1183.64	**1258.32**
	30	**1159.19**	1519.00	748.02	1294.93	1184.75	1258.85
	40	**1159.19**	1681.41	776.51	1319.45	1182.95	1331.04
	50	1159.32	1574.99	762.12	1131.63	1183.66	1258.87
	60	1242.53	1754.68	809.56	1386.67	1183.55	1309.70
	70	1209.49	1703.96	754.40	1367.60	1198.97	1297.13
	80	1251.24	1617.61	782.87	1319.50	1198.35	1825.50
	90	1243.11	1661.29	782.87	1319.45	1215.66	1331.04
	100	1285.36	1737.28	778.90	1319.45	1210.66	1300.94
20	0	1166.29	1258.09	601.94	1294.97	1185.31	**1258.32**
	10	1159.24	**1126.62**	720.41	1294.97	1183.06	**1258.32**
	20	**1159.19**	1244.61	758.72	1294.93	1183.55	**1258.32**
	30	**1159.19**	1519.00	748.02	**1131.59**	1183.66	1258.85
	40	**1159.19**	1472.63	776.51	1319.45	1182.95	1317.54
	50	1159.32	1574.99	762.12	1131.63	1183.64	1258.87
	60	1165.33	1653.64	756.08	**1131.59**	1183.55	1309.70
	70	1209.49	1654.93	754.40	1319.45	1183.70	1297.13
	80	1250.36	1617.61	746.72	1319.45	1198.35	1747.33
	90	1243.11	1661.29	746.72	1307.78	1197.12	1331.04
	100	1166.28	1737.28	778.90	1319.45	1209.32	1300.94
30	0	1166.29	1258.09	**601.17**	1294.97	1185.31	**1258.32**
	10	1159.24	**1126.62**	720.41	1294.97	1183.06	**1258.32**
	20	**1159.19**	1190.78	758.72	1294.93	1183.55	**1258.32**
	30	**1159.19**	1494.99	748.02	**1131.59**	1183.66	1258.85
	40	**1159.19**	1472.63	764.23	1131.63	1182.95	1287.69
	50	1159.32	1574.99	762.12	1131.63	1183.64	1258.87
	60	1165.33	1653.64	756.08	**1131.59**	1183.55	1309.70
	70	1209.49	1599.50	754.40	1319.45	1183.54	1297.13
	80	1228.50	1617.61	746.72	1319.45	1198.35	1346.29
	90	1228.50	1661.29	746.72	1307.78	1197.12	1331.04
	100	1166.28	1663.12	778.90	1319.45	1209.32	1300.94
40	0	1166.24	1258.09	**601.17**	1294.97	1185.31	**1258.32**
	10	1159.24	**1126.62**	720.41	1294.97	**1178.70**	**1258.32**
	20	**1159.19**	1190.78	758.72	1294.93	1183.20	**1258.32**
	30	**1159.19**	1494.99	748.02	**1131.59**	1183.66	1258.85
	40	**1159.19**	1472.63	764.23	1131.63	1182.95	1287.69
	50	1159.32	1560.98	762.12	1131.63	1183.02	1258.87
	60	**1159.19**	1611.23	756.08	**1131.59**	1183.55	1309.70
	70	1209.49	1599.50	754.40	1131.63	1183.54	1297.13
	80	1228.50	1617.61	746.72	1319.45	1198.35	1346.29
	90	1211.28	1661.29	746.72	1307.78	1197.12	1316.99
	100	1166.28	1663.12	778.90	1319.45	1194.81	1300.94

Table 7.12: Results from GRASP version 2

No. of iterations	α	**Cluster1**	**Cluster2**	**Cluster3**	**Cluster4**	**Cluster5**	**Cluster6**
10	0	1159.24	**1098.85**	588.73	1131.63	1215.82	1312.55
	10	**1159.19**	1121.74	468.90	1131.63	1191.93	1307.07
	20	**1159.19**	1248.68	466.08	1131.63	1191.93	**1258.32**
	30	**1159.19**	1434.26	776.52	1131.63	1193.98	1258.87
	40	**1159.19**	1562.11	798.59	1131.63	1193.98	1302.20
	50	**1159.19**	1541.85	758.49	**1131.59**	1193.98	1309.90
	60	**1159.19**	1520.02	746.98	**1131.59**	1197.30	1304.89
	70	**1159.19**	1587.05	757.57	1131.63	1194.09	1304.57
	80	1211.21	1547.97	778.33	1183.26	1194.57	1300.94
	90	1185.51	1597.83	772.82	1131.63	1262.53	1344.45
	100	1166.29	1689.23	772.50	1183.26	1261.94	1326.07
20	0	1159.24	**1098.85**	588.73	1131.63	1215.82	1312.55
	10	**1159.19**	1121.74	468.90	1131.63	1190.51	1258.87
	20	**1159.19**	1212.51	**454.17**	1131.63	1190.51	**1258.32**
	30	**1159.19**	1257.22	758.77	**1131.59**	1193.98	**1258.32**
	40	**1159.19**	1173.77	762.90	**1131.59**	1193.98	1302.20
	50	**1159.19**	1541.85	758.49	**1131.59**	1193.98	1305.03
	60	**1159.19**	1520.02	746.98	**1131.59**	1191.83	1304.43
	70	**1159.19**	1545.37	757.57	**1131.59**	**1189.16**	1297.86
	80	**1159.19**	1547.97	762.65	1183.26	1194.57	1300.94
	90	1166.24	1549.03	771.48	1131.63	1202.90	1327.57
	100	1159.24	1650.59	755.79	**1131.59**	1198.81	1300.94
30	0	1159.24	**1098.85**	588.73	1131.63	1215.82	1312.55
	10	**1159.19**	1121.74	468.90	1131.63	1190.51	1258.87
	20	**1159.19**	1181.58	**454.17**	1131.63	1190.51	**1258.32**
	30	**1159.19**	1220.22	747.92	**1131.59**	1193.98	**1258.32**
	40	**1159.19**	1146.69	762.90	**1131.59**	1193.41	**1258.32**
	50	**1159.19**	1541.85	758.49	**1131.59**	1193.98	**1258.32**
	60	**1159.19**	1520.02	746.98	**1131.59**	1191.83	1304.43
	70	**1159.19**	1543.84	754.91	**1131.59**	**1189.16**	**1258.32**
	80	**1159.19**	1547.97	762.65	**1131.59**	1194.57	1300.94
	90	1165.83	1549.03	771.48	1131.63	1189.48	1295.22
	100	1159.24	1540.50	755.79	**1131.59**	1198.81	1263.80
40	0	1159.24	**1098.85**	588.73	1131.63	1215.82	1312.55
	10	**1159.19**	1121.74	468.90	1131.63	1190.51	1258.85
	20	**1159.19**	1181.58	**454.17**	1131.63	1190.51	**1258.32**
	30	**1159.19**	1220.22	747.92	**1131.59**	1193.51	**1258.32**
	40	**1159.19**	1146.69	762.90	**1131.59**	1190.51	**1258.32**
	50	**1159.19**	1541.85	758.49	**1131.59**	1193.98	**1258.32**
	60	**1159.19**	1520.02	746.98	**1131.59**	1191.83	1304.43
	70	**1159.19**	1477.33	754.91	**1131.59**	**1189.16**	**1258.32**
	80	**1159.19**	1531.94	762.65	**1131.59**	1194.57	**1258.32**
	90	1159.24	1549.03	771.48	1131.63	1189.48	1295.22
	100	1159.24	1521.88	755.79	**1131.59**	1198.81	1263.80

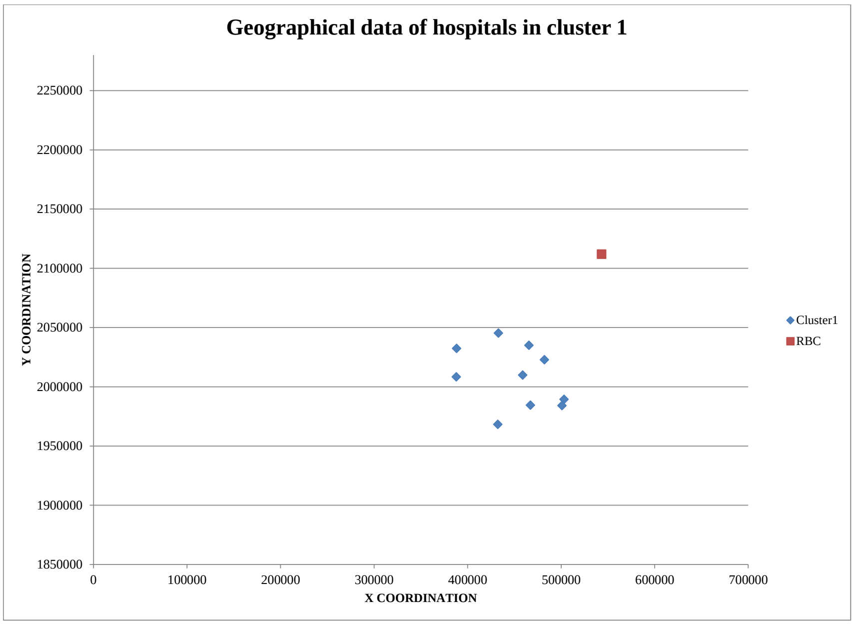


Figure 7.4: Location sites of hospitals in cluster 1

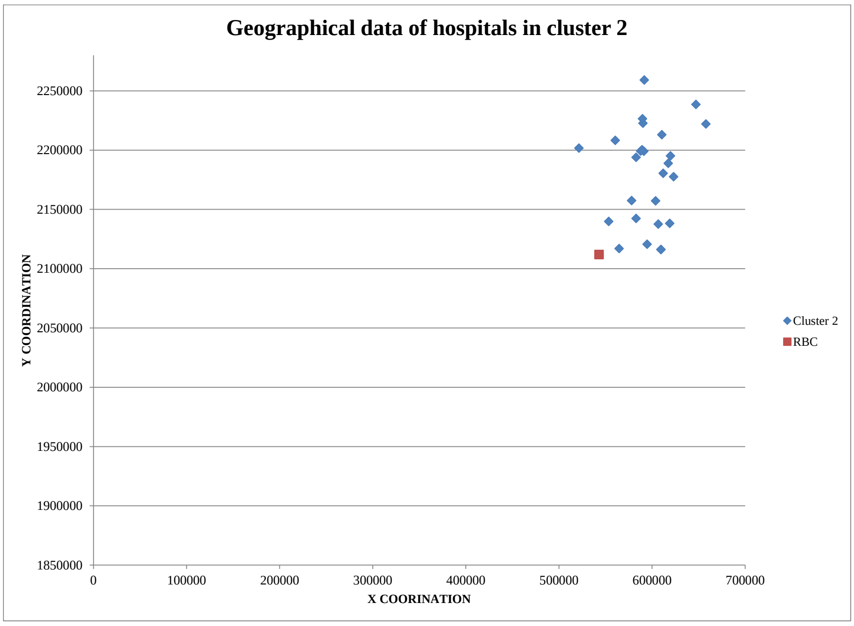


Figure 7.5: Location sites of hospitals in cluster 2

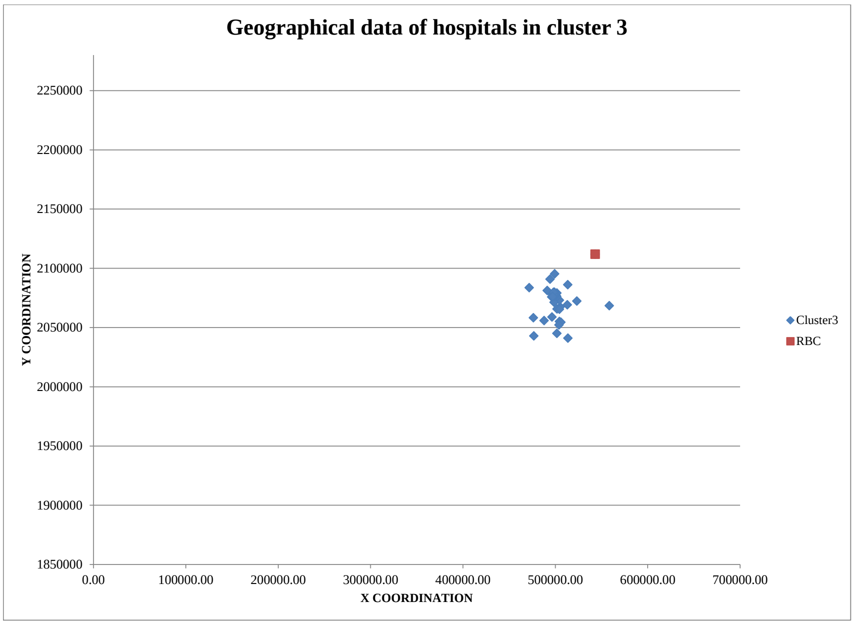


Figure 7.6: Location sites of hospitals in cluster 3

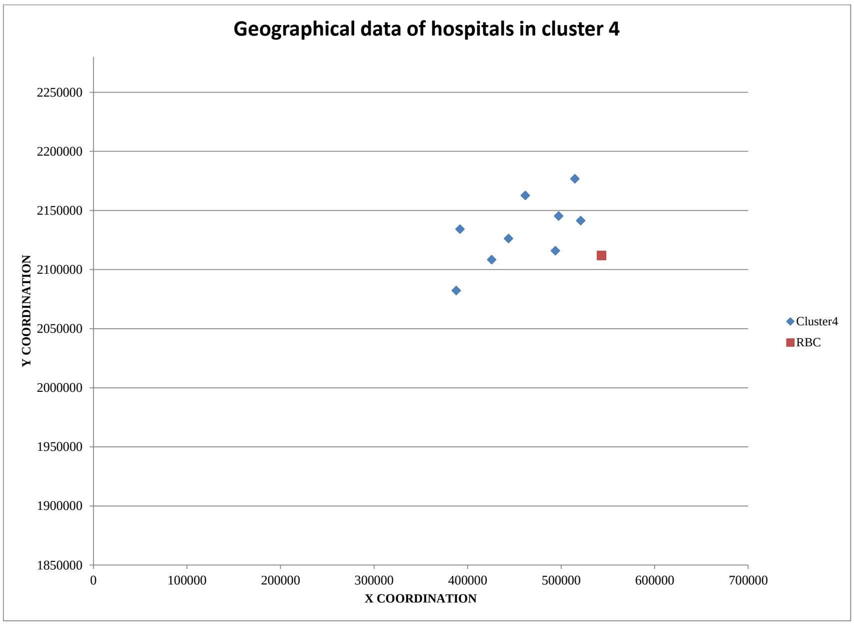


Figure 7.7: Location sites of hospitals in cluster 4

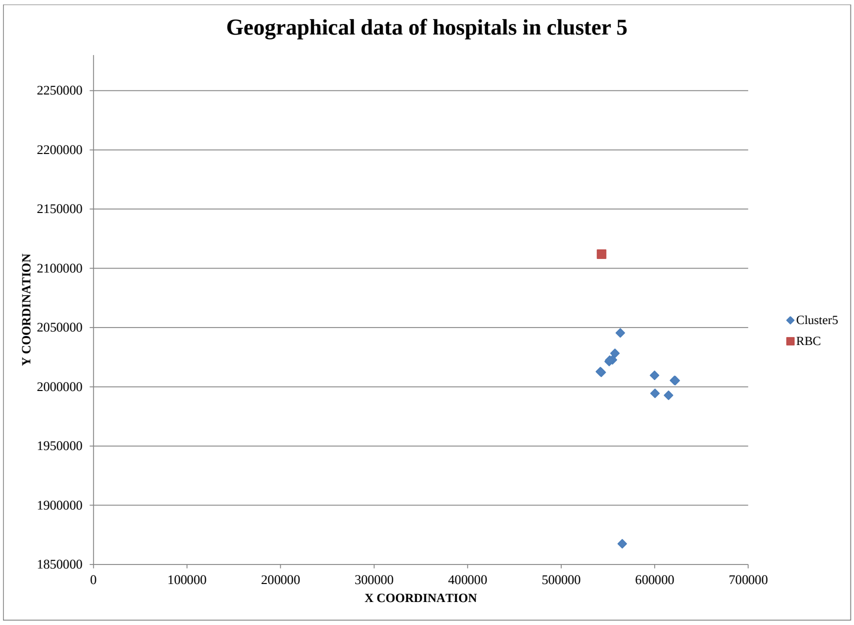


Figure 7.8: Location sites of hospitals in cluster 5

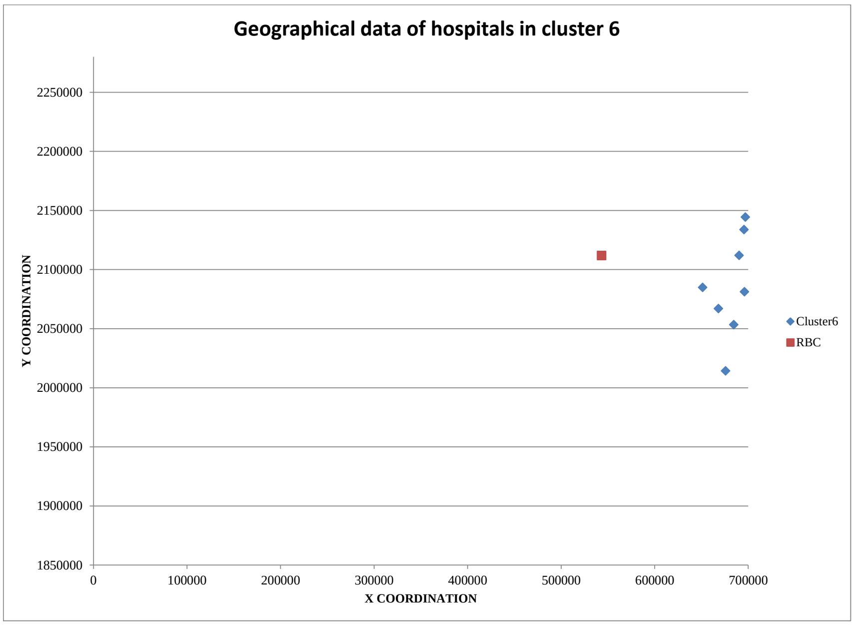


Figure 7.9: Location sites of hospitals in cluster 6

Table 7.10 gives results for fixed route six-day deliveries using both the original GRASP algorithm (Version 1) and proposed improved version (Version 2) in comparison with use of both optimisation software and the improved C&W algorithm. A total weekly travel distance of approximately 6,290 km is achieved using the GRASP algorithm version 2. It can be seen that GRASP version 2 dominates version 1 to provide the best solution for most clusters with variation of multiple initial solutions. However, GRASP version 1 gives a better solution for cluster 5 than GRASP version 2 and also the C&W Savings algorithm. Figure 7.3 illustrates routes based on GRASP version 2, coloured for the different clusters.

The quality of the GRASP solutions depends on two parameters: the alpha value which defines the set of possible nodes considered in the route and the number of iterations. Tables 7.11 and 7.12 give details of alpha values at which best solutions are obtained in the different clusters.

We finally consider the spatial characteristics of the clusters as shown in Figures 7.4, 7.5, 7.6, 7.7, 7.8 and 7.9, in relation to the most successful algorithms for each cluster. GRASP version 2 was the least successful with cluster 5: it can be seen that one hospital in cluster 5 is quite far from the other hospitals in that cluster. Contrastingly, GRASP version 2 was the most successful with all other clusters, in which hospitals are relatively close together though not necessarily close to the RBC. Considering GRASP version 1, the solutions for clusters 2 and 3 are worse than those obtained with the C&W algorithm: hospitals in clusters 2 and 3 are mostly close to the RBC. Using GRASP version 1, hospitals which may be close to the RBC but far from the current hospital in the route will not be included in the RCL.

7.4 Blood distribution with revised policy of three-day distribution, and hub distribution

In this section, we present a revised policy in order to reduce travel costs for blood distribution, by reducing the number of delivery days, and also by introducing hub delivery hospitals. The number of delivery days is reduced to the fewest possible, three days, to further reduce costs while maintaining blood quality standards. Deliveries to hub hospitals are made to reduce the number of small, community hospitals in the delivery route.

7.4.1 Modelling for reduction of delivery days to three days only

A reduced number of delivery days can reduce transportation costs: we demonstrate in this section the possible savings, although holding costs are not considered. Clustering is used to divide hospitals into three delivery days: the methods of K-Means and Fuzzy C-Means Clustering are compared for this case study. The improved C&W and improved GRASP algorithms are compared for delivery routes to the clustered hospitals. Moreover, results are compared with use of a new distribution centre (DC) at Chiang Rai, as recommended on the results of Chapters 5 and 6.

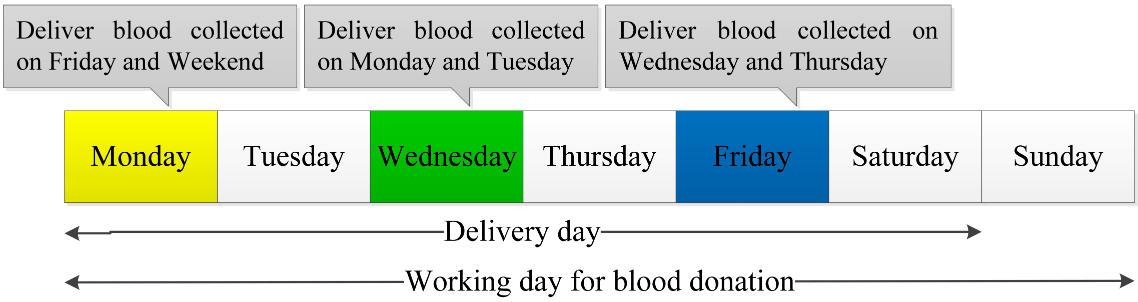
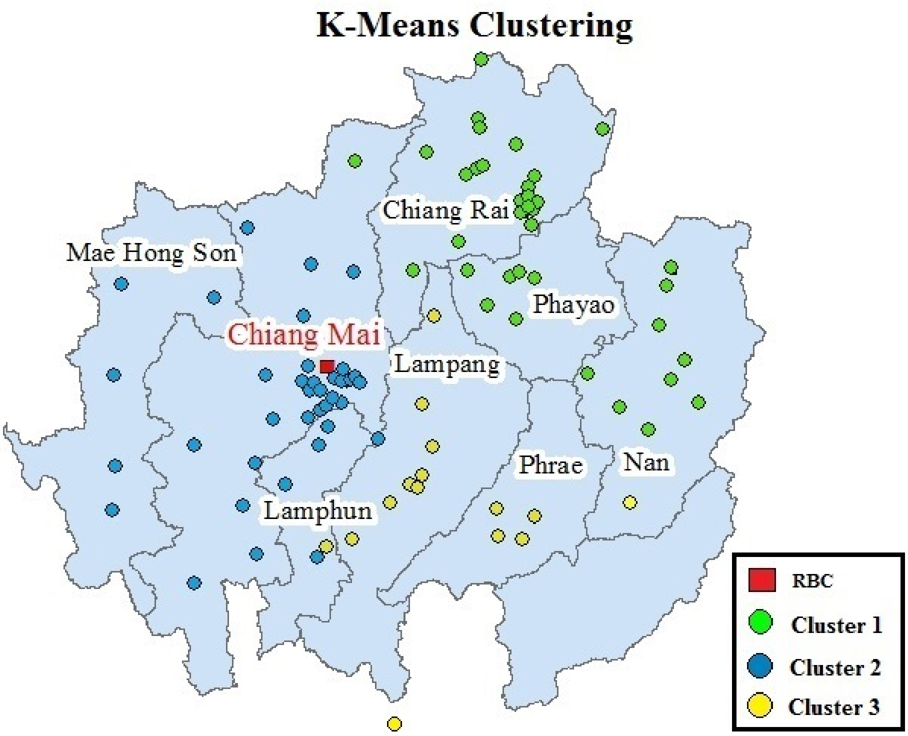


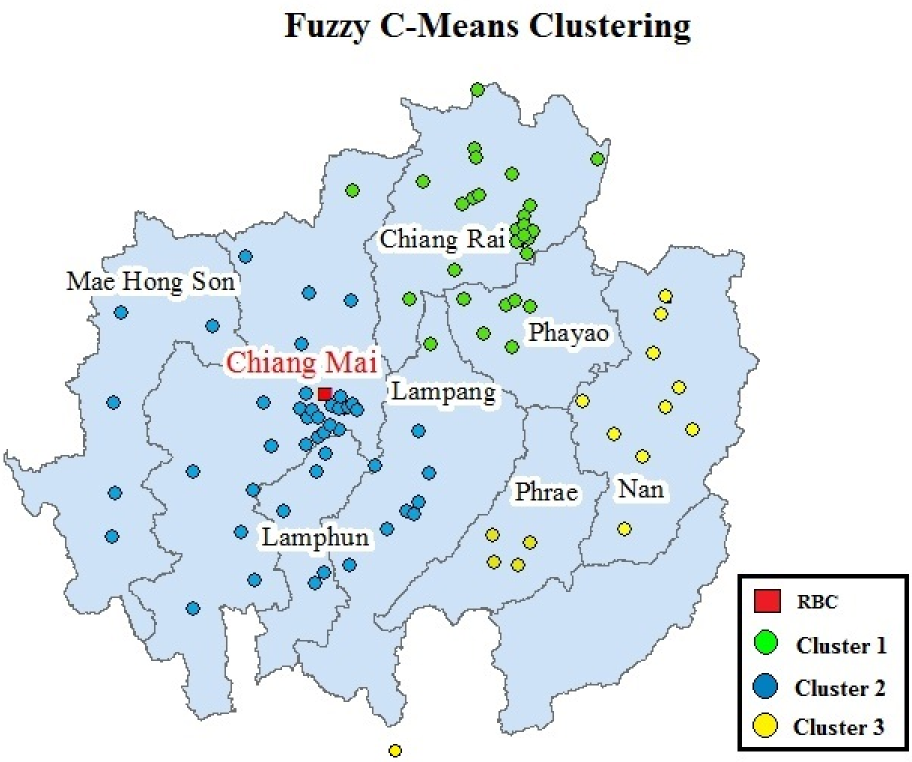
Figure 7.10: The policy for blood deliveries on three delivery days

The TRCS has a policy of distributing blood within three days of receipt from donors. Blood can be distributed on weekdays from Monday to Saturday, while it is collected on every day from Monday to Sunday. This means that blood collected on Fridays and at weekends must be sent to hospitals on a Monday. Blood collected on Mondays and Tuesdays can be delivered on Wednesdays, while blood collected on Wednesdays and Thursdays is delivered on Fridays. Thus, the optimal three delivery days are Mondays, Wednesdays, and Fridays, as shown in Figure 7.10.

The hospitals of the upper North region were clustered by the geographical data into three groups by using two algorithms for comparison: the K-Means algorithm and Fuzzy C-Means algorithm (Bezdek, 1981). Both K-Means and Fuzzy C-Means (FCM) algorithms are similar in the objective of minimising intra-cluster variance. The main idea of the K-Means algorithm is to define k centroids for a given number of clusters. However, in FCM each point has a degree of belonging to clusters rather than belonging completely to just one cluster. This “membership value” is used to determine members of a cluster, on the basis of “distance” between the cluster and the data points. The clustering was implemented using MATLAB R2011b. The result can be seen in Figure 7.11 and Appendix K. It can be noticed that the results obtained from the K-Means algorithm correspond closely to the result of allocation in Chapter 6, Figure 6.7.



(a) K-Means Clustering



(b) Fuzzy C-Means Clustering

Figure 7.11: Results of clustering hospitals with K-Means and Fuzzy C-Means Clustering

Table 7.13: Comparison of the number of hospitals in each cluster obtained from two clustering algorithm

Comparison of clustering methods				
Cluster No.	**K-Means Clustering**		**Fuzzy C-Means Clustering**	
	numbers	**average similarity**	**numbers**	**average similarity**
Cluster 1	36	0.611	27	0.590
Cluster 2	59	0.361	69	0.314
Cluster 3	17	0.470	16	0.435

Summaries are given in Table 7.13 of the numbers of hospitals and average similarity in each cluster based on the two clustering algorithms. Considering the similarity measurement, the K-Means algorithm provides a better solution than FCM. Ghosh and Dubey (2013) also provide an example of clustering where the K-Means algorithm is superior to Fuzzy C-Means algorithms, for clustering flower characteristics. It is suggested that Fuzzy C-Means is best suited to incomplete or noisy data, such as is encountered with image analysis (Yong et al., 2004).

Table 7.14: Results for fixed route blood distribution with revised policy of three-day delivery (no hubs)

Cluster no.	**Total distances (km.)**		
	C&W and LS	**GRASP (Version 2)**	**One RBC and One DC**
1	1,227.77	1,046.93	1,013.19
2	1,804.22	1,655.89	1,655.89
3	662.95	651.22	651.22
Total	3,694.94	3,354.04	3,320.30

Based on both the K-Means clustering algorithm and Fuzzy C-Means, hospitals in Phayao province and Chiang Rai, except Chiang Rai Prachanukroh, are grouped in cluster 1, while cluster 2 comprises the hospitals in Chiang Mai, Mae Hong Son and Lamphun provinces. Hospitals in Phrae province are placed in the last cluster. However hospitals in Lampang province are in cluster 2 based on FCM, but are in cluster 3 based on K-Means. Similarly, hospitals in Nan province are grouped in cluster 1 with the K-Means algorithm and cluster 3 with FCM.

Both the improved C&W and GRASP Version 2 are employed to solve the problem. The scenario of a DC at Chiang Rai as well as the RBC at Chiang Mai is also modelled using GRASP version 2. The maximum number of vehicles needed for blood distribution per day is 3 with both methods and scenarios. Results for each cluster are shown in Table 7.14. Results are much decreased on 6-day deliveries (see Table 7.10) because of less travel back to the RBC from hospitals at a distance. Cluster 1 needed 2 routes, cluster 2 needed 3 routes and cluster 3 needed 1 route given the maximum travel distance of 720 km. When the hospitals in Cluster 1 can receive deliveries from the new DC at Chiang Rai (final column of results), there is a savings of 33.74 km per week or 1,754.48 km per year. This represents a considerable distance when travelling in this mountainous area, which is currently supplied by air freight.

7.4.2 Blood Distribution to Hub Hospitals

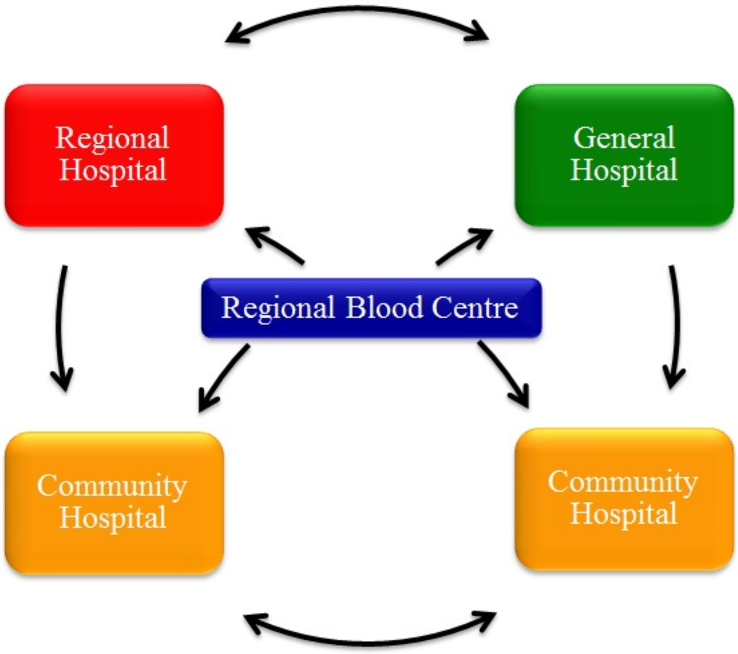


Figure 7.12: Hierarchical structure of healthcare system

In principle, RBCs have the responsibility for supplying blood to all hospitals in the region, as shown in Figure 7.12. However, the hospitals in the upper levels of the hospital hierarchy (described in Section 2.3) can support hospitals in the lower levels with blood requests. Thus, the regional hospitals can provide blood to general hospitals, while the community hospitals and primary healthcare facilities can collect blood from the general hospitals. Moreover, some small community hospitals do not have their own blood bank, and so request blood when needed from the nearest general hospitals. However, a small community hospital could have its own blood inventory if it is in an area that experiences many accidents and is located quite far from any general hospitals or an RBC.

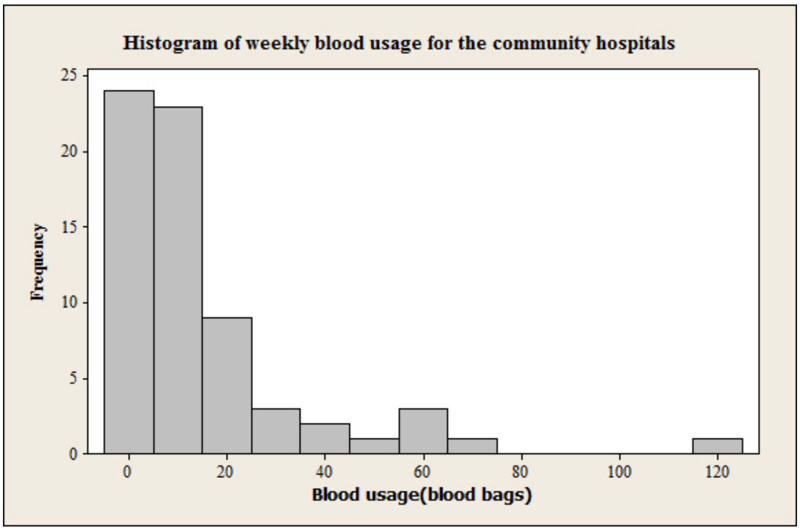


Figure 7.13: Histogram of blood usage for all hospitals in the upper North region

From Figure 7.13, it can be seen that more than 40 community hospitals use an amount of blood less than or equal to 10 blood bags per week. We propose the policy of assigning some community hospitals with high blood usage to be hubs for blood distribution.

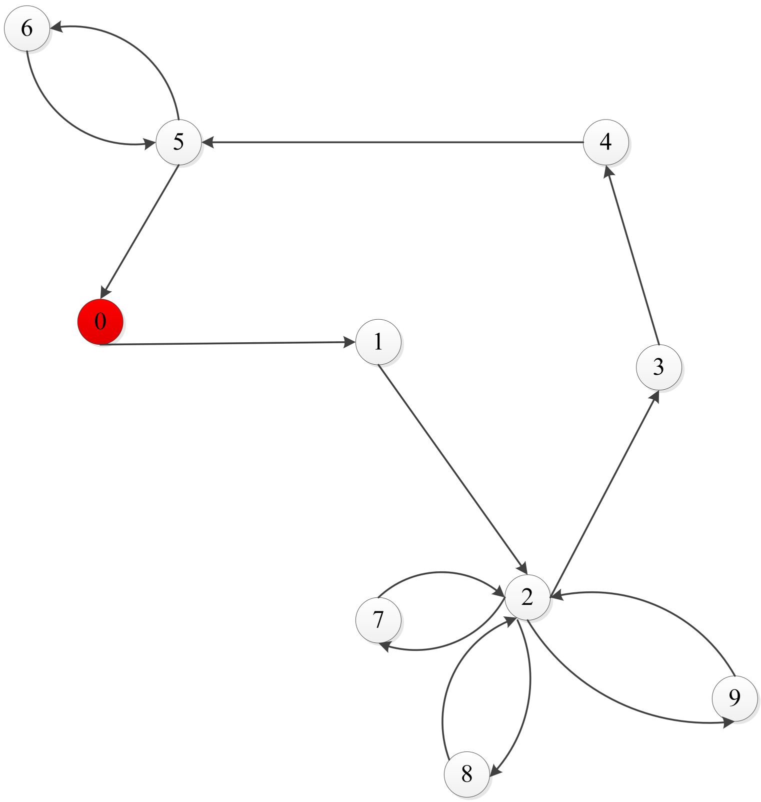


Figure 7.14: Example of on-tour and off-tour hospitals

The mathematical formulation that follows for solving the hub vehicle routing allocation problem is adapted from Beasley and Nascimento (1996)'s version of the Vehicle Routing-Allocation Problem, which classifies demand points as on-tour and off-tour. Blood is delivered from the RBC to in-tour hospitals. The off-tour hospitals can collect blood at the nearest on-tour hospitals designated as a hub. In our model, on-tour hospitals are the general hospitals and the community hospitals with high blood usage. Some hospitals in the route are assigned to be a hub, according to certain conditions, while the remainder are off-tour hospitals. A general private hospital cannot be selected as a hub; neither can a small hospital be the hub for a bigger hospital. An example of routing to on- and off-tour hospitals is shown in Figure 7.14: nodes 1 - 5 represent on-tour hospitals, while nodes 6 - 9 are off-tour hospitals and node 0 is the RBC. Nodes 2 and 5 are hub hospitals from which off-tour hospitals collect blood.

Notation

Parameter	**Description**
I	set of sites of hospitals and the RBC
J	set of sites of hospitals
K	set of vehicles
N^b	set of big-sized hospitals
N^g	set of General Public hospitals
N^m	set of medium-sized hospitals
N^p	set of General Private hospitals
N^s	set of small-sized hospitals
Q_k	vehicle capacity of route k, $k \in K$
d_{ij}	distance between the i^{th} node and the j^{th} node, $i \in I,\ j \in I$
m	maximum total travel distance in each route
n	number of hospitals
q_i	the quantity of blood requests of the hospital at site $i, i \in J$

Decision variables

Variable	**Description**
s_{ik}	= auxiliary variable for sub-tour elimination constraints of the node at site i in vehicle k, $i \in J, k \in K$
x_{ijk}	$= \begin{cases} 1, & \text{if the } i^{th} \text{ node precedes the } j^{th} \text{ node with } k^{th} \text{ vehicle,} \\ & i \in I, j \in I, k \in K, \\ 0, & \text{otherwise.} \end{cases}$

Variable	Description
y_{ij}	$= \begin{cases} 1, & \text{if hospital } j \text{ collects blood at hospital } i,\ i \in J, j \in J, \\ 0, & \text{otherwise.} \end{cases}$
z_j	$= \begin{cases} 1, & \text{if the hospital at the } j^{th} \text{ site is on-tour, } j \in J, \\ 0, & \text{otherwise.} \end{cases}$
w_j	$= \begin{cases} 1, & \text{if the hospital at the } j^{th} \text{ site is off-tour, } j \in J, \\ 0, & \text{otherwise.} \end{cases}$

Objective function and constraints

The objective function (7.11) minimises the total distance both on-tour and off-tour. Hospitals selected as on-tour are delivered blood directly from the RBC, while hospitals off-tour must send vehicles to collect blood at the RBC and return to the hospital. The formulation is as follows:
Minimise

$$\sum_{i\in I}\sum_{j\in I}\sum_{k\in K} x_{ijk}d_{ij} + \sum_{i\in I}\sum_{j\in J} y_{ij}\left(d_{ij}+d_{ji}\right) \tag{7.11}$$

subject to

$$z_j + w_j = 1, \quad \forall j \in J, \tag{7.12}$$

$$\sum_{i\in I} y_{ij} = w_j, \quad \forall j \in J, \tag{7.13}$$

$$\sum_{i\in I}\sum_{k\in K} x_{ijk} = z_j, \quad \forall j \in J, \tag{7.14}$$

$$\sum_{j\in J} x_{0jk} = 1, \quad \forall k \in K, \tag{7.15}$$

$$\sum_{j\in J} x_{j0k} = 1, \quad \forall k \in K, \tag{7.16}$$

$$\sum_{j\in J} x_{ijk} - \sum_{j\in J} x_{jik} = 0, \quad \forall i \in I, \quad \forall k \in K, \tag{7.17}$$

$$s_{ik} - s_{lk} + n x_{ilk} \leq n-1, \quad \forall i \in J, \quad \forall l \in J, \quad \forall k \in K, \tag{7.18}$$

$$\sum_{i\in I}\sum_{k\in K} x_{ijk} = 1, \quad \forall j \in N^g \cup N^p, \tag{7.19}$$

$$y_{ij} = 0, \quad \forall i \in N^p, \quad \forall j \in J, \tag{7.20}$$

$$y_{ij} = 0, \quad \forall i \in N^s, \quad \forall j \in N^m \cup N^b, \tag{7.21}$$

$$y_{ij} = 0, \quad \forall i \in N^m, \quad \forall j \in N^b, \tag{7.22}$$

$$y_{ij} + y_{ji} \leq 1, \quad \forall i \in I, \quad \forall j \in J, \tag{7.23}$$

$$\sum_{i \in J} \left(\sum_{j \in I} (x_{ijk} q_i) + \sum_{j' \in J} (y_{ij'} q_{j'}) \right) \leq Q_k, \quad \forall k \in K, \tag{7.24}$$

$$\sum_{i \in I} \sum_{j \in I} (x_{ijk} d_{ij}) \leq m, \quad \forall k \in K, \tag{7.25}$$

$$s_{ik} \in \mathbb{I}^+, \quad \forall i \in J, \quad \forall k \in K. \tag{7.26}$$

$$w_j \in \{0, 1\}, \quad \forall j \in J, \tag{7.27}$$

$$x_{ijk} \in \{0, 1\}, \quad \forall i \in I, \quad \forall j \in I, \quad \forall k \in K, \tag{7.28}$$

$$y_{ij} \in \{0, 1\}, \quad \forall i \in J, \quad \forall j \in J, \tag{7.29}$$

$$z_j \in \{0, 1\}, \quad \forall j \in J, \tag{7.30}$$

Constraints (7.12) ensure that each hospital is either on-tour or off-tour. Constraints (7.13) and (7.14) give the relationship between variables. Constraints (7.15) and (7.16) ensure that on-tour starts and ends at the RBC. Constraints (7.17) are flow balance constraints. Constraints (7.18) are the sub-tour elimination constraints. Constraints (7.19) ensure that the General Hospitals are assigned to on-tour. The Private Hospitals cannot be made hubs through Constraints (7.20). Constraints (7.21) and (7.22) are used to assign hospitals to bigger hospital sizes for off-tour. Constraints (7.23) avoid an assignment between two hospitals in both directions off-tour. Constraints (7.24) enforce the capacity of vehicles. Constraints (7.25) enforce the maximum travel distance for each route.

7.4.3 Results of Hub Vehicle Routing Allocation Problem for Blood Distribution

Table 7.16: Results of Hub Routing Vehicle Allocation Problem with one vehicle for Cluster 1 (Time = 1000 seconds, Optimality Gap = 39.41%)

No.	Off-Tour	On-Tour
1	95 ← 10	Route 1: 0→102→76→80→75→2→68→95→9→39→74→92
2	9 ← 13	→96→36→19→58→0 (857 blood bags)
3	80 ← 22	
4	80 ← 29	
5	58 ← 31	
6	58 ← 48	
7	75 ← 50	
8	68 ← 51	

Continued on next page

No.	Off-Tour	On-Tour
9	58 ← 55	
10	92 ← 59	
11	68 ← 66	
12	9 ← 70	
13	9 ← 73	
14	68 ← 81	
15	68 ← 88	
16	9 ← 98	
17	95 ← 99	
18	74 ← 104	
19	74 ← 105	
20	75 ← 106	
21	68 ← 107	
Total Distances	1,962.30 km	710.25 km

Table 7.17: Results of Routing Vehicle Allocation Problem with two vehicles for Cluster 1 (Time = 4483 seconds, Optimality Gap = 37.95%)

No.	Off-Tour	On-Tour
1	58 ← 31	Route 1: 0→106→36→92→96→19→58→104→13→74→39
2	58 ← 48	→9→98→22→80→29→70→73→50→76→75→102→0
3	58 ← 55	(596 blood bags)
4	92 ← 59	Route 2: 0→2→68→51→88→81→99→10→0
5	68 ← 66	(261 blood bags)
6	81 ← 95	
7	13 ← 105	
8	68 ← 107	
Total Distances	690.16 km	1,298.31 km

Table 7.18: Results of Hub Routing Vehicle Allocation Problem with three vehicles for Cluster 1 (Time = 380 seconds, Optimality Gap = 39.41%)

No.	Off-Tour	On-Tour
1	95 ← 10	Route 1: 0→31→48→0 (79 blood bags)
2	29 ← 22	Route 2: 0→102→2→107→66→95→68→70→29→0
3	68 ← 51	(281 blood bags)
4	58 ← 55	Route 3: 0→75→76→50→73→58→19→92→96→36→59→
5	75 ← 80	104→13→105→74→39→9→98→106→0 (497 blood bags)
6	68 ← 81	
7	68 ← 88	
8	95 ← 99	

Continued on next page

No.	Off-Tour	On-Tour
Total Distances	518.61 km	1,739.50 km

Table 7.19: Results of Hub Routing Vehicle Allocation Problem with three vehicles for Cluster 2 (Time = 4500.00, Optimality Gap = 40.36%)

No.	Off-Tour	On-Tour
1	44 ← 5	Route 1: 0→12→108→7→79→64→17→20→62→52→57→1
2	82 ←67	→30→4→0 (1067 blood bags)
3	52 ← 15	Route 2: 0→91→21→26→61→35→60→49→72→8→23→32
4	62 ← 16	→18→3→85→0 (938 blood bags)
5	35 ← 27	Route 3: 0→87→24→45→44→71→93→0 (387 blood bags)
6	23 ← 28	
7	62 ← 33	
8	44 ← 34	
9	93 ← 40	
10	60 ← 53	
11	85 ← 54	
12	87 ← 56	
13	67 ← 63	
14	35 ← 69	
15	18 ← 83	
16	87 ← 84	
17	72 ← 86	
18	3 ← 89	
19	20 ← 90	
20	71 ← 103	
21	62 ← 109	
Total Distances	859.35 km	2,101.10 km

Table 7.20: Results of Routing Vehicle Allocation Problem with one vehicle for Cluster 3 (Optimality Gap = 0.00%)

No.	Off-Tour	On-Tour
1	78 ← 65	Route1: 0→46→100→43→41→47→94→78→77→25→38
2	78 ← 97	→101→37→42→11→6→0 (865 blood bags)
Total Distances	582.82 km	682.98 km

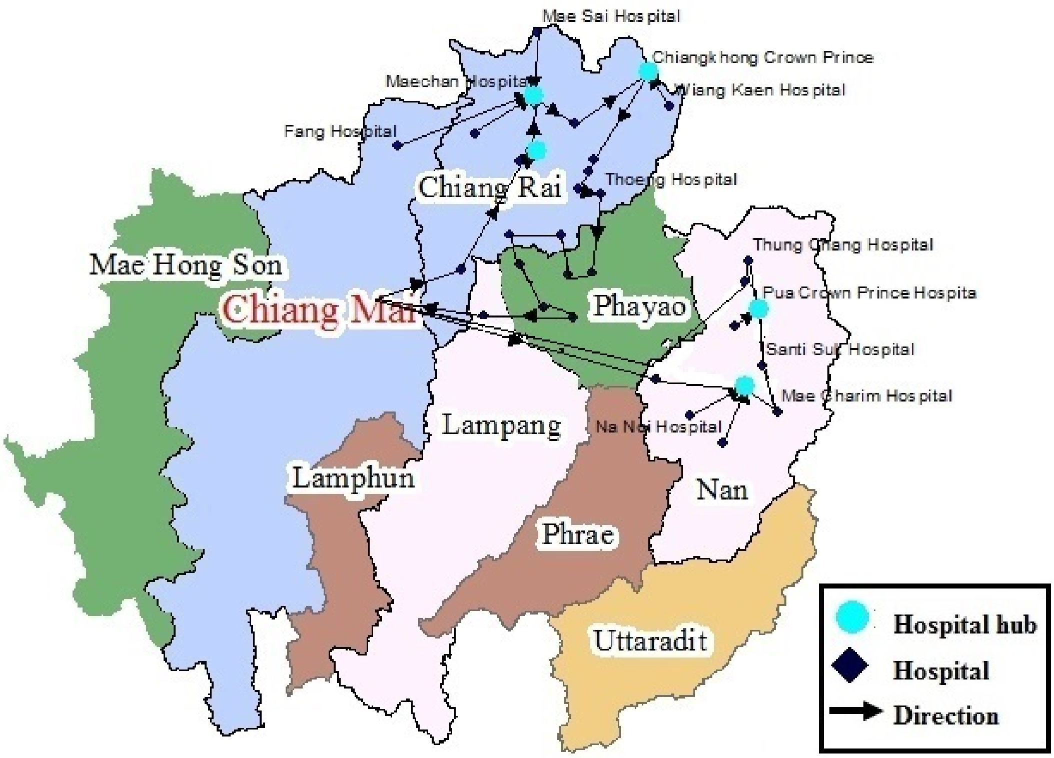


Figure 7.15: Allocation and Routing for Cluster 1 with two vehicles for blood delivery

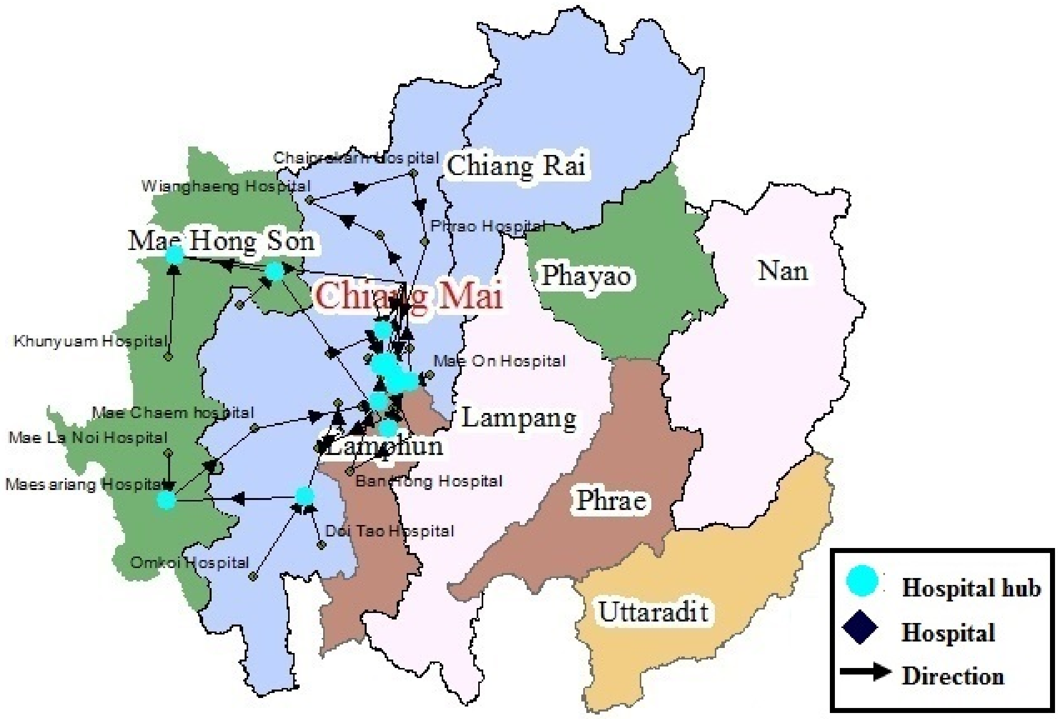


Figure 7.16: Allocation and Routing for Cluster 2 with three vehicles for blood delivery

Model runs were executed with varying numbers of vehicles. For cluster 1, results could be obtained with 1, 2 or 3 vehicles within the capacity and distance constraints: shortest total transportation distances were achieved with 2 vehicles. However, 3 vehicles were required for cluster 2 and only 1 vehicle was needed for cluster 3 since hospitals in this cluster are close to the RBC. Optimality was achieved for cluster 3 only: for other clusters, better optimality gaps were achieved with longer runs, but the computer software ran out of memory. The results are shown in Tables 7.16, 7.17, 7.18, 7.19, and 7.20 and Figures 7.15, 7.16, and 7.17 according to the three clusters. The maximum distance in each route is 720 kilometres and vehicle capacity is assumed to be 1,090 blood bags (33 large size containers, as detailed in Section 2.4.2 with the maximum number of vehicles on each route assumed to be three.

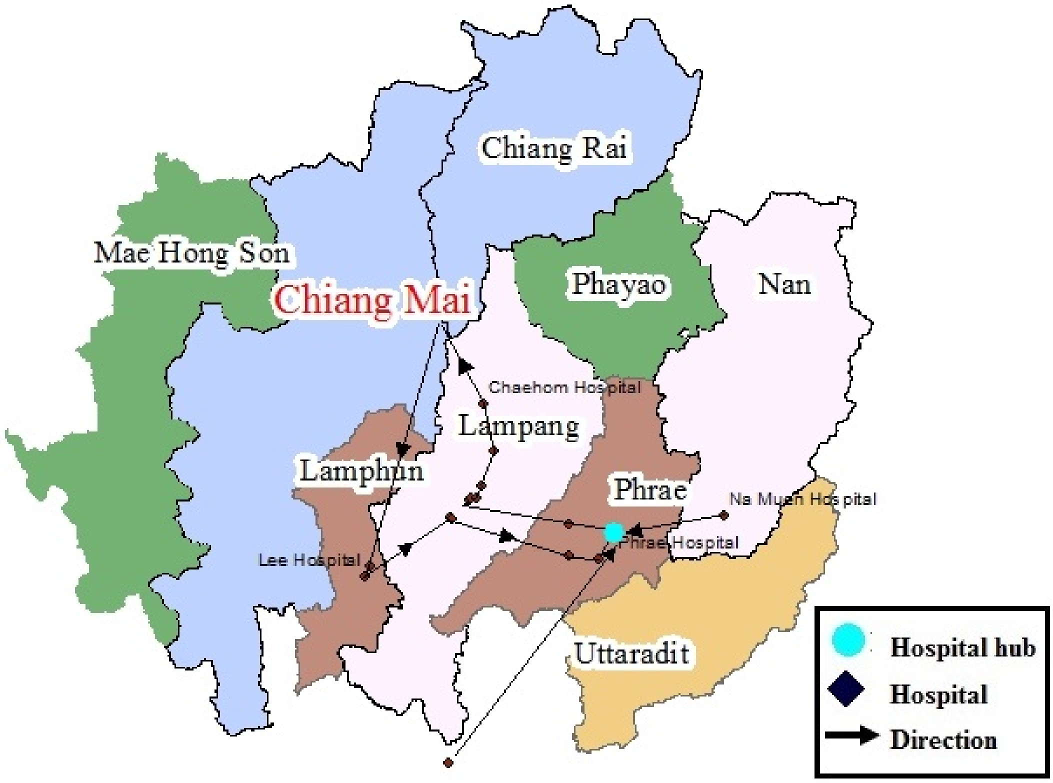


Figure 7.17: Allocation and Routing for Cluster 3 with one vehicle for blood delivery

A comparison was made between results obtained from the model and an assignment to on- and off-tour made by expert judgement of TRCS decision makers, see Table 7.21. The number of hospitals off-tour proposed by the model is less than that by judgement, as the TRCS would favour shorter on-tour routes. Model routes have longer on-tour routes but the total distance for blood distribution is reduced, despite the lack of optimality. Decision makers made 46 hospitals off-tour while the model made 31 hospitals off-tour.

Approximately 30 percent of the total hospitals proposed by decision makers for off-tour correspond to the result obtained from the model.

Table 7.21: Comparison of Results of Hub Routing Vehicle Allocation Problem by inspection and using the Mathematical Model

Cluster No.	**Model**		**Judgement**	
	Off-Tour	**On-Tour**	**Off-Tour**	**On-Tour**
1	690.16	1298.31	1,321.84	1,046.93
2	859.35	2,101.10	1,152.81	1,655.89
3	582.82	682.98	1,188.26	651.22
Total Distances	2,132.33 km	4,120.78 km	3,662.91 km	3,354.04 km

7.5 Vehicle Routing Problem with multi-frequency blood deliveries

The Vehicle Routing Problem with multi-frequency blood deliveries is focused on designing routes for capacitated vehicles on each day of the planning horizon (the six-day delivery week from Monday to Saturday) to visit customers with various delivery frequencies. All the blood donated each day is delivered to hospitals, so there are no holding costs. In this case study, historical data have been used to set the delivery frequencies in advance. Moreover, as quantities of blood are restricted, blood is allocated proportionately to hospitals according to historical requests made. Blood deliveries are assumed to be made routinely by a fleet of homogeneous vehicles which leave from and return to the blood distribution centre or depot. Each hospital can be served at most once per day, on up to six days per week. Each vehicle makes at most one trip per day, but there is no limitation on the availability of vehicles. A mathematical programming formulation of this problem based on the PVRP can be found in Appendix L. However, results could not be obtained because of the problem size, and a heuristic approach to finding solutions was therefore adopted.

7.5.1 Heuristics for solving Vehicle Routing Problem for multi-frequency blood deliveries

A two-phase heuristic is proposed for solving the Vehicle Routing Problem for multi-frequency blood deliveries, with construction and improvement phases.

7.5.1.1 Construction phase

Table 7.22: Heuristics for solving Vehicle Routing Problem for blood distribution with multi-frequency deliveries

Construction Phase: Vehicle Routing Problem for blood distribution with multi-frequency deliveries
01. Form the clusters containing the hospital nodes $C_t, t = 1, 2, \ldots, 6$, and sort by the total amount of blood targets in each cluster according to amount of blood available on different days
02. In Cluster $C_t, t = 1, 2, \ldots, 6$, sort hospitals in non-decreasing order of their visit frequencies
03. Set f_i to be the delivery frequency for node i, $\forall i \in N$
04. Set $E(t)$ to be the expected amount of blood available on day t, $t = 1, 2, \ldots, 6$
05. Set q_i to be target weekly blood supply of node i, $\forall i \in N$
06. Set Q to be the vehicle capacity
07. Initialise $\beta_i = 0$, where β_i is blood allocation for node i, $\forall i \in N$
08. Initialise $D_k = 0$, where D_k is the total distance of route for vehicle k, $\forall k \in K$
09. Initialise $\omega_k = 0$, where ω_k is the total amount of blood carried by vehicle k, $\forall k \in K$
10. Initialise $F_i = 0$, where F_i is the total number of visits to node i, $\forall i \in N$
11. Initialise $\gamma_t = 0$, where γ_t is the total amount of blood allocated on day t, $t = 1, 2, \ldots, 6$
12. Initialise $k = 1$
13. Initialise $i' = 0$ and $j' = 0$
14. For t =1 to 6
15. Do while there are hospital nodes $\in C_t$ to be considered and $\gamma_t < E(t)$
16. Select the next hospital node i in C_t such that $\beta_i + \lceil \frac{q_i}{f_i} \rceil \leq q_i$ or $F_i < f_i$ and $\gamma_t + \min(\lceil \frac{q_i}{f_i} \rceil, E(t) - \gamma_t) < E(t)$
17. If $D_k + d_{ii'} + d_{0i} - d_{0i'} \leq m$ or $D_k + d_{j'i} + d_{i0} - d_{j'0} \leq m$ and $\omega_k + \min(\lceil \frac{q_i}{f_i} \rceil, E(t) - \gamma_t) < Q$ then
18. Assign delivery day
19. Allocate blood to node i ($y_{ikt} = \min(\lceil \frac{q_i}{f_i} \rceil, E(t) - \gamma_t)$)
20. Design delivery route ($x_{i'ikt}$) using Savings Algorithms
21. Update amount of blood allocated to node i ($\beta_i = \beta_i + y_{ikt}$)
22. Update total amount of blood allocated on day t ($\gamma_t = \gamma_t + \beta_i$)
23. Update total delivery frequency of node i ($F_i = F_i + 1$)

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Table 7.22: Heuristics for solving Vehicle Routing Problem for blood distribution with multi-frequency deliveries

Construction Phase: Vehicle Routing Problem for blood distribution with multi-frequency deliveries
24. Update total travelling distance ($D_k = D_k + d_{ii'} + d_{0i} - d_{0i'}$), if arc (i, i') is added into the route or ($D_k = D_k + d_{j'i} + d_{i0} - d_{j'0}$), if arc (j', i) is added into the route
25. Update total amount of blood in vehicle k ($\omega_k = \omega_k + y_{ikt}$)
26. Set $i' = i$, if arc (i, i') is added into the route or Set $j' = i$, if arc (j', i) is added into the route
27. Else
28. Set $k = k + 1$
29. Set $i' = 0$
30. End if
31. Loop
32. Order clusters $(C_t, C_{\tau_1}, \ldots, C_{\tau_1})$ such that C_{τ_l}, $l = 1, \ldots, 5$, is closer to its predecessor in the list than all other clusters, according to distance between centroids
33. For $l = 1, \ldots, 5$
34. Do while there is a cluster to be considered and $\gamma_t < E(t)$
35. Set Cluster $C_{t'} = \{i \in C_{\tau_l} \;\; s.t. \;\; f_i > 1\}$
36. Sort hospitals in Cluster $C_{t'}$ in non-increasing order of the frequency f_i
37. Set $C_t = C_{t'}$
38. Repeat steps 15 - 31
39. Loop
40. Next
41. Do while there are hospitals i already assigned to routes k, and $\gamma_t < E(t)$
42. If $y_{ikt} > 0$ and $\beta_i < q_i$ then
43. Give extra blood $e_i = \left(\frac{(q_i - \beta_i)}{\sum_{i \in \{1,2,\ldots,n\}} (q_i - \beta_i)}\right)(E(t) - \gamma_t)$, within vehicle capacity Q
44. Update $y_{ikt}, \beta_i, \gamma_t, \omega_k$
45. End if
46. Loop
47. Next

For the construction of the initial solution, hospitals are first clustered using the K-Means Clustering technique. A target weekly blood supply or quota for each hospital is calculated according to the proportion of historical blood requests made by the hospital and the total blood available per week. Daily hospital blood targets are calculated from weekly targets divided by the delivery frequencies set for the hospitals. The six clusters are then assigned to delivery days according to the total daily blood targets of hospitals within the clusters. Delivery routes for each day are designed using the improved C&W Savings algorithm, with constraints on maximum total travelling distance of a route and also vehicle capacity. Hospitals in the same cluster are assigned to the same day. Remaining blood is then allocated to neighbouring clusters, in order of the highest frequency hospitals first. Finally, any remaining blood is assigned to hospitals already on routes, in proportion to blood targets as yet unsatisfied. The construction phase is illustrated in pseudo-code in Table 7.22.

7.5.1.2 Improvement phase

For the local search improvement phase, there are four movements of neighbourhood for the tabu search: Relocation, Crossover, Exchange, and 2-opt (see details in Section 7.1.4).

7.5.2 Results of Vehicle Routing Problem for blood distribution with multi-frequency deliveries

Table 7.23: Schedule for daily blood distribution

Day	Delivery route	Total distance (km)	Blood quantity (bags)	CPU time (sec.)
Monday	0-109-61-80-97-45-103-27-74-85-91-0	679.349	51	8.45
	0-6-48-1-46-36-17-81-18-0	660.894	35	
	0-105-25-86-71-66-59-19-112-34-21-31-0	712.559	30	
	0-5-32-24-40-26-104-49-44-39-43-11-12-0	719.980	27	
	0-100-33-83-0	682.953	24	
	0-82-106-13-93-7-0	678.376	12	
	0-90-47-8-16-0	633.310	11	
	0-50-79-54-92-0	686.407	10	
Tuesday	0-23-99-75-95-101-72-88-17-35-84-65-69-0	716.924	60	7.03
	0-74-91-1-36-59-46-28-43-58-0	715.352	48	
	0-22-81-33-60-20-38-0	607.778	35	
	0-8-67-68-87-3-0	574.005	14	
	0-57-50-30-9-52-78-77-110-0	699.748	14	
	0-107-14-41-108-76-47-0	612.735	8	
Wednesday	0-74-22-55-62-94-91-3-0	579.420	48	3.28
	0-109-81-111-64-65-29-0	400.883	46	
	0-69-88-42-96-73-58-0	672.720	38	

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Table 7.23: Schedule for blood distribution

Day	**Delivery route**	**Total distance (km)**	**Blood quantity (bags)**	**CPU time (sec.)**
Thursday	0-29-84-35-88-91-22-74-37-43-58-89-69-0	715.427	115	3.69
	0-56-51-15-0	494.816	22	
	0-10-102-98-0	562.114	3	
	0-2-53-70-0	521.326	3	
Friday	0-69-4-63-88-91-0	179.167	93	1.82
	0-35-64-65-0	130.940	39	
Saturday	0-65-64-69-0	152.455	86	0.59
Total		13,789.638	872	

Table 7.23 shows the schedule of blood deliveries to the 112 hospitals in the upper North region. As expected with multiple deliveries to hospitals, the total distance travelled is high, more than 13,000 km. When compared with other days, deliveries are made mostly on Mondays, with eight vehicles used, because much blood is collected on Saturdays and Sundays. Appendix M gives full results of allocated blood and delivery days. Frequencies for blood distribution are defined by the decision maker, using the historical data. Blood is allocated to the different hospitals on different days according to their visit frequencies.

Table 7.24: Assigned frequency (f_i) for blood distribution to hospitals in case study

Distance (km.)	**Frequency for blood distribution (Time/Week)**						**Total number of hospitals**
	1	**2**	**3**	**4**	**5**	**6**	
0-50	3	2	0	0	0	0	5
50-100	26	7	4	3	2	0	42
100-150	23	3	2	0	0	0	28
150-200	14	0	0	0	0	0	14
200-250	11	0	0	0	0	0	11
250-300	10	1	0	0	0	0	11
300-350	1	0	0	0	0	0	1
Total	88	13	6	3	2	0	112

As shown in Table 7.24 and Figure 7.19, frequencies chosen for blood distribution to hospitals differ according to the distance between the hospital and the RBC. This is in accordance with the observed patterns of existing blood collection frequencies, see Section 4.3. Blood is delivered with high frequencies to the hospitals which are within 100 kilometres. There are approximately 79% of the total hospitals served once per week, 11% twice per week, 5% three times per week, 3% four times per week, and 2% five times per week.

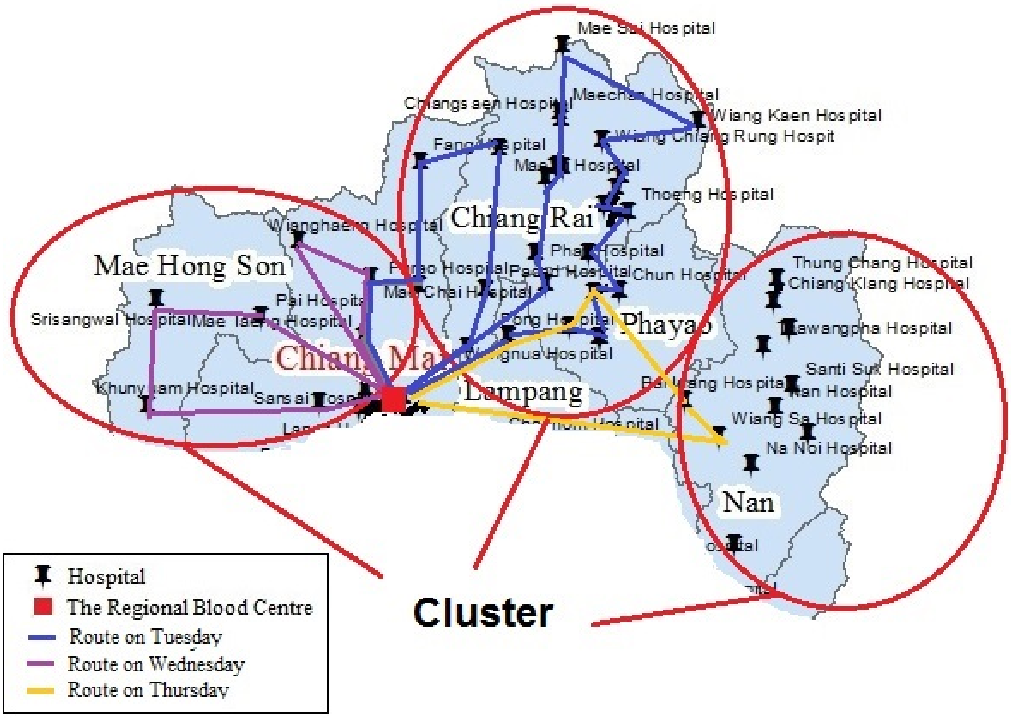

Figure 7.18: Example of blood allocation and routing for hospitals in neighbouring clusters

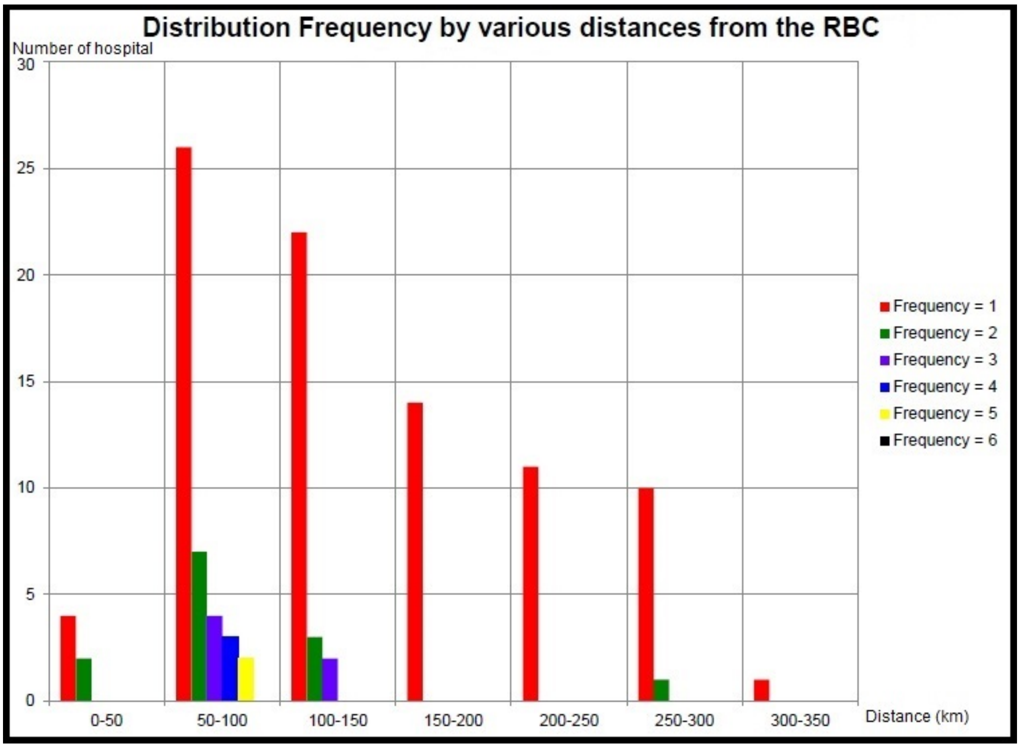

Figure 7.19: Histogram of distribution frequency by distance from the Regional Blood Centre (RBC)

Figure 7.18 shows an example of blood allocation and routing for hospitals in neighbouring clusters, with some of the routes constructed for three days. Blue routes (Tuesday) show hospitals served in the Chiang Rai cluster: it can be observed that some hospitals in the neighbouring Mae Hong Son cluster are also served on the blue routes. The main distribution routes for Mae Hong Son cluster are illustrated in pink (Wednesday). The Nan cluster is mainly served on Thursdays: one of the Thursday routes is shown in yellow, serving both hospitals in the neighbouring Chiang Rai cluster and the Nan cluster.

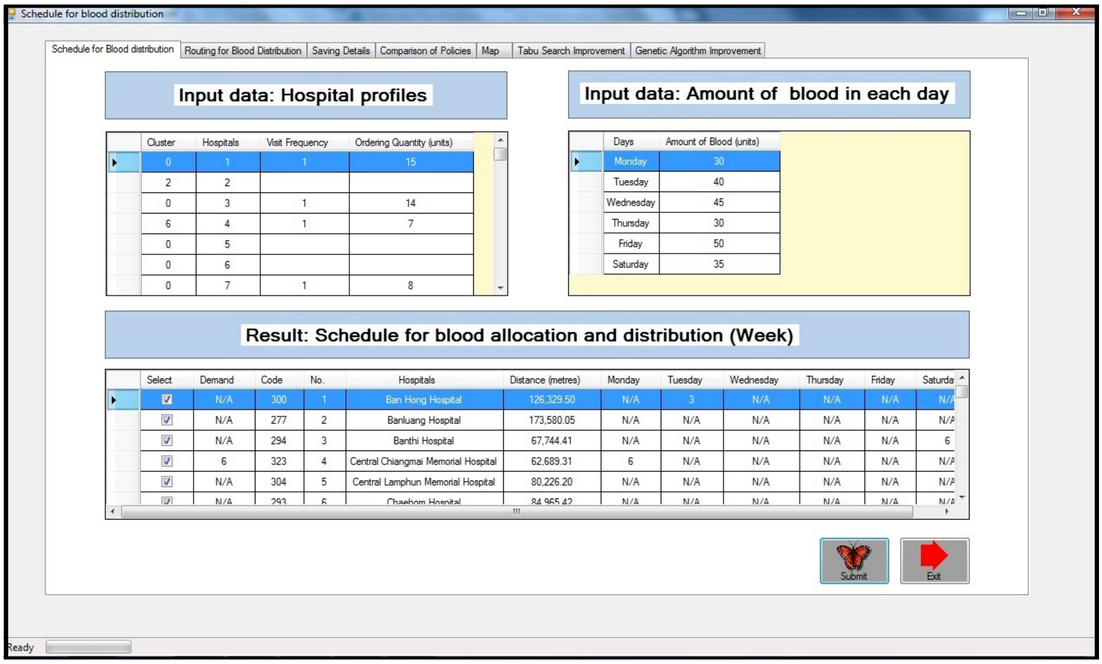

Figure 7.20: Screen of Application for Periodic Vehicle Routing Problem

The application program was developed in Visual Basic.Net with a User Interface based on Windows Application shown in Figures 7.20 and 7.21. Figure 7.20 demonstrates input data and results of blood allocation for hospitals, while Figure 7.21 shows delivery routes within the constraints mentioned. Data including the profile of hospitals in the spreadsheet file are read into the application. However, the amount of blood available in each day can be changed on the interface.

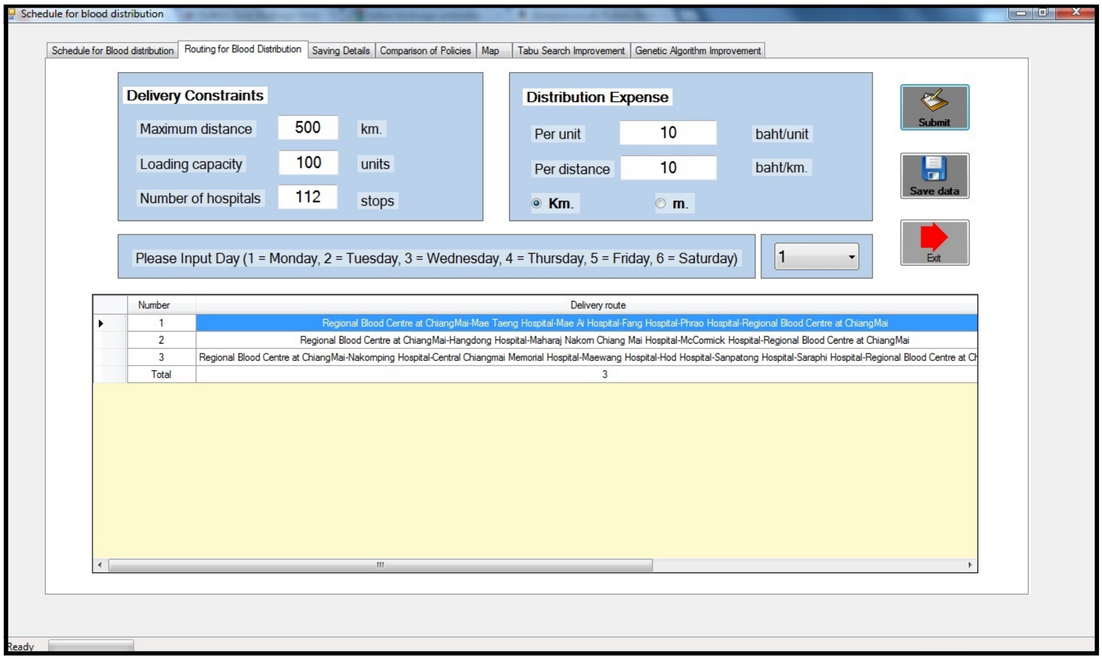

Figure 7.21: Screen of Application for Periodic Vehicle Routing Problem

7.6 Summary and Conclusion

Distribution is the part of supply chain process needed to fulfil customer demands. The main objective of this chapter is to arrange fixed schedules for blood deliveries for a one-week planning horizon, giving routes from the Regional Blood Centre (or the distribution centre) to hospitals. For this vehicle routing problem with blood allocation, we have designed a number of policies to suit conditions of sufficient and insufficient supply.

Firstly, algorithms for policies of a single visit frequency (once per week) for all hospitals are presented for the case of sufficient supply. For six-day delivery, which does not involve the RBC in blood storage costs, we present comparisons between improved versions of both Clarke and Wright and GRASP heuristics for vehicle routing, and compare also with optimal solutions where available. Of these methods, the lowest total travel distance of 6,291 km is obtained with GRASP. To reduce the total transportation costs, we also apply heuristics to three-day delivery, and introduce the problem of delivery to hub hospitals, although heuristics are not developed for this policy. The results show that the 3-day delivery policy to all hospitals reduces transportation costs (to 3,354 km) in comparison to 6-day delivery, but storage costs would practically be involved. Further reductions in costs would be expected with deliveries to hub and on-tour hospitals only. Improvements are demonstrated on total distance travelled in comparison with expert judgement. However, the hub policy would be difficult to implement in the real situation because the hospital hubs would need to carry increased inventory costs.

It is not possible to deliver once per week to all hospitals when there is insufficient supply. For this case, multiple-visit frequencies for hospitals are determined from historical data, and hospitals are clustered to ensure a fair supply to each locality. We present a two-phase heuristic as solution method for the problem. Total transportation costs are, however, greatly in excess (13,789 km) of those for single-visit frequency policies, although holding costs would be reduced.

The fixed, regular routing algorithms proposed in this chapter make the assumption that blood supplies are steady, while in reality there is variability in amounts of blood donated. Chapter 8 addresses the situation of variable blood supplies with an online system for blood allocation and routing. The system proposed consists of both fixed and variable routing components, and both transportation and holding costs are considered in detail for the alternative policies presented.

Chapter 8

Online Blood Allocation and Variable Distribution Routes

This chapter presents algorithms for blood allocation and delivery in conditions of variability and shortage of supply. In particular, these algorithms construct delivery routes from RBCs to hospitals by taking total travelling cost and holding costs into consideration. More distant hospitals are prioritised with fixed delivery routes and fixed blood allocations. Hospitals closer to the RBC are allocated varying blood amounts on variable routes: blood is re-allocated and deliveries are re-scheduled when the actual amount of blood available becomes known on any day. Five policies for variable blood allocation and delivery routes are presented, offering a range of alternatives for decision makers, according to relative levels of transport and holding costs and also complexity and transparency of the policies offered. Three of the policies are based on daily modifications to an initial plan, which is determined in advance for deliveries in the region. Two further policies, with plans developed each day, achieve reductions in transportation or holding costs. A finite planning horizon over six days is used for this case study in the eight provinces of the upper North region.

8.1 The online blood allocation and routing scheme

There are currently 112 hospitals which individually collect blood from the RBC at Chiang Mai. As described in Chapter 2, Section 2.5, the current system can lead to an inequitable distribution of blood. A centrally coordinated scheme for allocating blood deliveries is therefore proposed, using vehicles travelling from the RBC along planned delivery routes. In consultation with an administrator, hospitals have been classified into two groups according to their geographical location, in order to assign them to either fixed routes or variable routes. It is recommended that hospitals which are far from the RBC (more than 70 kilometres or travelling time more than one hour) are included in routes that are fixed for each day. Hospitals closer to the RBC are assigned to routes that vary by day and by hospitals visited; on the variable routes, hospitals may receive blood on several days to complete their target allocation over the planning horizon. The fixed routes are based on geographically-clustered hospitals; variable routes are constructed entirely using route savings.

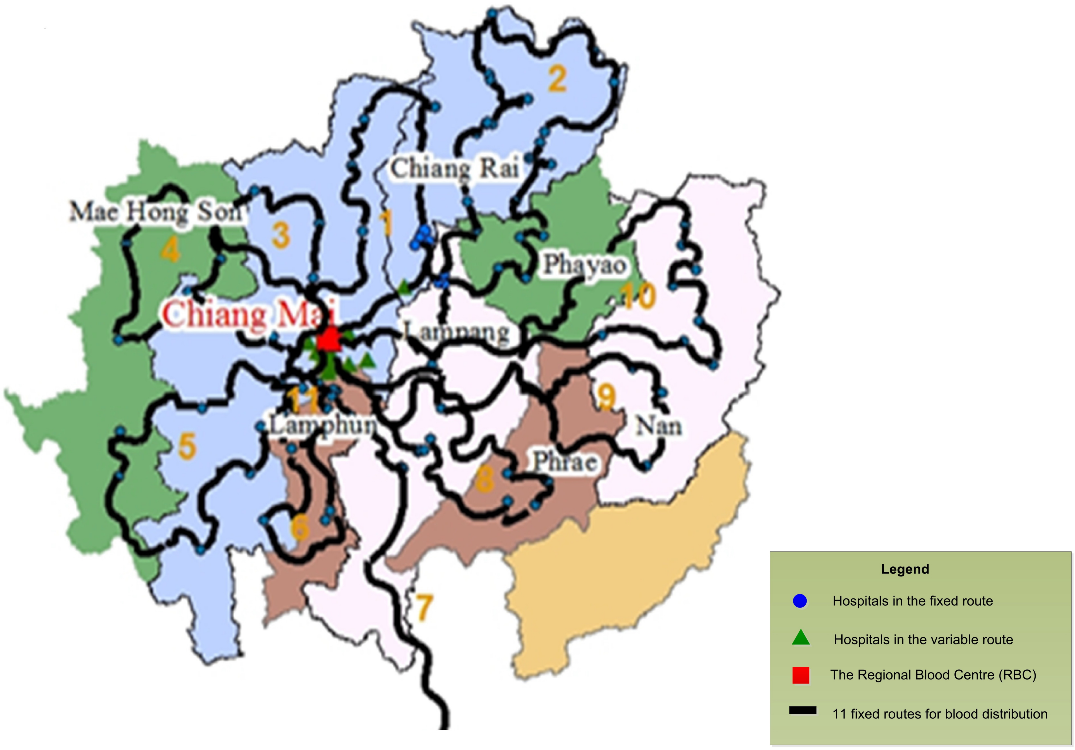

Figure 8.1: Locations of hospitals on proposed fixed and variable routes

Figure 8.1 shows the fixed routes constructed for distant hospitals, using the improved Clark and Wright heuristic method described in detail in Chapter 7, Section 7.1. The hospitals close to the RBC to be served on the variable routes are also indicated in Figure 8.1. In this figure, a circular symbol represents a hospital on a fixed route, while a triangular symbol represents a hospital on a variable route. The rectangular symbol denotes the RBC in Chiang Mai province. In this case study, 83 hospitals are on fixed routes and 29 hospitals are on variable routes.

A principal objective of an RBC administrator is to minimise total transportation costs for blood distribution over the planning period, while satisfying the blood requirements of hospitals. Reducing the frequency of visits to each hospital can help to minimise the total transportation cost. When there is only a small amount of blood available, it may not be suitable to make deliveries because of high logistics and transportation costs. Accumulation of donated blood to make transportation worthwhile is thus an alternative strategy for distribution, but this may increase the short-term holding costs. The implications of the different policies proposed in this study are detailed for the decision maker in terms of transportation and holding costs.

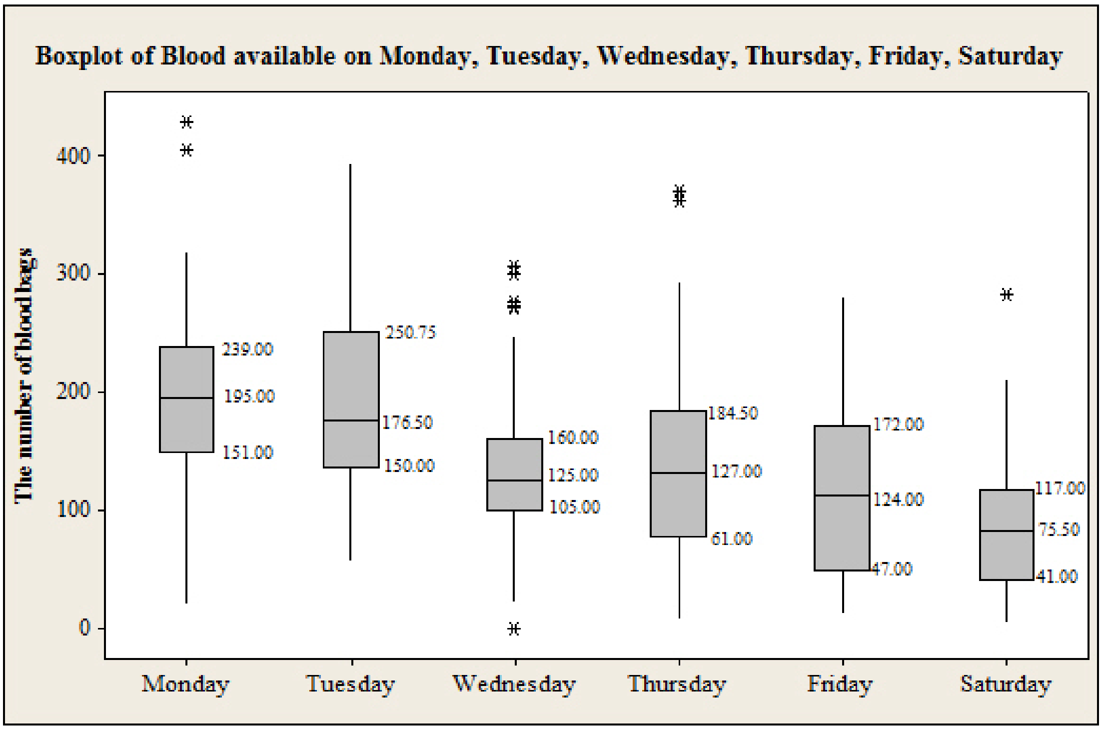

Figure 8.2: Box Plot for blood available for distribution in different days of week

A weekly target blood supply for each hospital is used to determine a fair blood allocation for all hospitals in this online system. Targets are calculated from the expected total amount of donated blood likely to become available over the planning period, and from the proportions of weekly historical blood requests made by different hospitals. The amounts of donated blood available and percentiles from Monday to Saturday are illustrated in Figure 8.2. On each delivery day, blood is firstly allocated to hospitals on the fixed route and the remainder is assigned to hospitals on the variable route. The fixed hospital routes designed for the study region are allocated blood according to the 25th percentile: in other words, total blood targets for these hospitals can be met 75% of the time, according to the daily probability distribution of blood.

Table 8.1: Priorities of hospitals for blood allocation

Types of hospitals	Priority
Private hospital	5
Public hospital	4
High-usage community hospital	3-2
Low-usage community hospital	1

Priorities determining the importance of different hospitals are used for blood allocation in this study, according to TRCS policies. Hospitals are assigned a priority number, shown in Table 8.1, based on the type of hospital (described in Chapter 2, Section 2.3) and level of blood usage. Operations are more commonly carried out in the larger hospitals and thus these hospitals are given a higher priority: smaller hospitals may refer patients needing operations to larger hospitals, thus avoiding the need for blood transfusions. Moreover, should shortages occur and low priority hospitals not receive blood, requests may be made to the larger hospitals in case of need.

Table 8.2: Numbers of blood bags available for distribution on each day

Day in week	Minimum	Maximum	Mean	Standard Deviation	Median
Monday	21.00	429.00	199.70	75.20	195.00
Tuesday	48.00	394.00	178.90	87.30	176.50
Wednesday	22.00	306.00	132.17	71.22	125.00
Thursday	8.00	371.00	143.10	76.00	127.00
Friday	14.00	281.00	131.56	66.33	124.00
Saturday	4.00	283.00	86.07	54.03	75.50

The distributions of blood available by day of the week are shown as box plots in Figure 8.2. On Mondays, blood is ready for distribution as a result of donations made on Saturdays and Sundays, so the quantity of blood available is greater than on the other days of the week. Median values from Wednesday to Friday are similar. There is a high variation in the amount of donated blood available for distribution on Tuesdays. Descriptive statistical data on daily availability of blood are given in Table 8.2.

The methodology devised in this study for allocating blood supplies to different hospitals is as follows. Expected daily amounts of blood supplies are calculated (see Table 8.2), based on historical data of daily donated blood. From these expected values, target weekly allocations of blood are assigned to each hospital (see Appendix N) based on the proportions of all blood requests made by each hospital. Hospitals are then assigned to fixed or variable routes, as described earlier in this section, according to distance from the RBC. Hospitals on the fixed routes are allocated to one of the six delivery days by K-means clustering, according to their geographical locations and daily amount of blood available. Of the total of 872 blood bags expected to be available for distribution, 555 bags were allocated to hospitals on the fixed routes (see Table 8.3), leaving an expected 317 bags for the variable routes.

Table 8.3: Calculated amounts of blood (bags) assigned in this study to fixed and variable routes

Day in week	**Expected amount of blood available**	**Amount of blood allocated to hospitals in fixed routes**	**Target amount of blood for hospitals in variable routes**
Monday	200	151	49
Tuesday	179	150	29
Wednesday	132	105	27
Thursday	143	61	82
Friday	132	47	85
Saturday	86	41	45
Total	872	555	317

Table 8.4: Example of randomly generated blood supply available for variable routes

Day in week	**Amount of blood (bags)**		
	Sampled amount of blood from Normal Distribution	**Allocation to fixed routes**	**Blood remaining for variable routes**
Monday	240	151	89
Tuesday	186	150	36
Wednesday	146	105	41
Thursday	101	61	40
Friday	97	47	50
Saturday	127	41	86
Total	897	555	342

Test data were generated of daily amounts of blood available, of which an example is given in Table 8.4, for comparison of different distribution policies. The Normal distribution was found appropriate for generating these data (see Chapter 4, Section 4.3.6) with predefined mean and standard deviation parameters for each day. Donated blood is allocated first to hospitals in fixed routes, with the fixed amount of 555 bags assigned as described above. After this, blood remaining, 342 bags in this sample, is distributed to hospitals on variable routes near the RBC.

Three of the five policies proposed for blood allocation and routing are based on an initial plan, to which amendments are made as daily amounts of available blood become known. Policy 1 is closely related to the initial plan. On any delivery day, if more blood than expected (in the initial plan) becomes available, amounts of blood are increased for hospitals on that day's route, up to target amounts, considering highest priority hospitals first. If no hospital is below target, then extra blood is stored for later distribution. Policy 2 is similar to Policy 1, but if extra blood is available on any day, new hospitals are added to the days route, so that more hospitals benefit. Policy 3 combines features of Policies 1 and 2: extra blood is given firstly to on-route hospitals according to priority, and secondly to extra hospitals added to the route. However, with Policy 3, deliveries are only made if the amount of blood available is more than a given amount, to reduce transportation costs. For all Policies 1, 2 and 3, if less blood becomes available than expected in the initial plan, blood deliveries are reduced to lowest priority hospitals, considering farthest away hospitals first.

Two further policies for blood allocation and delivery are based solely on the daily known amounts of blood. Policy 4 aims to reduce the frequency of blood deliveries and involves low holding costs. Each day, a "starting" hospital is found with the greatest target that can be satisfied with the blood available. Hospitals closest to the starting hospital are then added to a route whose target is less than or equal to the remaining available blood. Remaining blood is allocated to a hospital close to the end of the route. However, transportation costs may be high as route savings are not considered. Policy 5 reduces delivery frequencies whilst also reducing distance travelled using route savings costs (see Section 7.1.2, Chapter 7). Blood is delivered to a hospital only when the whole target supply can be met. Holding costs thus arise with Policy 5, since blood is stored until targets can be met. These costs are calculated by multiplying amounts of blood stored overnight by unit refridgeration costs (10 Thai Baht).

8.2 Solution Method

This section describes the methodology for allocating blood and determining the fixed and variable routes for the online system of planning.

The problem of determining the fixed routes for blood distribution to distant hospitals considered in this case study is related to the Capacitated Vehicle Routing Problem (CVRP) (see Chapter 3, Section 3.3) in which the capacity of a vehicle for distribution is limited. The methodology of 6-day routing described in Chapter 7, Section 7.1 is followed for the fixed routes: however, only distant hospitals are included in these routes. Because of the extended distances travelled, these hospitals are delivered blood only once per week to reduce transportation costs. Each route serves hospitals in the same cluster or area, and fixed amounts of blood are delivered as described in Section 8.1.

An online system for blood allocation and routing is proposed for the variable routes to hospitals close to the RBC. The frequencies of distribution to hospitals on the variable routes vary according to the target amounts and locations of the hospitals, for which five different algorithms are described for the associated policies. For the first three algorithms, an initial plan for distribution throughout the planning period is drawn up on the basis of quantities of blood expected to be donated and target deliveries for each hospital. However, the actual amount of donated blood ready for distribution cannot be known until the morning of each day. Delivery schedules are updated daily throughout the planning period when available blood quantities are known. For the final two algorithms, no initial plan is made and routes are determined each day according to the blood ready for delivery.

Heuristics (a Greek-based word meaning to find a solution based on a rule-of-thumb) are used as the solution approach for the online system, since the problem is non-deterministic polynomial time hard (NP-hard), being derived from the VRP problem. The overall system can be divided into two phases for algorithms 1, 2 and 3, while algorithms 4 and 5 only require phase 2. Phase 1 consists of constructing the initial solution for the blood distribution schedule based on historical data, and Phase 2 concerns updating the solution over the period of planning once the actual amount of blood available is known. The distribution plan is then updated and is used as the current plan for the next day's calculations.

8.2.1 Initial Plan for Online Blood Allocation and Routing based on Heuristics algorithm

For algorithms 1, 2 and 3, an initial plan of allocation and routing for blood is made over the period of the planning horizon (6 days of deliveries per week). Target blood supplies are assigned for each hospital, as described in Section 8.1 and detailed in Appendix N. Daily delivery routes and blood allocation are computed given the expected availability of blood and maximum permitted travel time. The Improved Clarke and Wright Savings Algorithm (see Section 7.1.2, Chapter 7) is used to select hospitals for a route and amounts of blood are allocated to those hospitals corresponding to their target blood supply, while not exceeding the daily expected value of blood supply. The algorithm considers inserting hospitals in a route by calculating the saving costs s_{ij} between a pair of the hospital i and j, where $s_{ij} = d_{0i} + d_{0j} - d_{ij}$ and d_{ij} is the travel distance measured in kilometers between hospital nodes i and j. Savings costs are then listed in descending order. However, the solution must not violate the constraints on target blood supply, maximum travel distance and the assumptions listed in Section 8.3.1.

8.2.2 Re-Planning Phase of Online Blood Allocation and Routing

With algorithms 1, 2 and 3, the initial schedule for blood distribution is updated when actual information of the daily blood supply has become known. Each day's blood distribution is used to update the database of blood supplied and routes for the rest of the planning period, in order to guide the next day's rescheduling. With algorithms 4 and 5, each day's routes are calculated when blood supplies become known and amounts of blood supplied are updated in the database.

8.3 Algorithms for blood distribution

8.3.1 Assumptions

- Routes depart from the RBC which is represented by node 0 and return there after visiting hospitals
- Weekly blood target supplies for hospitals are provided
- It is determined in advance whether each hospital is on a fixed or variable route
- The travel distance or time between each pair of hospitals and between the RBC and hospitals is known
- All hospitals can be supplied by one RBC and one vehicle
- Each route starts and stops at the RBC
- The capacity of the vehicle is predefined
- It is assumed that hospitals can receive blood at any time of the day, so no delivery time window is required

8.3.2 Notation

Parameter	Description
n	number of hospitals
t	period of time for blood delivery
c_i	priority of hospital i, $\forall i \in \{1, 2, \ldots, n\}$
d_{ij}	distance between node i and node j, $\forall i \in \{0, 1, 2, \ldots, n\}$, $\forall j \in \{1, 2, \ldots, n\}$
I_t	blood inventory of the RBC on day t in units of blood (bags), $\forall t \in \{1, 2, \ldots, 6\}$
m	maximum total distance of the route (km)

Parameter	Description
p	level point of blood to determine the delivery for blood, in units of blood (bags)
q_i	target blood supply at the i^{th} hospital in units of blood (bags), $\forall i \in \{1, 2, \dots, n\}$
Q	capacity of a vehicle in units of blood
S_t	total amount of blood available on day t in units of blood (bags), $\forall t \in \{1, 2, \dots, 6\}$
α	petrol price per litre
γ	fuel consumption rate of a vehicle, litres per kilometer

Decision variables

Variable	Description
a_t	= total amount of blood allocated to all hospitals on day t, $\forall t \in \{1, 2, \dots, 6\}$
x_{ijt}	$= \begin{cases} 1, & \text{if node } i \text{ precedes node } j \text{ on day } t, \forall i \in \{0,1,2,\dots,n\}, \forall j \in \{0,1,2,\dots,n\}, \forall t \in \{1,2,\dots,6\} \\ 0, & \text{otherwise} \end{cases}$
y_{it}	= amount of blood allocated to hospital i on day t in the initial plan, $\forall i \in \{1, 2, \dots, n\}, \forall t \in \{1, 2, \dots, 6\}$
z_{it}	= change in amount of blood allocated to hospital i on day t, $\forall i \in \{1, 2, \dots, n\}, \forall t \in \{1, 2, \dots, 6\}$

8.3.3 Solution algorithms

Details of algorithms follow for Policies 1 to 5 on day $t, t = 1, \dots, 6$. Policies 1, 2 and 3 are based on an initial plan, which is updated each day in the database (as 'current solution'). For all policies, the initial inventory, I_0, is set to zero. The blood allocation in the initial solution is based on the daily expected value of donated blood. Total transportation costs are considered in all solution approaches. For all policies, vehicle capacity is not exceeded, i.e., $\sum_{i=1}^{n} y_{it} \leq Q$, $\forall t \in \{1, 2, \dots, 6\}$. The total transportation cost is calculated by the following formula: $\alpha\beta \left(\sum_{t=1}^{6} \sum_{i=0}^{n} \sum_{j=0}^{n} x_{ijt} d_{ij} \right)$.

8.3.3.1 Policy 1

Table 8.7: Pseudo-code for Policy1

Re-schedule for Policy 1
01. Processing for day $t, \forall t \in \{1, 2, \ldots, 6\}$
02. Input x_{ijt} from current solution $, \forall i \in \{0, 1, \ldots, n\}, \forall j \in \{0, 1, \ldots, n\}$
03. Input y_{it} from current solution, $\forall i \in \{1, 2, \ldots, n\}$
04. Set $q'_i = q_i$, $\forall i \in \{1, 2, \ldots, n\}$
05. Set $z_{it} = 0, \forall i \in \{1, 2, \ldots, n\}$
06. Set $S_t = S_t + I_t$
07. If $S_t > E(S_t)$ then
08.   Set $i = 1$
09.   Do while $i \leq n$ and $S_t > 0$
10.   If $c_i \geq 3$ and $y_{it} > 0$ and $q'_i > 0$ and $\sum_{i=1}^{n} y_{it} + \min((q'_i - y_{it}), (S_t - E(S_t))) \leq Q$ then
11.   Set $z_{it} = \min((q'_i - y_{it}), (S_t - E(S_t)))$
12.   Set $q'_i = (q'_i - (y_{it} + z_{it}))$
13.   Set $y_{it} = y_{it} + z_{it}$
14.   Set $S_t = (S_t - E(S_t)) - z_{it}$
15.   End If
16.   Set $i = i + 1$
17.   Loop
18. Else If $S_t < E(S_t)$ then
19.   Do while there is a node to be considered and $S_t < 0$
20.   Select node i with $\min_{i,j \in \{1,2,\ldots,n\}} (s_{ij} : y_{it} > 0, y_{jt} > 0)$ – Find the furthest node of the route
21.   If $c_i < 3$ then
22.   Set $z_{it} = \max(-y_{it}, S_t - E(S_t))$
23.   Set $q'_i = (q'_i - (y_{it} + z_{it}))$
24.   Set $y_{it} = y_{it} + z_{it}$
25.   Set $S_t = (S_t - E(S_t)) - z_{it}$
26.   Set $x_{ijt} = 0$, if $y_{it} = 0$, $\forall j \in \{0, 1, 2, \ldots, n\}$ – Remove node i from the route
27.   Remove s_{ij} from the list
28.   End If
29.   Loop
30. Else If $S_t = E(S_t)$ then

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Table 8.7: Pseudo-code for Policy1

Re-schedule for Policy 1
31.   Use the current plan
32. End If
33. Set $a_t = \sum_{i=1}^{n}(y_{it} + z_{it})$
34. Set $I_{t+1} = S_t$ - a_t
35. Set $q_i = q'_i, \forall i \in \{1, 2, \ldots, n\}$
36. Update $x_{ij\tau}, y_{i\tau}, q_i, \forall i \in \{0, 1, 2, \ldots, n\}, \forall j \in \{0, 1, 2, \ldots, n\}, \forall \tau \in \{t, \ldots, 6\}$

Pseudo-code for day $t, t = 1, \ldots, 6$, under Policy 1 is given in Table 8.7. Routes from the initial plan are unchanged, with extra blood going to high priority hospitals already on the route. There are reductions in amounts of blood or no deliveries to distant low priority hospitals if there is a shortage.

8.3.3.2 Policy 2

Table 8.8: Pseudo-code for Policy 2

Re-schedule for Policy 2
01. Processing for day $t, \forall t \in \{1, 2, \ldots, 6\}$
02. Input x_{ijt} from current solution, $\forall i \in \{0, 1, \ldots, n\}, \forall j \in \{0, 1, \ldots, n\}$
03. Input y_{it} from current solution , $\forall i \in \{1, 2, \ldots, n\}$
04. Set $q'_i = q_i$, $\forall i \in \{1, 2, \ldots, n\}$
05. Set $z_{it} = 0, \forall i \in \{1, 2, \ldots, n\}$
06. Set $S_t = S_t + I_t$
07. If $S_t > E(S_t)$, then
08.   Do while $S_t > 0$ and there is no node to be considered
09.   Select node i with $\max_{i,j \in \{1,2,\ldots,n\}} (s_{ij} : y_{it} = 0, y_{jt} > 0)$ such that $\sum_{i=1}^{n} y_{it} + \min((q'_i - y_{it}), (S_t - E(S_t))) \leq Q$ and $c_i \geq 3$ and $q'_i > 0$ – Find the closest node
10.   Recalculate the total distance of the route
11.   If it does not violate the maximum distance constraint then
12.   Set $z_{it} = \min((q'_i - y_{it}), (S_t - E(S_t)))$
13.   Set $q'_i = (q'_i - (y_{it} + z_{it}))$
14.   Set $y_{it} = y_{it} + z_{it}$
15.   Set $S_t = (S_t - E(S_t)) - z_{it}$
16.   Update x_{ijt}, where node i connects to node j already in the route
17.   Remove s_{ij} from the list
18.   End If

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Table 8.8: Pseudo-code for Policy 2

Re-schedule for Policy 2
19. Loop
20. Else If $S_t < E(S_t)$ then
21. Do while there is a node to be considered and $S_t < 0$
22. Select node i with $\min_{i,j \in \{1,2,\ldots,n\}} (s_{ij} : y_{it} > 0, y_{jt} > 0)$ – Find the furthest node of the route
23. If $c_i < 3$ then
24. Set $z_{it} = \max(-y_{it}, S_t - E(S_t))$
25. Set $q'_i = (q'_i - (y_{it} + z_{it}))$
26. Set $y_{it} = y_{it} + z_{it}$
27. Set $S_t = (S_t - E(S_t)) - z_{it}$
28. Set $x_{ijt} = 0$, if $y_{it} = 0$, $\forall j \in \{0, 1, 2, \ldots, n\}$ – Remove node i from the route
29. Remove s_{ij} from the list
30. End If
31. Loop
32. Else If $S_t = E(S_t)$, then
33. Use the current plan
34. End If
35. Set $a_t = \sum_{i=1}^{n} (y_{it} + z_{it})$
36. Set $I_{t+1} = S_t$ - a_t
37. Set $q_i = q'_i, \forall i \in \{1, 2, \ldots, n\}$
38. Update $x_{ij\tau}, y_{i\tau}, q_i, \forall i \in \{0, 1, 2, \ldots, n\}, \forall j \in \{0, 1, 2, \ldots, n\}, \forall \tau \in \{t, \ldots, 6\}$

Pseudo-code for day $t, t = 1, \ldots, 6$, under Policy 2 is given in Table 8.8. If extra blood is available, more high priority hospitals are added to the route with the best route savings. As with Policy 1, there are reductions in amounts of blood or no deliveries to distant low priority hospitals if there is a shortage.

8.3.3.3 Policy 3

Table 8.9: Pseudo-code for Policy 3

Re-schedule for Policy 3
01. Processing for day $t, \forall t \in \{1, 2, \ldots, 6\}$
02. Input x_{ijt} from current solution, $\forall i \in \{0, 1, \ldots, n\}, \forall j \in \{0, 1, \ldots, n\}$
03. Input y_{it} from current solution , $\forall i \in \{1, 2, \ldots, n\}$

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Table 8.9: Pseudo-code for Policy 3

Re-schedule for Policy 3
Set $q'_i = q_i$, $\forall i \in \{1, 2, \ldots, n\}$
Set $z_{it} = 0, \forall i \in \{1, 2, \ldots, n\}$
Set $S_t = S_t + I_t$
If $S_t \geq P$ then
If $S_t > E(S_t)$ then
Set $i = 1$
Do While $i \leq n$ and $S_t > 0$
If $y_{it} > 0$ and $c_i \geq 3$ and $q'_i > 0$ and $\sum_{i=1}^{n} y_{it} + \min((q'_i - y_{it}), (S_t - E(S_t))) \leq Q$ then
Set $z_{it} = \min((q'_i - y_{it}), (S_t - E(S_t)))$
Set $q'_i = (q'_i - (y_{it} + z_{it}))$
Set $y_{it} = y_{it} + z_{it}$
Set $S_t = (S_t - E(S_t)) - \sum_{i=1}^{n} z_{it}$
End If
Set $i = i + 1$
Loop
If $S_t > 0$ then
Do while $S_t > 0$ and there is no node to be considered
Select node i with $\max_{i,j \in \{1,2,\ldots,n\}} (s_{ij} : y_{it} = 0, y_{jt} > 0)$ such that $\sum_{i=1}^{n} y_{it} + \min((q'_i - y_{it}), (S_t - E(S_t))) \leq Q, c_i \geq 3$ and $q'_i > 0$ – Find the closest node
Recalculate the total distance of the route
If it does not violate the maximum distance constraint then
Set $z_{it} = \min((q'_i - y_{it}), (S_t - E(S_t)))$
Set $q'_i = (q'_i - (y_{it} + z_{it}))$
Set $y_{it} = y_{it} + z_{it}$
Set $S_t = (S_t - E(S_t)) - z_{it}$
Update x_{ijt}, where node i connects to node j already in the route
Remove s_{ij} from the list
End If
Loop
End If
Else If $S_t < E(S_t)$, then
Do while there is node to be considered and $S_t < 0$

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Table 8.9: Pseudo-code for Policy 3

Re-schedule for Policy 3
Select node i with $\min_{i,j \in \{1,2,\ldots,n\}} (s_{i,j} : y_{it} > 0, y_{jt} > 0)$ – Find the furthest node of the route
If $c_i < 3$ then
Set $z_{it} = \max(-y_{it}, S_t - E(S_t))$
Set $q'_i = (q'_i - (y_{it} + z_{it}))$
Set $y_{it} = y_{it} + z_{it}$
Set $S_t = (S_t - E(S_t)) - z_{it}$
Set $x_{ijt} = 0, \forall j \in \{0,1,2,\ldots,n\}$ – Remove node i from the route
Remove s_{ij} from the list
End If
Loop
Else If $S_t = E(S_t)$, then
Use the current plan
End If
Set $a_t = \sum_{i=1}^{n}(y_{it} + z_{it})$
Else If $S_t < P$ then
Set $q'_i = q'_i + y_{it}, \forall i \in \{1,2,\ldots,n\}$
Set $y_{it} = 0, \forall i \in \{1,2,\ldots,n\}$
Set $a_t = 0$
End If
Set $I_{t+1} = S_t$ - a_t
Set $q_i = q'_i, \forall i \in \{1,2,\ldots,n\}$
Update $x_{ij\tau}, y_{i\tau}, q_i, \forall i \in \{0,1,2,\ldots,n\}, \forall j \in \{0,1,2,\ldots,n\}, \forall \tau \in \{t,\ldots,6\}$

Pseudo-code for day $t, t = 1,\ldots,6$, under Policy 3 is given in Table 8.9. Policy 3 combines feature of Policies 1 and 2: if more blood is available than expected in the current plan, firstly more blood is assigned to high priority hospitals already on the route. Then, if extra blood remains, more high priority hospitals are added to the route, according to route savings. Furthermore, no deliveries are made if the blood available on day t is $< P$ units. As with Policies 1 and 2, there are reductions in amounts of blood or no deliveries to distant low priority hospitals if there is a shortage.

8.3.3.4 Policy 4

Table 8.10: Pseudo-code for Policy 4

Schedule for Policy 4
Processing on day $t, \forall t \in \{1, 2, \dots, 6\}$
Set $S_t = S_t + I_t$
Select node i with $\max\limits_{i \in \{1,2,\dots,n\}} (q_i : q_i \leq S_t$ and $q_i \leq Q)$
Set $x_{0it} = 1$
Set $y_{it} = q_i$
Set $S_t = S_t - y_{it}$
Calculate the total distance of the route
Remove node i from the list
Do While there is a node to be considered and $S_t > 0$
Select node j with $\min(d_{ij})$ such that $\max\limits_{j}(q_j : q_j \leq S_t)$ and $\sum_{i=1}^{n} y_{it} + q_j \leq Q; \forall j \in \{1, 2, \dots, n\}$, $i \neq j$
Recalculate the total distance of the route
If it does not violate maximum distance constraint then
Set $x_{ijt} = 1$
Set $y_{jt} = q_j$
Set $S_t = S_t - y_{it}$
Set $i = j$
Remove node j from the list
End If
Loop
If $S_t > 0$ then
Select node j with $q_j > S_t$ and $\min(d_{ij})$ such that $\sum_{i=1}^{n} y_{it} + S_t \leq Q; \forall j \in \{1, 2, \dots, n\}$, $i \neq j$
Set $x_{ijt} = 1$
Set $y_{jt} = S_t$
Set $S_t = 0$
End If
Set $a_t = \sum_{i=1}^{n} y_{it}$
Set $I_{t+1} = S_t$ - a_t

Pseudo-code for day $t, t = 1, \dots, 6$, under Policy 4 is given in Table 8.10. Policy 4 aims to reduce numbers of deliveries. Unlike Policies 1, 2 and 3, Policy 4 is not based on an initial plan to which amendments are made. On day $t, t = 1, \dots, 6$, Policy 4 first finds a hospital for which the blood target amount is the greatest that does not exceed the amount available. Blood is then allocated to a hospital closest to this "starting hospital" whose target can be fulfilled, and so on to hospitals closest to the latest hospital to be added to the route. Finally, if blood remains, blood is assigned to the closest hospital to the latest one, but the target may be partially fulfilled.

8.3.3.5 Policy 5

Table 8.11: Pseudo-code for Policy 5

Schedule for Policy 5
Processing for day $t, \forall t \in \{1, 2, \ldots, 6\}$
Set $S_t = S_t + I_t$
Select nodes i and j such that s_{ij} is the maximum route saving and $q_i + q_j \leq S_t$ and $q_i + q_j \leq Q$ and $d_{0i} + d_{ij} + d_{j0} \leq m, \forall i \in \{1, 2, \ldots, n\}, \forall j \in \{1, 2, \ldots, n\}$
Set $x_{ijt} = 1$
Set $y_{it} = q_i$ and $y_{jt} = q_j$
Set $S_t = S_t - (q_i + q_j)$
Calculate the total distance of the route
Remove s_{ij} from the savings list
Do While there is a node to be considered and $S_t > 0$
Select node i' with the large saving
Recalculate the total distance of the route
If it does not violate the maximum distance and $\sum_{i'=1}^{n} y_{i't} + q_{i'} \leq Q$ then
Set $y_{i't} = q_{i'}$ if $(E(S_t) - q_{i'}) \geq 0$ and $y_{i't} = 0$, otherwise
Set $S_t = S_t - y_{i't}$
Update the delivery route
Update the saving list
End If
Loop
Set $a_t = \sum_{i=1}^{n} y_{it}$
Set $I_{t+1} = S_t$ - a_t

Pseudo-code for day $t, t = 1, \ldots, 6$, under Policy 5 is given in Table 8.11. Like Policy 4, Policy 5 reduces visit frequency, while also considering route savings costs. The first two nodes added to the route give the greatest route savings where targets can be fully met. Thereafter, nodes are added according to route savings, again fully meeting targets. Any blood remaining is stored until the next day.

8.4 Experimental results

Table 8.12: Hospitals in variable routes

Hospital code	**Type**	**Distance from RBC (km)**	**Weekly requests (bags)**	**Weekly target blood supply (bags)**
3	Community(30 beds)	67.74	4	3
4	General Private	62.69	4	3
8	General Private	63.08	5	4
12	Others	0.00	1	1
16	Community(10 beds)	61.85	1	1
17	Others	65.01	1	1
18	General Private	63.83	5	4
19	General Public	63.92	131	82
21	Others	63.18	2	2
24	Others	59.00	1	1
29	Community(30 beds)	46.43	5	4
31	General Private	60.57	1	1
32	Others	0.00	1	1
34	Military	61.36	1	1
35	Community(10 beds)	67.03	5	4
47	General Private	62.26	19	16
54	Community(10 beds)	62.81	1	1
56	Community(10 beds)	56.97	2	2
64	General Public	65.18	169	107
65	General Private	62.81	23	19
66	General Private	69.23	1	1
69	General Public	62.04	66	49
84	General Private	62.80	1	1
87	Community(30 beds)	65.84	3	2
92	Others	62.36	1	1
93	General Private	63.98	1	1
105	Community(30 beds)	32.26	1	1
109	Community(90 beds)	36.47	2	2
112	Military	66.41	1	1
Total			459	317

The amounts of blood allocated to hospitals on the fixed routes are shown in Appendix N. Hospitals on the variable routes and allocated amounts of blood are listed in Table 8.12; hospital codes are provided in Appendix A.2.

Table 8.13: Comparison of blood distribution policies for one sample of donations

Measurement	**Initial solution**	**Policy1**	**Policy2**	**Policy3**	**Policy4**	**Policy5**
Total distance(km)	926.23	921.83	936.72	662.71	922.94	648.49
Total of blood allocated(bag)	317	342	338	330	340	342
Total transportation cost (Thai Baht)	3,704.92	3,687.32	3,746.88	2,650.64	3,691.76	2,593.96
Average transportation cost/bag	11.69	10.78	11.09	8.03	10.86	7.59
Holding cost(Baht)	0	250	40	880	60	950
Total costs (Thai Baht)	3,704.92	3,937.32	3,786.88	3,530.64	3,702.62	3,543.96
Average processing time(second)		0.05	2.13	0.46	1.37	1.04

Table 8.13 gives a comparison of the five distribution policies according to results for the variable routes, with sampled blood availability of 342 bags. Assumptions are made regarding fuel and holding costs. The fuel cost depends on the distance travelled, while the holding cost varies with the number of blood bags stored in the RBC. Policies 1, 2 and 3 are modified from the initial solution. Policy 1 is a simple approach, guaranteeing that the transportation cost is not worse than that of the initial solution. However, the total cost is the highest when compared with the other policies. In this example, excess blood received early in the week could be stored for use later in the week. However, it is possible in some instances that some hospitals do not receive any blood if amounts of blood becoming available are less than the expected value. Blood is delivered from the RBC every day with both Policies 1 and 2. However, a small number of blood bags may be left after blood assignment if blood available is more than the target blood supply (as is the case with these sampled data). The transportation cost of the Policy 2 is higher than that of the Policy 1 because more hospitals may be added to the routes. While Policy 3 gives the best solution for the RBC as it provides a low transportation and logistics cost, the holding cost is high. The latter effect results from a reduced number of days for distribution: blood is delivered only when the total blood available is greater than a certain amount. In this case study, the amount is chosen to be the average daily blood supply over the planning horizon but this could be decided otherwise by the decision maker.

Policy 4 is based on finding hospitals for which the maximum blood target supply can be satisfied by the amount of blood available. Costs are similar to those of the initial solution. Policy 5, which also provides blood to hospitals only when an amount of blood can meet its target supply, gives the lowest transportation cost per bag compared with the other policies. With this policy, the total number of routes over a planning horizon is likely to decrease and hence transportation costs would be lowered. However, the drawback of this policy is the high holding cost while collecting blood to satisfy the whole blood target supply of hospitals.

From Table 8.13, both Policies 3 and 5 can be recommended. Policy 3 gives the lowest total costs, while Policy 5 has the lowest transportation cost of all policies. Both policies have relatively high holding costs, though Policy 3 gives slightly lower holding costs than Policy 5. If holding costs per bag or transportation cost per kilometre were to change, there could be a different balance between Policies 3 or 5.

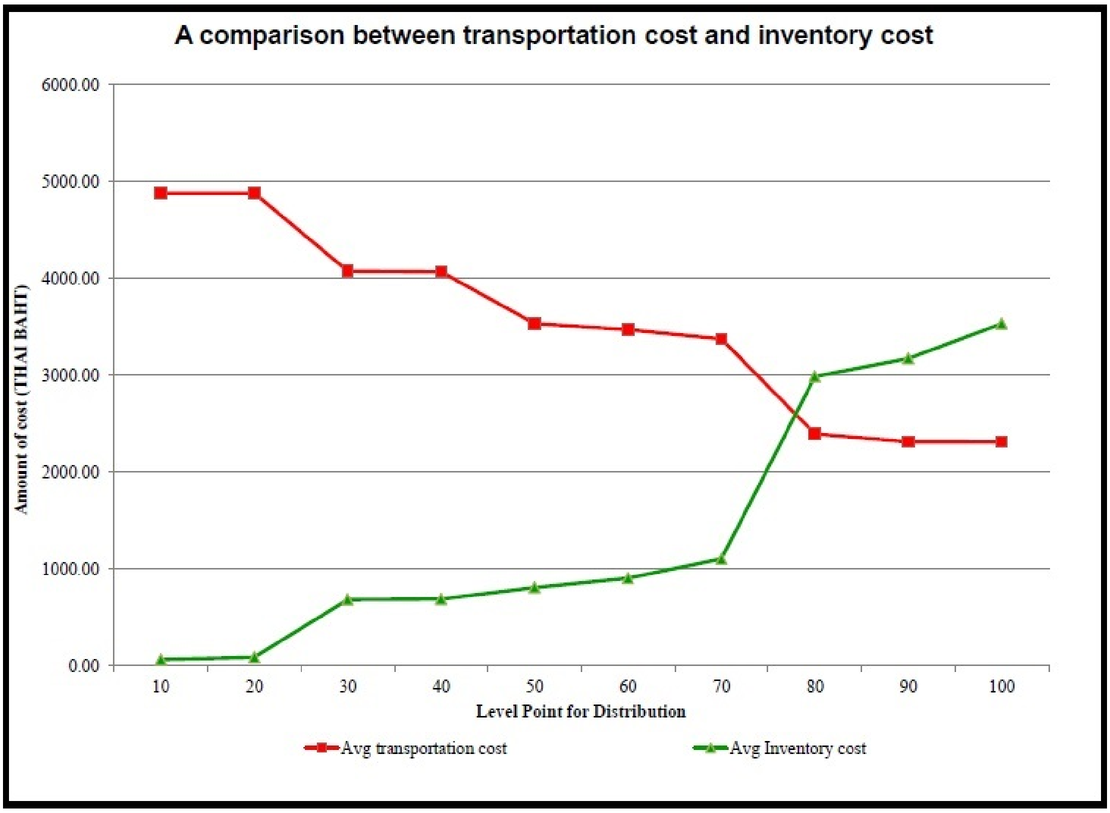

Figure 8.3: A comparison of transportation cost and inventory cost with Policy 3 by different minimum levels for blood distribution

Further experimentation was carried out of different minimum delivery levels for Policy 3. As can be seen in Figure 8.3, when the minimum level for deliveries increases, the transportation cost also generally increases, while the inventory cost decreases, as expected. Total costs are shown in Figure 8.4: the optimal point for least cost blood delivery is within the range of 50 to 60 blood bags.

Policies 3 and 5 were tested with four further sampled weeks of available blood. Results are shown in Figure 8.5. Over the four-week period, the total cost of the Policy 5 is 4,269.29 Thai Baht (Inventory cost = 1,905.00 Thai Baht and Transportation cost = 2,364.29 Thai Baht) while the total cost of Policy 3 is 3,936.53 Thai Baht (Inventory cost = 883.50 Thai Baht and Transportation cost = 3,053.03 Thai Baht). The expected total blood supply is shown as a solid red line in the upper graph of Figure 8.5, and

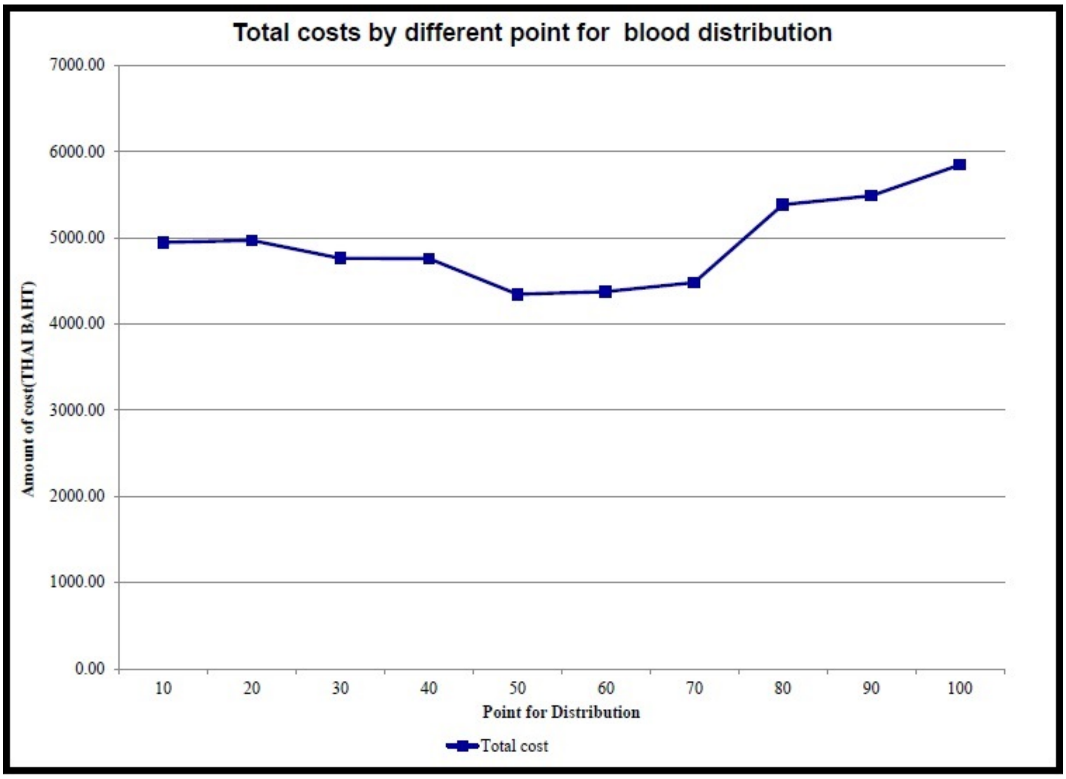

Figure 8.4: Total costs with Policy 3 by different minimum levels for blood distribution

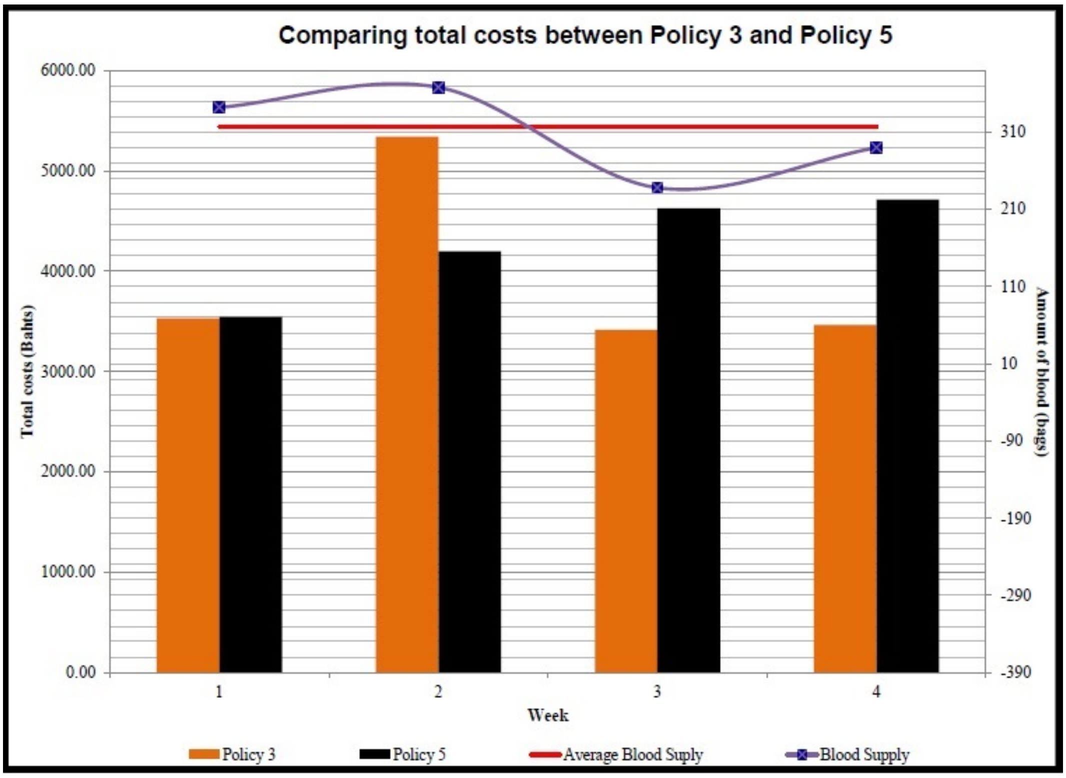

Figure 8.5: Comparing total costs between Policy 3 and 5

the wavy blue line gives the actual total amounts available for each week of the test. It can be seen that the total cost of Policy 3 is higher than that of Policy 5 in week 2. This is because, in this week, the quantities of donated blood are greater than the minimum delivery point, and so blood is delivered to hospitals each day, leading to high total transportation costs for Policy 3. Conversely, Policy 3 has lower costs than Policy 5 in weeks 3 and 4 when supplies are lower than expected.

Table 8.14: Advantages and disadvantages of the five distribution policies

Policy	**Advantage**	**Disadvantage**
1	Quick computational processing	The holding cost is increased when daily actual supply is much higher than target blood supply for hospitals in the route
	Transportation costs not worse than the initial solution	Some hospitals cannot receive blood when blood available on day is less than the expected value of blood supply
2	More hospitals can receive blood when there is an excess supply	The highest transportation cost
3	Low transportation costs with a minimum level for blood distribution	Holding cost in the RBC is comparatively high
	It is a suitable policy when the total amount of blood available in a week is less than the expected amount of blood available	Hospitals may wait for several days if shortage condition occurs
		Some low priority and distant hospitals may not receive blood when blood is in short supply
4	A hospital with a high target blood supply can be served when the amount of blood available is high	Distance from the RBC not considered when finding start node
5	The minimal number of visits to each hospital, resulting in the minimal transportation costs	The highest holding cost in the RBC
		A hospital with high target blood supply may wait for a long time to receive blood

We summarise the advantages and disadvantages of the five blood distribution policies in Table 8.14.

8.5 Summary and Conclusion

The quantity of blood available on any delivery day is dependent on the willingness of blood donors. Therefore, blood allocations and routes for blood distribution in conditions of blood shortage may need to be changed from initial plans as quantities of available blood become known. In this chapter, we have addressed this planning problem which is an integration of the vehicle routing problem and an allocation problem for blood. It is applied to a real-life case study of an RBC in Thailand. The main benefit of this study is to supply useful information to a decision maker for arrangement of blood allocation and routing, to save costs and satisfy the needs of hospitals for blood.

A unique on-line scheme has been developed for both the allocation and routing of scarce blood supplies to hospitals from the RBC. For this scheme, the proposal is made to divide hospitals into fixed and variable routes for blood deliveries, according to distance from the RBC. Five different policies for blood allocation and routing have been tested, considering target blood supplies, hospital priorities, and distances from the RBC. The three policies based on variations from an initial plan give a decision maker a flexible choice of ways to allocate blood. Policies 4 and 5 compute new blood delivery routes daily to meet target supplies: Policy 5 achieves the lowest transportation cost. Computational results on sampled data are reported: it is demonstrated that it is advantageous to deliver blood only when the total blood available is greater than a predefined level. Two policies are recommended as best for overall costs, enabling trade-offs to be made between transportation costs and holding costs.

Chapter 9

Conclusion

9.1 Summary of the research

Blood is a much-needed perishable product which is provided to hospitals for treatment and emergency needs, and the quantity of blood available on any given day is dependent on the willingness of blood donors. Moreover, it is difficult to predict exact quantities of blood that will be needed. As a result, many countries face serious blood shortages at times. Supply chain and logistics management are therefore important in improving the efficiency and effectiveness of the blood supply system.

This study has explored the problems experienced in blood supply chain and logistics by the Thai Red Cross Society (TRCS), as a case study of a developing country. We propose alternative solutions for management of the supply chain and logistics, particularly to improve supplies and also for distribution in situations of both sufficient supplies and shortages. Firstly, we consider location decisions for blood service facilities, as these locations affect both blood supplies and blood distribution. Total costs are the major constraint because investment to improve facilities by a non-profit organisation is limited. Secondly, we propose policies for vehicle routing for blood distribution, with associated allocation of blood supplies where supplies are uncertain.

We commence the study of locations for blood service facilities with analysis of the current locations of the twelve RBCs throughout the country and demonstrate efficiencies possible with re-allocation of hospitals to these sites. We then apply p-median analysis to determine optimal locations for the current number of RBCs, providing further improvements. Discussions of these results with the assistant director of the NBC met with general agreement: some recommended locations confirmed NBC thinking, while the recommendation of an RBC in the upper North region was influential in changing possible NBC plans. The classical Maximal Covering Model is also used to determine numbers of blood centres needed to serve provincial hospitals within a given time constraint.

Several novel location models are presented in this study. We develop goal programming models for both location-allocation and location-routing: test results indicate savings that could be achieved from changing the current system of hospitals collecting blood from RBCs to a supplier-managed system. Moreover, a novel integer linear programming model is proposed to identify locations for low-cost extensions to the RBC network, since the costs of developing fully-functioning RBCs are prohibitive. Construction of these donation/distribution centres can achieve blood supply improvements as well as improved transportation of blood to hospitals. Again, results confirm that the opening of a distribution centre in the upper North region would be advantageous.

Distribution is the part of the supply chain process that fulfils customer demands. In the current TRCS system, all hospitals collect blood at the RBC using their own vehicles. Furthermore, there is no regular plan for blood allocation and many hospitals may not receive the amounts of blood requested and may buy it from unauthorised sources without high-quality testing. This research designs routes for blood distribution to hospitals in the upper North region of the country. The main objectives are to arrange a schedule and routes for blood delivery over a one-week planning horizon from the RBC to all hospitals in that region. The delivery days of the RBC are potentially from Monday to Saturday, but recruitment of blood donors is open every day, including Sundays. We propose both fixed routes and variable routes with alternative policies for blood allocation and distribution. With fixed routing, schedules are defined for blood delivery to hospitals with fixed visit frequencies, while schedules for variable routes are changed based on the amount of blood available on the day.

Fixed routes are generally suited to the situation of sufficient blood supplies. We consider policies under which blood is delivered to each hospital once during the delivery week and also where different hospitals receive blood with frequencies varying according to demand and distance from the RBC. As well as six-day deliveries of blood, to reduce the total transportation cost, we also consider three-day deliveries, representing the fewest possible days on which blood collected can be delivered freshly. Furthermore, we model a policy whereby deliveries are made to hub hospitals, from which smaller hospitals can collect blood.

For six-day fixed route blood deliveries, optimising software cannot handle the problem with a large enough data set, so heuristic and meta-heuristic methods are employed to solve the problem. Hospitals are first clustered by geographical locations into six clusters, and routes are found separately for each cluster. An improved Clarke and Wright Savings algorithm is proposed, which combines the best of the Sequential and Parallel methods and adds a local search. Results are compared to routes obtained with a novel version of the GRASP algorithm, which contains supplementary randomisation. It is found that the more complex GRASP procedure gives the better solutions than the simpler improved Clarke and Wright.

For the revised policy of three-day fixed route deliveries, a comparison is again made between the improved Clarke and Wright Savings algorithm and the new GRASP algorithm. This three-day policy is seen to greatly reduce the transportation costs of the RBC. Also, a comparison is made between K-Means and Fuzzy C-Means clustering applied to cluster hospitals: K-Means clustering is found to give a better solution than the Fuzzy C-Means algorithm. Furthermore, three-day fixed route deliveries to hub hospitals are modelled. This policy is suitable where there are hospitals with low-blood usage far from the RBC that could collect blood from nearby larger hospitals. However, it is difficult to implement in practice because the hub hospitals must take responsibility for inventory costs instead of the off-tour hospitals.

The final fixed route policy explored is that of multi-frequency deliveries, which is adapted for situations of shortage of supply. Historical data are used to design visit frequencies. To allow for situations of blood shortages, blood is allocated proportionately to hospitals, according to historic amounts requested. The proposed algorithm for multi-frequency deliveries aims to ensure a fair supply to all hospitals by the proportion of blood requests in each cluster. Processing is divided into two phases: firstly, hospitals are clustered and clusters are assigned to delivery days; secondly, hospitals are assigned to delivery routes.

An online algorithm is proposed for variable blood allocation and routing, according to amounts of blood available each day: this system is suitable for situations of blood shortage. A combination of fixed and variable routes is employed, with fixed routes designed for the more distant hospitals and variable routes for those nearby. Five policies are compared for blood allocation and distribution over the planning horizon for the variable routes, according to the quantities of donated blood available each day. The different policies are compared by transportation and holding costs, using sampled daily supplies of blood. Results suggest that blood should be delivered only when the total blood available is greater than a predefined level.

9.2 Limitations of the research

There are several limitations of this research, regarding the data available, particularly regarding traffic congestion, unknown exact blood requirements of hospitals and abnormally high blood usage.

Firstly, difficulties were found in obtaining complete data on blood requests and supplies, because of a lack of organised data collection. Quantities are still recorded manually in RBCs, and therefore there may be some mistakes and incomplete data. Moreover, in the current RBC system, all paper documents are destroyed after one year, enabling only limited data collection to be made. Data on blood requests and deliveries were not available from several regions of Thailand, thus necessitating a case study in one region where there would be co-operation with this research. Furthermore, traffic congestion data is not allowed for in travelling times calculated between pairs of nodes. These data were not available for congested city areas of the provinces. However, the upper North region where the case study is set is largely rural.

Data related to blood requests may not represent the actual blood requirements of hospitals because it is known that most hospitals place orders for amounts greater than are needed in reality. An entirely fair system of blood allocation could not therefore be proposed. Moreover, this research has been designed to determine regular plans for blood delivery to hospitals in normal situations. We do not account for abnormal or high usage events, such as national festivals, where incidents may lead to high blood usage.

9.3 Further research

Several aspects of the blood supply chain could be incorporated into future research. In the current situation, blood shortage is the major problem. However, blood and the different blood products have a short shelf life and so blood outdates could be included in future studies, as could the supply chains for the different products. The complexities of modelling supplies of different blood groups could also be studied. From a practical perspective, uncertainty of blood requests from hospitals might also be included in the problem in addition to uncertainty of supplies. Another possible direction is to consider the 'cost' of allocating hospitals to one RBC only.

The modelling could be applied and extended in several other directions. An immediate possibility is to apply the algorithms for scheduled blood allocation and distribution to the other regions of the country. Moreover, these methods could be applied in other developing countries facing a similar problem. The solution methods could also be applied to deliveries of other types of perishable product in short supply, such as vaccines, drugs, or agricultural products.

Further development of the proposed modelling could be appropriate. For example, heuristics for the location of low-cost Type 1 and 2 collection and distribution facilities could be developed and used for the nationwide problem, should appropriate demand data become available from all hospitals throughout the country. AHP methods could be used to inform the goal programming modelling for blood centre location-allocation and location-routing, if expert opinion were available about nationwide sites. Heuristics could also be developed for the hub location-routing problem, for which optimal solutions could not be obtained using optimisation software.

Finally, a major challenge for a successful blood supply chain is collaboration between hospitals to provide regular data updates, for example on inventory levels. A database is a necessity for updating and sharing of data with others. Furthermore, the on-line algorithms for blood delivery can be extended to include inventory of hospitals, to support decisions on blood allocation and delivery to hospitals.

9.4 Conclusion and novel contributions

Supply chain and logistics for blood products differ from those for other perishable products. In general, blood is a scarce resource and there is uncertainty about amounts of blood that can be collected from donors. In this research, a real-life case study is used to understand the problems of the blood supply chain and to develop models and algorithms that address these problems. The contribution of this research is to introduce specific problems related to blood shortages and limited resources, and to present solution schemes. The complex problem of blood supply chain systems is decomposed into sub-problems, with the main focus of the research on two areas: firstly, decision-making for location of collection and distribution centres, and, secondly, planning of distribution routes to hospitals.

Novel mathematical models are introduced to decide firstly on locations for RBCs, which have the full functions of collection, testing and distribution. Secondly, the problem of location is considered for two kinds of low-cost facilities providing blood services by performing specific tasks in order to meet satisfaction on both the supply and demand sides.

The concept of supplier-managed distribution is applied to improve the system whereby hospitals obtain blood products. Several fixed routing problems are applied to blood deliveries, with improved heuristics proposed. The blood distribution problem under shortage and uncertain supplies is introduced in this research. The online blood distribution problem is presented with novel applicable heuristic algorithms for solving the problem under different policies. Both blood allocation and routing are considered in the algorithms. The allocation made as each day's supply is revealed depends on the allocation of blood made on previous days, and given supply targets determined in advance by a decision maker.

Finally, this research adds to the value and benefits of OR/MS research in solving real world problems in the blood supply chain and logistics area. The solution methods applied are transparent enough to provide clear understanding for non-experts in this area.

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Appendix A

Data Dictionary

A.1 Province codes

Table A.1: Data Dictionary for Provinces

Code	Description
1	Bangkok
2	Krabi
3	Kanchanaburi
4	Kalasin
5	Kamphaeng Phet
6	Khon Kaen
7	Chanthaburi
8	Chachoengsao
9	Chonburi
10	Chainat
11	Chaiyaphum
12	Chumphon
13	Chiang Rai
14	Chiang Mai
15	Trang
16	Trat
17	Tak
18	Nakhon Nayok
19	Nakhon Pathom
20	Nakhon Phanom
21	Nakhon Ratchasima
22	Nakhon Si Thammarat

Continued on next page

Table A.1: Data Dictionary for Provinces

Code	Description
23	Nakhon Sawan
24	Nonthaburi
25	Narathiwat
26	Nan
27	Buriram
28	Pathum Thani
29	Prachuap Khiri Khan
30	Prachinburi
31	Pattani
32	Phra Nakorn Si Ayutthaya
33	Phayao
34	Phang Nga
35	Phattalung
36	Phichit
37	Phisanulok
38	Phetchaburi
39	Phetchabun
40	Phrae
41	Phuket
42	Maha Sarakham
43	Mukdahan
44	Mae Hong Son
45	Yasothon
46	Yala
47	Roi Et
48	Ranong
49	Rayong
50	Ratchaburi
51	Lopburi
52	Lampang
53	Lamphun
54	Loei
55	Si Saket
56	Sakhon Nakhon
57	Songkhla

Continued on next page

Table A.1: Data Dictionary for Provinces

Code	Description
58	Satun
59	Samut Prakan
60	Samut Songkhram
61	Samut Sakhon
62	Sa Kaeo
63	Saraburi
64	Singburi
65	Sukhothai
66	Suphanburi
67	Surat Thani
68	Surin
69	Nong Khai
70	Nong Bua Lamphu
71	Ang Thong
72	Amnat Charoen
73	Udon Thani
74	Uttaradit
75	Uthai Thani
76	Ubon Ratchathani

A.2 Hospital codes

Table A.2: Data Dictionary for hospitals

Code	Name
1	Ban Hong Hospital
2	Banluang Hospital
3	Banthi Hospital
4	Central Chiangmai Memorial Hospital
5	Central Lamphun Memorial Hospital
6	Chaehom Hospital
7	Chaiprakarn Hospital
8	Chang Phuak Hospital
9	Chiang Kham Hospital
10	Chiang Klang Hospital

Continued on next page

Table A.2: Data Dictionary for hospitals

Code	Name
11	Chiang Mai Heath Promotion
12	Chiang Mai Provincial
13	Chiangdao Hospital
14	Chiangkhong Crown Prince Hospital
15	Chiangmai Klaimor Hospital
16	Chiangmai Municipal Hospital
17	Chiangmai Neurological Hospital
18	Chiangmai Ram Hospital
19	Chiangrai Prachanukroh Hospital
20	Chiangsaen Hospital
21	Children and Medical Clinic
22	Chomthong Hospital
23	Chun Hospital
24	Clinics for Kidney Diseases
25	Dara Rassami Hospital
26	Denchai Crown Prince Hospital
27	Doi Lo Hospital
28	Doi Tao Hospital
29	Doisaket Hospital
30	Dok Khamtai Hospital
31	Dr. Wong
32	Faculty of Medicine
33	Fang Hospital
34	Fort Kawila Hospital
35	Hangdong Hospital
36	Hariphunchai Memorial Hospital
37	Hod Hospital
38	Kasemrad Sriburin Hospital
39	Khai Surasak Montree Hospital
40	Khelangnakorn-Ram Hospital
41	Khun Tan Hospital
42	Khunyuam Hospital
43	Ko Kha Hospital
44	Lampang Cancer Centre
45	Lampang Hospital

Continued on next page

Table A.2: Data Dictionary for hospitals

Code	Name
46	Lamphun Hospital
47	Lanna Hospital
48	Lee Hospital
49	Long Hospital
50	Mae Ai Hospital
51	Mae Chaem Hospital
52	Mae Chai Hospital
53	Mae Charim Hospital
54	Mae Hia Hospital
55	Mae La Noi Hospital
56	Mae On Hospital
57	Mae Sai Hospital
58	Mae Taeng Hospital
59	Mae Tha Hospital
60	Maechan Hospital
61	Maelao Hospital
62	Maesariang Hospital
63	Maewang Hospital
64	Maharaj Nakorn Chiang Mai Hospital
65	McCormick Hospital
66	Mcken Hospital
67	Na Muen Hospital
68	Na Noi Hospital
69	Nakornping Hospital
70	Nan Hospital
71	Omkoi Hospital
72	Padad Hospital
73	Pai Hospital
74	Pasang Hospital
75	Phan Hospital
76	Phaya Mengrai Hospital
77	Phayao Hospital
78	Phayao Ram Hospital
79	Phrae Christain Hospital
80	Phrae Hospital

Continued on next page

Table A.2: Data Dictionary for hospitals

Code	Name
81	Phrao Hospital
82	Pong Hospital
83	Pua Crown Prince Hospital
84	Rajavej Chiang Mai Hospital
85	Rhuampath Chiangmai Hospital
86	Samoeng Hospital
87	San Kamphaeng Hospital
88	Sanpatong Hospital
89	Sansai Hospital
90	Santi Suk Hospital
91	Saraphi Hospital
92	Si Phum Hospital
93	Siamrad Chiang Mai Hospital
94	Sirivej Lamphun Hospital
95	Somdet Prayannasungworn Hospital
96	Srisangwal Hospital
97	Sung Men Hospital
98	Thawangpha Hospital
99	The Overbrook Hospital
100	Thep Panya Hospital
101	Thoeng Hospital
102	Thung Chang Hospital
103	Thung Hua Chang Hospital
104	Van Santvoord Hospital
105	Wangnua Hospital
106	Wat Chan 80th Celebrations Hospital
107	Wiang Chiang Rung Hospital
108	Wiang Kaen Hospital
109	Wiang Pa Pao Hospital
110	Wiang Sa Hospital
111	Wianghaeng Hospital
112	Wing 41 Hospital

Appendix B

Profile of provinces in Thailand

B.1 Population, area, and land prices

Table B.1: Population, Area, and land price in different provinces

Province code	Population	Area (km^2)	Average land price (BAHT per ft^2)
1	8,305,218	1,569	12,917,115.00
2	362,203	4,709	979,548.00
3	801,519	19,483	538,213.00
4	824,538	6,947	376,749.00
5	797,391	8,608	678,149.00
6	1,741,980	10,886	2,152,853.00
7	485,611	6,338	904,198.00
8	715,603	5,351	301,399.00
9	1,555,358	4,363	1,722,282.00
10	305,587	2,470	236,814.00
11	963,907	12,778	592,034.00
12	467,801	6,009	592,034.00
13	1,172,928	11,678	1,453,175.00
14	1,737,041	20,107	1,614,639.00
15	598,877	4,918	968,784.00
16	247,876	2,819	1,722,282.00
17	526,382	16,407	260,495.00
18	246,868	2,122	387,513.00
19	943,892	2,168	204,521.00
20	583,726	5,513	96,878.00
21	2,525,975	20,494	990,312.00

Continued on next page

Table B.1: Population, Area, and land price in different provinces

Province code	**Population**	**Area** (km^2)	**Average land price** (BAHT per ft^2)
22	1,450,466	9,943	1,054,898.00
23	992,749	9,598	3,582,347.00
24	1,334,083	622	2,411,195.00
25	670,002	4,475	340,151.00
26	452,814	11,472	484,392.00
27	1,274,921	10,323	559,732.00
28	1,327,147	1,526	1,506,997.00
29	467,466	6,368	452,099.00
30	546,996	4,762	365,985.00
31	609,015	1,940	387,513.00
32	870,671	2,557	172,228.00
33	417,380	6,335	861,141.00
34	258,535	4,171	1,194,833.00
35	480,976	3,425	1,076,426.00
36	548,242	4,531	409,042.00
37	912,827	10,816	430,571.00
38	472,589	6,225	430,571.00
39	940,076	12,668	107,643.00
40	427,398	6,539	172,228.00
41	525,709	543	710,441.00
42	827,639	5,292	193,757.00
43	357,339	4,340	269,107.00
44	209,153	12,681	118,407.00
45	487,976	4,162	105,490.00
46	433,167	4,521	473,628.00
47	1,084,985	8,299	904,198.00
48	249,017	3,298	1,184,069.00
49	821,072	3,552	753,498.00
50	796,748	5,197	1,291,712.00
51	769,925	6,200	1,399,354.00
52	743,143	12,534	818,084.00
53	412,741	4,506	365,985.00
54	546,028	11,425	139,935.00
55	1,055,980	8,840	538,213.00

Continued on next page

Table B.1: Population, Area, and land price in different provinces

Province code	**Population**	**Area** (km^2)	**Average land price** (BAHT per ft^2)
56	941,810	9,606	150,700.00
57	1,481,021	7,394	2,368,138.00
58	274,863	2,479	473,628.00
59	1,828,694	1,004	1,373.520.00
60	185,564	417	193,757.00
61	887,191	872	538,213.00
62	555,961	7,195	172,228.00
63	717,054	3,577	193,757.00
64	199,982	823	86,114.00
65	629,707	6,596	645,856.00
66	845,561	5,358	538,213.00
67	1,009,351	12,892	172.228.00
68	1,122,900	8,124	139,935.00
69	458,772	3,027	232,508.00
70	485,974	3,859	64,586.00
71	254,292	968	484,392.00
72	283,732	3,161	172,228.00
73	1,288,365	11,730	204,521.00
74	438,578	7,839	667,384.00
75	297,493	6,730	861,141.00
76	1,746,790	15,745	1,937,567.00

B.2 Figure: Comparison of land prices by different provinces

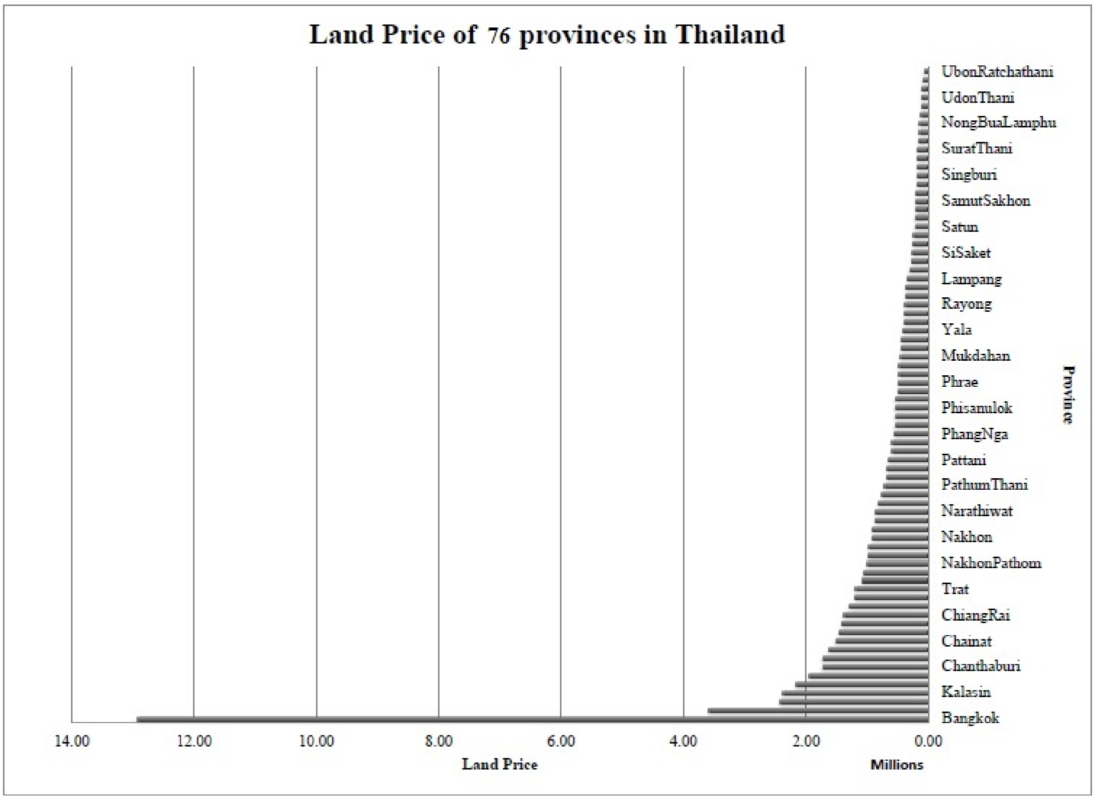

Figure B.1: Land price sorted by descending

Appendix C

Profile of twelve regional blood centres

Table C.1: Twelve Regional Blood Centres over the country

Fiscal year foundation	**Regional Blood Centre**	**Locations**	**Province served**
1996	RBC IX	Phitsanulok	(1) Nan (2) Phetchabun (3) Phichit (4) Phrae (5) Uttaradit
1996	RBC V	Nakhon Ratchasima	(1) Buriram (2) Chaiyaphum (3) Maha Sarakham (4) Surin (5) Sisaket
1996	RBC X	Chaingmai	(1) Chiangrai (2) Lampang (3) Lamphun (4) Mae Hong Son (5) Phayao
1997	RBC XI	Nakhon Si Thammarat	(1) Chumphon (2) Krabi (3) Phang Nga (4) Ranong (5) Surat Thani (6) Phatthalung (7) Trang
			(1) Nong Bua Lamphu (2) Nong Khai

Continued on next page

Table C.1: Twelve Regional Blood Centres over the country

Fiscal year foundation	**Regional Blood Centre**	**Locations**	**Province served**
1997	RBC VI	Khon Kaen	(3) Loei (4) Sakon Nakhon (5) Udon Thani
1998	RBC IV	Ratchaburi	(1) Kanchanaburi (2) Nakhon Pathom (3) Phetchaburi (4) Prachuap Khiri Khan (5) Samut Songkhram
1999	RBC III	Chonburi	(1) Chachoengsao (2) Chanthaburi (3) Prachinburii (4) Rayong (5) Sa Kaeo
2000	RBC XII	Songkhla	(1) Narathiwat (2) Pattani (3) Satun (4) Yala
2001	RBC II	Lopburi	(1) Ang Thong (2) Chainat (3) Nakhon Nayok (4) Saraburi (5) Sing Buri (6) Suphan Buri
2003	RBC VII	Ubon Ratchathani	(1) Amnat Charoen (2) Kalasin (3) Mukdahan (4) Nakhon Phanom (5) Roi Et (6) Yasothon
2004	RBC VIII	Nakhon Sawan	(1) Kamphaeng Phet (2) Sukhothai (3) Tak (4) Uthai Thani
2010	RBC XIII	Phuket	(1) Phuket

Appendix D

List of hospitals in upper North region

Table D.1: Hospitals in the upper North region of Thailand

Hospital code	Type	No. of beds	Province
1	Community	30	Lamphun
2	Community	30	Nan
3	Community	30	Lamphun
4	General Private	120	Chiang Mai
5	General Private	60	Lamphun
6	Community	60	Lampang
7	Community	30	Chiang Mai
8	General Private	101	Chiang Mai
9	General Public	232	Phayao
10	Community	30	Nan
11	Primary Care	90	Chiang Mai
12	Community	30	Chiang Mai
13	Community	30	Chiang Mai
14	Community	90	Chiang Rai
15	General Private	56	Chiang Mai
16	Community	22	Chiang Mai
17	Specialist	240	Chiang Mai
18	General Private	220	Chiang Mai
19	Regional	757	Chiang Rai
20	Community	60	Chiang Rai
21	General Private Health Centre	10	Chiang Mai

Continued on next page

Table D.1: Hospitals in the upper North region of Thailand

Hospital code	**Type**	**No. of beds**	**Province**
22	Community	90	Chiang Mai
23	Community	30	Phayao
24	Specialist	30	Chiang Mai
25	Military	30	Chiang Mai
26	Community	30	Phrae
27	Community	30	Chiang Mai
28	Community	30	Chiang Mai
29	Community	30	Chiang Mai
30	Community	30	Phayao
31	General Private	30	Chiang Mai
32	Teaching	400	Chiang Mai
33	Community	50	Chiang Rai
34	Military	90	Chiang Mai
35	Community	10	Chiang Mai
36	General Private	100	Lamphun
37	Community	30	Chiang Mai
38	Private General	120	Chiang Rai
39	Military	150	Lampang
40	General Private	103	Lampang
41	Community	30	Chiang Rai
42	Community	10	Mae Hong Son
43	Community	30	Lampang
44	Specialised	137	Lampang
45	Regional	803	Lampang
46	General Public	434	Lamphun
47	General Private	180	Chiang Mai
48	Community	60	Lamphun
49	Community	60	Phrae
50	Community	30	Chiang Rai
51	Community	30	Chiang Mai
52	Community	30	Phayao
53	Community	30	Nan
54	Community	30	Chiang Mai
55	Community	10	Mae Hong Son
56	Community	10	Chiang Mai

Continued on next page

Table D.1: Hospitals in the upper North region of Thailand

Hospital code	**Type**	**No. of beds**	**Province**
57	Community	90	Chiang Rai
58	Community	30	Chiang Mai
59	Community	30	Lamphun
60	Community	90	Chiang Rai
61	Community	10	Chiang Rai
62	Community	90	Mae Hong Son
63	Community	40	Chiang Mai
64	Teaching	2279	Chiang Mai
65	General Private	400	Chiang Mai
66	General Private	150	Chiang Mai
67	Community	30	Nan
68	Community	30	Nan
69	General Public	416	Chiang Mai
70	General Public	420	Nan
71	Community	30	Chiang Mai
72	Community	30	Chiang Rai
73	Community	60	Mae Hong Son
74	Community	60	Lamphun
75	Community	90	Chiang Rai
76	Community	30	Chiang Rai
77	General Public	360	Phayao
78	General Private	100	Phayao
79	General Private	60	Phrae
80	General Public	395	Phrae
81	Community	30	Mae Hong Son
82	Community	30	Phayao
83	Community	90	Nan
84	General Private	150	Chiang Mai
85	General Private	100	Chiang Mai
86	Community	30	Chiang Mai
87	Community	30	Chiang Mai
88	Community	60	Chiang Rai
89	Community	30	Chiang Mai
90	Community	30	Nan
91	Community	30	Chiang Mai

Continued on next page

Table D.1: Hospitals in the upper North region of Thailand

Hospital code	**Type**	**No. of beds**	**Province**
92	Community	30	Chiang Mai
93	General Private	50	Chiang Mai
94	General Private	59	Lamphun
95	Community	30	Chiang Rai
96	Community	150	Mae Hong Son
97	Community	30	Phrae
98	Community	30	Nan
99	General Private	223	Chiang Rai
100	General Private	109	Chiang Mai
101	Community	60	Chiang Rai
102	Community	30	Nan
103	Community	30	Lamphun
104	General Private	29	Lampang
105	Community	30	Lampang
106	Community	10	Chiang Mai
107	Community	30	Chiang Rai
108	Community	30	Chiang Rai
109	Community	60	Chiang Rai
110	Community	60	Nan
111	Community	30	Chiang Mai
112	Military	30	Chiang Mai

Appendix E

Results: A list of sites for the Regional Blood Centres varying the maximum service distance

Table E.1: A list of sites for the Regional Blood Centres varying the maximum service distance

Hospital code	Maximum Service Distance					
	50 km	**100 km**	**150 km**	**200 km**	**250 km**	**300 km**
1	✓	✓	✓	✓	✓	✓
2	✓			✓		
3	✓					
4	✓			✓		
5	✓	✓				
6	✓		✓		✓	✓
7	✓	✓	✓	✓		
8	✓					
9	✓	✓	✓	✓		✓
10						
11	✓	✓				
12	✓	✓	✓	✓		
13	✓	✓			✓	✓
14	✓		✓	✓	✓	✓
15	✓					
16						
17	✓					
18						

Continued on next page

Table E.1: A list of sites for the Regional Blood Centres varying the maximum service distance

Hospital code	**Maximum Service Distance**					
	50 km	**100 km**	**150 km**	**200 km**	**250 km**	**300 km**
19						
20	✓					
21	✓	✓				
22	✓	✓	✓			
23		✓				
24						
25	✓					
26	✓	✓				
27	✓		✓	✓	✓	✓
28						
29						
30	✓	✓	✓			
31						
32		✓		✓	✓	✓
33	✓		✓	✓		
34		✓				
35	✓					
36	✓					
37	✓	✓	✓	✓	✓	✓
38	✓					
39	✓	✓	✓			
40	✓					
41	✓		✓			
42		✓				
43	✓					
44						
45	✓					
46	✓	✓	✓			
47	✓					
48						
49	✓				✓	
50	✓	✓			✓	
51						
52	✓					

Continued on next page

Table E.1: A list of sites for the Regional Blood Centres varying the maximum service distance

Hospital code	Maximum Service Distance					
	50 km	**100 km**	**150 km**	**200 km**	**250 km**	**300 km**
53		✓				
54	✓	✓				
55	✓					
56	✓	✓	✓			
57	✓	✓	✓	✓	✓	✓
58						
59						
60						
61						
62	✓					
63	✓					
64						
65	✓					
66	✓					
67	✓	✓			✓	✓
68	✓	✓				
69	✓					
70	✓					
71	✓		✓			
72		✓				
73	✓	✓	✓	✓	✓	✓
74	✓	✓				
75	✓					
76	✓	✓	✓	✓	✓	✓

Appendix F

XPress Code: Location-Allocation model for new full-function RBCs

```
model GoalLAP ! Start a new model
uses "mmxprs","mmive","mmodbc","mmquad"; ! Load the optimizer library
forward procedure preemptive ! Declare some procedures that are
forward procedure archimedian ! defined later
declarations
NGOALS = 5 ! Number of goals
dev: array(1..2*NGOALS) of mpvar ! Deviation from goals
mindev: qexp ! Objective function
goal: array(1..NGOALS) of linctr ! Goal constraint

! define a user type
Myarray1 = array(RBC) OF REAL
Myarray2 = array(Hospital) OF REAL
Myarray3 = array(Node,Node) OF REAL
Myarray4 = array(Goals) OF REAL

! Set parameters
m = 3
n = 5
g = 5
RBC = 1..m
Hospital = (m+1)..(m+n)
Node = 1..m+n
Goals = 1..g
BloodCollected_RBC : Myarray1
BloodCollected_NBC : Myarray1
BloodCollected_Branch : Myarray2
Capacity_RBC : Myarray1
FixedCost : Myarray1
PreExisting : Myarray1
RiskScore : Myarray1
PolicyScore : Myarray1
CooperativeScore : Myarray1
Distance : Myarray3
Target : Myarray4

! Define a decision variable
```

```
OpenRBC : array(RBC) OF MPVAR
HospitalAllocation : array(Hospital,RBC) OF MPVAR
Over1 : array(RBC) OF MPVAR
Under1 : array(RBC) OF MPVAR
Over2 : array(RBC) OF MPVAR
Under2 : array(RBC) OF MPVAR
Over3 : array(RBC) OF MPVAR
Under3 : array(RBC) OF MPVAR
Over4 : array(Hospital) OF MPVAR
Under4 : array(Hospital) OF MPVAR
Over5 : array(RBC) OF MPVAR
Under5 : array(RBC) OF MPVAR
Constraint6: array(RBC) of qexp
end-declarations

initializations from "mmodbc.odbc:Location_Data.xlsx"
Capacity_RBC as "[Data$B1:B6]"
PreExisting as "[Data$C1:C6]"
RiskScore as "[Data$D1:D6]"
PolicyScore as "[Data$E1:E6]"
CooperativeScore as "[Data$F1:F6]"
Probability as "[Data$H1:H6]"
Capacity_Vehicle as "[Data$I1:I6]"
Target as "[Data$G1:5]"
end-initializations

initializations from "mmodbc.odbc:Demand_Data.xlsx"
Demand as 'Demand1'
end-initializations

! Decision variables must be binary
! Constraint6(j in RBC,l in Scenario).settype(CT_EQ);
! settype(Constraint6,CT_EQ)
FORALL(i in Hospital,j in RBC) HospitalAllocation(i,j) is_binary
FORALL(j in RBC) OpenRBC(j) is_binary

FORALL (i in Hospital) DO
Constraint1(i) := (SUM(j in Node) HospitalAllocation(i,j)) = 1
END-DO

Constraint2 := (SUM(j in RBC) OpenRBC(j) *  BloodCollected_RBC(j)) + Under1 = Target(1)

Constraint3 := (SUM(j in RBC)(RiskScore(j) * OpenRBC(j))) + Under2 = Target(2)

Constraint4 := (SUM(j in RBC)(PolicyScore(j) * OpenRBC(j))) + Under3 = Target(3)

Constraint5 := (SUM(j in RBC)(CooperativeScore(j) * OpenRBC(j))) + Under4(j) = Target(4)

Constraint6(j) := (SUM(j in Node) SUM(i in Hospital) HospitalAllocation(i,j) *( Distance(i,j)+Distance(j
- Over5(j) =  0

FORALL(j in RBC) DO
IF PreExisting(j)= 1 THEN
Constraint7(j) := SUM(i in Hospital) HospitalAllocation(i,j) * Demand(i) <= OpenRBC(j) * Capacity_RBC(j)
END-IF
END-DO

FORALL(j in RBC) DO
IF PreExisting(j)= 1 THEN
Constraint8(j) := OpenRBC(j) = 1
END-IF
END-DO
```

```
FORALL (i in Hospital, j in RBC) DO
Constraint9(i,j) := HospitalAllocation(j,i) - OpenRBC(j) <= 0
END-DO

FORALL (j in RBC) DO
Constraint10(j) := SUM(i in Hospital) HospitalAllocation(j,i) - OpenRBC(j) >= 0
END-DO

Constraint11 := SUM(j in RBC) FixedCost(j) * OpenRBC(j) <= Budget


! Define the goal constraints
goal(1):= (Under1) / Target(1) = 1
goal(2):= (Under2) / Target(2) = 1
goal(3):= (Under3) / Target(3) = 1
goal(4):= (Under4) / Target(4) = 1
goal(5):= (Over5) / Target(5) = 1
declarations
STypes={CT_GEQ, CT_LEQ, CT_EQ}
ATypes: array(STypes) of string
end-declarations
ATypes(CT_GEQ):= ">="; ATypes(CT_LEQ):= "<="; ATypes(CT_EQ):= "="
preemptive ! Pre-emptive goal programming
archimedian ! Archimedian goal programming
!**********************************************************************
procedure printsol
forall(g in 1..NGOALS)
if (dev(2*g).sol>0) then
writeln(" Goal(",g,") deviation from target: -", dev(2*g).sol)
elif(dev(2*g-1).sol>0) then
writeln(" Goal(",g,") deviation from target: +", dev(2*g-1).sol)
end-if
end-procedure
!**********************************************************************
procedure preemptive
writeln("Pre-emptive:")
(!
Add successively the goals to the problem and solve it, until all
goals have been added or a goal cannot be satisfied. This assumes that
the goals are given ordered by priority.
!)
! Remove (=hide) goal constraint from the problem
forall(i in 1..NGOALS) goal(i).hidden:=true
i:=0
while (i<NGOALS) do
i+=1
goal(i).hidden:=false ! Add (=unhide) the next goal
case goal(i).type of ! Add deviation variable(s)
CT_GEQ: do
deviation:= dev(2*i)
mindev += deviation
end-do
CT_LEQ: do
deviation:= -dev(2*i-1)
mindev += dev(2*i-1)
end-do
CT_EQ : do
deviation:= dev(2*i) - dev(2*i-1)
mindev += dev(2*i) + dev(2*i-1)
end-do
else
```

```
writeln("Wrong constraint type")
break
end-case
goal(i)+= deviation
minimize(mindev) ! Solve the LP-problem
FORALL (k in Vehicle) DO
writeln("Vehicle ",k)
FORALL (i1 in Node)DO
FORALL(j in Node) DO
write (getsol(Routing(i1,j,k,l)))
END-DO
writeln
END-DO
END-DO
FORALL (j in RBC) DO
writeln("RBC ",j)
FORALL(i1 in Hospital) DO
write (getsol(HospitalAllocation(i1,j,l)))
END-DO
writeln
END-DO
FORALL (j in RBC) DO
write (getsol(OpenRBC(j,l)))
END-DO
goal(i)-= deviation ! Remove deviation variable(s) from goal
if (getobjval>0) then
writeln("Cannot satisfy goal ",i)
break
end-if
end-do
! Solution printout
writeln(" Goal", strfmt("Target",12), strfmt("Value",9))
forall(g in 1..i)
writeln(strfmt(g,5), strfmt(ATypes(goal(g).type),3),
strfmt(-goal(g).coeff,9),
strfmt( goal(g).act-dev(2*g).sol+dev(2*g-1).sol ,9))
printsol
end-procedure
!*******************************************************************
procedure archimedian
writeln("\nArchimedian:")
declarations
Penalty: array(1..NGOALS) of real ! Penalties for goal constraints
end-declarations
Penalty:: [2, 2, 3, 1, 4]
mindev:=0 ! Re-initialize objective function
! Define the objective as weighted sum of the deviation variables
forall(g in 1..NGOALS) do
case goal(g).type of ! Add deviation variable(s)
CT_GEQ: do
deviation:= dev(2*g)
mindev += Penalty(g)*deviation
end-do
CT_LEQ: do
deviation:= -dev(2*g-1)
mindev += Penalty(g)*dev(2*g-1)
end-do
CT_EQ : do
deviation:= dev(2*g) - dev(2*g-1)
mindev += Penalty(g)*(dev(2*g) + dev(2*g-1))
end-do
else writeln("Wrong constraint type")
```

```
break
end-case
goal(g)+= deviation
end-do
minimize(mindev) ! Solve the LP-problem
writeln(" Solution: x: ", x.sol, ", y: ", y.sol)
! Solution printout
writeln(" Goal", strfmt("Target",12), strfmt("Value",9), strfmt("Penalty",9))
forall(g in 1..NGOALS)
writeln(strfmt(g,5), strfmt(ATypes(goal(g).type),3),
strfmt(-goal(g).coeff,9),
strfmt( goal(g).act-dev(2*g).sol+dev(2*g-1).sol ,9),
strfmt(Penalty(g),9))
printsol
end-procedure
end-model
```

Appendix G

XPress Code: Location Routing Problem model for new full-function RBCs

```
model GoalLAP                                                   ! Start a new model
uses "mmxprs","mmive","mmodbc","mmquad";   ! Load the optimizer library
forward procedure preemptive                           ! Declare some procedures that are
forward procedure archimedian                          ! defined later

 declarations
 NGOALS = 5                                                     ! Number of goals
 dev: array(1..2*NGOALS) of mpvar               ! Deviation from goals
 mindev: qexp                                                   ! Objective function
 goal: array(1..NGOALS) of linctr                       ! Goal constraint

! define a user type
  Myarray1 = array(RBC) OF REAL
  Myarray2 = array(Hospital) OF REAL
  Myarray3 = array(Node,Node) OF REAL
  Myarray4 = array(Vehicle) OF REAL
  %Myarray5 = array(Node,Vehicle) OF REAL
  Myarray5 = array(Goals) OF REAL

! Set parameters
  m = 3
  n = 5
  r =  2
  g = 5
  RBC = 1..m
  Hospital = (m+1)..(m+n)
  Vehicle = 1..r
  Node = 1..m+n
  Goals = 1..g
  BloodCollected_RBC : Myarray1
  BloodCollected_NBC : Myarray1
  BloodCollected_Branch : Myarray2
  Capacity_RBC : Myarray1
  FixedCost : Myarray1
  PreExisting : Myarray1
  RiskScore : Myarray1
  PolicyScore : Myarray1
  CooperativeScore : Myarray1
  Distance : Myarray3
  Capacity_Vehicle : Myarray4
```

```
  Target : Myarray5

! Define a decision variable
  OpenRBC : array(RBC) OF MPVAR
  HospitalAllocation : array(Hospital,RBC) OF MPVAR
  Routing : array(Node,Node,Vehicle) OF MPVAR
  AuxSubTour : array(Hospital,Vehicle) OF MPVAR
  Over1 : array(RBC) OF MPVAR
  Under1 : array(RBC) OF MPVAR
  Over2 : array(RBC) OF MPVAR
  Under2 : array(RBC) OF MPVAR
  Over3 : array(RBC) OF MPVAR
  Under3 : array(RBC) OF MPVAR
  Over4 : array(Hospital) OF MPVAR
  Under4 : array(Hospital) OF MPVAR
  Over5 : array(RBC) OF MPVAR
  Under5 : array(RBC) OF MPVAR
  Constraint6: array(RBC) of qexp
end-declarations

  initializations from "mmodbc.odbc:Location_Data.xlsx"
  Capacity_RBC as "[Data$B1:B6]"
  PreExisting as "[Data$C1:C6]"
  RiskScore as "[Data$D1:D6]"
  PolicyScore as "[Data$E1:E6]"
  CooperativeScore as "[Data$F1:F6]"
  Probability as "[Data$H1:H6]"
  Capacity_Vehicle as "[Data$I1:I6]"
  Target as "[Data$J1:5]"
  MaxDistance as "[Data$K1:1]"
end-initializations

initializations from "mmodbc.odbc:Demand_Data.xlsx"
 Demand as 'Demand1'
end-initializations

! Decision variables must be binary
! Constraint6(j in RBC,l in Scenario).settype(CT_EQ);
! settype(Constraint6,CT_EQ)

FORALL(i in Hospital,j in RBC) HospitalAllocation(i,j) is_binary
FORALL(i in Node,j in Node,k in Vehicle) Routing(i,j,k) is_binary
FORALL(j in RBC) OpenRBC(j) is_binary
FORALL(i in Hospital,k in Vehicle) AuxSubTour(i,k) is_integer

FORALL (i in Hospital) DO
    Constraint1(i) := (SUM(j in Node,k in Vehicle) Routing(i,j,k)) = 1
END-DO

FORALL (k in Vehicle) DO
    Constraint2(k) := (SUM(j in RBC, i in Hospital) Routing(j,i,k)) <= 1
END-DO

FORALL (j in RBC) DO
    Constraint3(j) := (SUM(i in Hospital,k in Vehicle) Routing(j,i,k)) <= 1
END-DO

FORALL (k in Vehicle) DO
    Constraint4(k) :=  SUM(i in Hospital) (Demand(i) * SUM(j in Node)Routing(i,j,k)) <= Capacity_Vehicle(k)
END-DO

FORALL (i in Hospital, k in Vehicle) DO
```

```
   Constraint5(i,k) := SUM(j in Node) Routing(i,j,k) - SUM(j in Node) Routing(j,i,k) = 0
END-DO

FORALL (i in Hospital,j in Hospital, k in Vehicle) DO
    Constraint6(i,j,k) := AuxSubTour(i,k) - AuxSubTour(j,k) + (n * Routing(i,j,k)) <= (n-1)
END-DO

Constraint7(i,j,k) :=
SUM(i in Hospital) SUM(j in Node) SUM(k in Vehicle) Routing(i,j,k) =
SUM(i in Hospital) SUM(j in RBC) HospitalAllocation(i,j)

FORALL (i in Hospital, j in RBC,k in Vehicle) DO
   Constraint8(i,j,k) := SUM(i1 in Node) (Routing(j,i1,k)) +
   SUM(i1 in Node)(Routing(i,i1,k)) <= 1 + HospitalAllocation(i,j)
END-DO

Constraint9 := (SUM(j in RBC) OpenRBC(j) *  BloodCollected_RBC(j)) + Under1 = Target(1)
END-DO

Constraint10 := (SUM(j in RBC)(RiskScore(j) * OpenRBC(j))) + Under2 = Target(2)

Constraint11 := (SUM(j in RBC)(PolicyScore(j) * OpenRBC(j))) + Under3 = Target(3)

Constraint12 := (SUM(j in RBC)(CooperativeScore(j) * OpenRBC(j))) + Under4(j) = Target(4)

FORALL(j in RBC) DO
   IF PreExisting(j)= 1 THEN
       Constraint13(j) := SUM(i in Hospital) HospitalAllocation(i,j) * Demand(i) <=
       OpenRBC(j) * Capacity_RBC(j)
   END-IF
END-DO

Constraint14(j) := (SUM(k in Vehicle)SUM(j in Node)SUM(i in Node) Routing(i,j,k) *  Distance(i,j,k))
- Over5 = Target(5)

FORALL (j in RBC) DO
    Constraint16(j) := SUM(i in Hospital,k in Vehicle) Routing(j,i,k) - OpenRBC(j) = 0
END-DO

FORALL (j in RBC) DO
   Constraint17(j) := PreExisting(j)- SUM(i in Hospital,k in Vehicle) Routing(j,i,k) <= 0
END-DO

Constraint18 := SUM(j in RBC) FixedCost(j) * OpenRBC(j) <= Budget

FORALL (k in Vehicle) DO
Constraint19(j) := (SUM(j in Node)SUM(i in Node) Routing(i,j,k) *  Distance(i,j,k))
<= MaxDistance
END-DO

! Define the goal constraints
  goal(1):= (Under1) / Target(1) = 1
  goal(2):= (Under2) / Target(2) = 1
  goal(3):= (Under3) / Target(3) = 1
  goal(4):= (Under4) / Target(4) = 1
  goal(5):= (Over5) / Target(5) = 1

declarations
 STypes={CT_GEQ, CT_LEQ, CT_EQ}
 ATypes: array(STypes) of string
end-declarations
```

```
 ATypes(CT_GEQ):= ">="; ATypes(CT_LEQ):= "<="; ATypes(CT_EQ):= "="

 preemptive                         ! Pre-emptive goal programming
 archimedian                        ! Archimedian goal programming

!***********************************************************************

procedure printsol
   forall(g in 1..NGOALS)
   if (dev(2*g).sol>0) then
    writeln(" Goal(",g,") deviation from target: -", dev(2*g).sol)
   elif(dev(2*g-1).sol>0) then
    writeln(" Goal(",g,") deviation from target: +", dev(2*g-1).sol)
   end-if
end-procedure

!***********************************************************************

procedure preemptive
  writeln("Pre-emptive:")
(!
  Add successively the goals to the problem and solve it, until all
  goals have been added or a goal cannot be satisfied. This assumes that
  the goals are given ordered by priority.
!)

! Remove (=hide) goal constraint from the problem
  forall(i in 1..NGOALS) goal(i).hidden:=true
  i:=0
  while (i<NGOALS) do
    i+=1
    goal(i).hidden:=false           ! Add (=unhide) the next goal
    case goal(i).type of             ! Add deviation variable(s)
     CT_GEQ: do
              deviation:= dev(2*i)
              mindev += deviation
     end-do
     CT_LEQ: do
              deviation:= -dev(2*i-1)
              mindev += dev(2*i-1)
     end-do
     CT_EQ : do
              deviation:= dev(2*i) - dev(2*i-1)
              mindev += dev(2*i) + dev(2*i-1)
     end-do
     else
             writeln("Wrong constraint type")
             break
    end-case
    goal(i)+= deviation

    minimize(mindev)                ! Solve the LP-problem
    FORALL (k in Vehicle) DO
       writeln("Vehicle ",k)
       FORALL (i1 in Node)DO
        FORALL(j in Node) DO
              write (getsol(Routing(i1,j,k,l)))
        END-DO
        writeln
       END-DO
    END-DO
```

```
    FORALL (j in RBC) DO
      writeln("RBC ",j)
      FORALL(i1 in Hospital) DO
          write (getsol(HospitalAllocation(i1,j,l)))
      END-DO
      writeln
    END-DO


    FORALL (j in RBC) DO
      write (getsol(OpenRBC(j,l)))
    END-DO

    goal(i)-= deviation             ! Remove deviation variable(s) from goal
    if (getobjval>0) then
       writeln("Cannot satisfy goal ",i)
       break
    end-if
  end-do

! Solution printout
  writeln(" Goal", strfmt("Target",12), strfmt("Value",9))
  forall(g in 1..i)
     writeln(strfmt(g,5), strfmt(ATypes(goal(g).type),3),
     strfmt(-goal(g).coeff,9),
     strfmt( goal(g).act-dev(2*g).sol+dev(2*g-1).sol ,9))
  printsol

end-procedure

!**********************************************************************

procedure archimedian

 writeln("\nArchimedian:")

 declarations
    Penalty: array(1..NGOALS) of real ! Penalties for goal constraints
 end-declarations

 Penalty:: [2, 2, 3, 1, 4]

 mindev:=0                                       ! Re-initialize objective function

! Define the objective as weighted sum of the deviation variables
  forall(g in 1..NGOALS) do
    case goal(g).type of                     ! Add deviation variable(s)
     CT_GEQ: do
             deviation:= dev(2*g)
             mindev += Penalty(g)*deviation
            end-do
     CT_LEQ: do
             deviation:= -dev(2*g-1)
             mindev += Penalty(g)*dev(2*g-1)
            end-do
     CT_EQ : do
             deviation:= dev(2*g) - dev(2*g-1)
             mindev += Penalty(g)*(dev(2*g) + dev(2*g-1))
            end-do
     else    writeln("Wrong constraint type")
            break
    end-case
```

```
    goal(g)+= deviation
  end-do

  minimize(mindev)                             ! Solve the LP-problem
  writeln(" Solution: x: ", x.sol, ", y: ", y.sol)

! Solution printout
  writeln(" Goal", strfmt("Target",12), strfmt("Value",9), strfmt("Penalty",9))
  forall(g in 1..NGOALS)
   writeln(strfmt(g,5), strfmt(ATypes(goal(g).type),3),
     strfmt(-goal(g).coeff,9),
     strfmt( goal(g).act-dev(2*g).sol+dev(2*g-1).sol ,9),
     strfmt(Penalty(g),9))
  printsol
 end-procedure
end-model
```

Appendix H

IBM ILOG CPLEX Code: Location-Allocation model for low-cost blood facilities

```
{string} Stations = ...;
{string} Station = ...;
{string} Hospitals = ...;
{string} RBCs = ...;
float Fixed1[Stations] = ...;
float Fixed2[Stations] = ...;
float Construction1[Stations] = ...;
float Construction2[Stations] = ...;
float Distance1[Stations][Hospitals] = ...;
float Distance11[Station][Hospitals] = ...;
float Distance2[RBCs][Stations] = ...;
float Distance22[RBCs][Station] = ...;
float Distance3[RBCs][Hospitals] = ...;
float Budget = ...;
int Donations[Stations] = ...;
int Donation[Station] = ...;
int Usage[Hospitals] = ...;

dvar boolean Open1[Stations];
dvar boolean Open2[Stations];
dvar int Supply1[RBCs][Stations] in 0..1;
dvar int Supply2[RBCs][Stations] in 0..1;
dvar int Supply3[RBCs][Hospitals] in 0..1;
dvar int Supply4[Stations][Hospitals] in 0..1;

dexpr float MaxDistance =
    sum(r in RBCs,s in Station)(Distance22[r][s]);
dexpr float MaxWeightDistance =
   (sum(h in Hospitals)(Usage[h] * (max(s1 in Stations: s1 != h)(Distance1[s1][h])))) -
   (sum(h in RBCs)(Usage[h] * (max(s1 in Stations: s1 != h)(Distance1[s1][h]))));
dexpr float MinWeightDistance =
   (sum(h in Hospitals)(Usage[h] * (min(s1 in Stations: s1 != h)(Distance1[s1][h])))) ;
dexpr int MaxDonor = sum(s in Station)(Donation[s]);
dexpr float TotalDistance =
   sum(r in RBCs,s in Stations)(Distance2[r][s]* Supply1[r][s] +
                              Distance2[r][s]* Supply2[r][s]);
dexpr float TotalDemandWeightDistance1 =
   sum(s1 in Stations,h in Hospitals)(Distance1[s1][h] * Usage[h] * Supply4[s1][h]);
dexpr float TotalDemandWeightDistance2 =
   sum(r in RBCs,h in Hospitals)(Distance3[r][h] * Usage[h] * Supply3[r][h]);
```

```
dexpr float TotalDonor = sum(s in Stations)(Donations[s] * (Open1[s]+ Open2[s]));

minimize

   (0) * (1/MaxDistance) * (TotalDistance)+
   (0) * (1/(98189000)) * ((TotalDemandWeightDistance1+ TotalDemandWeightDistance2)) +
   (-1)* (1/MaxDonor) * (TotalDonor);

 subject to{
  forall( h in Hospitals )
    ctEachStoreHasOneStation:
      sum(r in  RBCs) Supply3[r][h] + sum(s1 in Stations)Supply4[s1][h] == 1;

  forall(s1 in Stations,r in RBCs)
    ctUseOpenWarehouses1_1_1:
        Supply1[r][s1]  <= Open1[s1];

  forall(s1 in Stations)
    ctUseOpenWarehouses1_1:
      sum(r in RBCs)
       Supply1[r][s1] == Open1[s1];

  forall(s1 in Stations,h in Hospitals)
    ctUseOpenWarehouses1_2_1:
       Supply4[s1][h] <= Open1[s1];

  forall(s2 in Stations)
    ctUseOpenWarehouses2_1:
      sum(r in RBCs)
        Supply2[r][s2] == Open2[s2];

  forall(s2 in Stations,r in RBCs)
    ctUseOpenWarehouses2_1_5:
       Supply2[r][s2] <= Open2[s2];

   forall(s in RBCs)
   ctNotOpeninLocatonOfPreexisting1:
   Open1[s] + Open2[s] == 0;

   ctMaximumBudget:
     sum(s1 in Stations)(Open1[s1] * 13669000) +
     sum(s1 in Stations)(Open1[s1] * Fixed1[s1]) +
     sum(s1 in Stations)(Open1[s1] * Construction1[s1]) +
     sum(s2 in Stations)(Open2[s2] * 2169000) +
     sum(s2 in Stations)(Open2[s2] * Fixed2[s2]) +
     sum(s2 in Stations)(Open2[s2] * Construction2[s2]) <= Budget;

   forall(s1 in Stations )
    ctUseOpenWarehouses3_2:
        Open1[s1] + Open2[s1] <= 1;

  }

{int} Allocatedof[s1 in Stations,r in RBCs,h in Hospitals] = {Supply1[r][s1] == 1 };
{int} Storesof[s2 in Stations, r in RBCs] = {Supply2[r][s2] == 1 };
{int} Open_Station1[s1 in Stations] = {Open1[s1] == 1};
float TotalDistance_RBC_Hospital =
      sum(r in RBCs, h in Hospitals)(Distance3[r][h] * Supply3[r][h]* Usage[h]);
float TotalDistance_Donation_Hospital =
      sum(s1 in Stations, h in Hospitals) (Distance1[s1][h]* Supply4[s1][h]* Usage[h]);
float TotalDistance_Donation_RBC =
      sum(r in RBCs,s1 in Stations)(Distance2[r][s1] * Supply1[r][s1])+
```

```
      sum(r in RBCs,s2 in Stations)(Distance2[r][s2] * Supply2[r][s2]);
float TotalWeightDistanceType1 =
      sum(s1 in Stations, h in Hospitals) (Supply4[s1][h] * Distance1[s1][h] * Usage[h]);
float TotalWeightDistanceType2 =
      sum(r in RBCs, h in Hospitals)(Supply3[r][h] * Distance3[r][h] * Usage[h]);
float Total_Donor =
      sum(s1 in Stations)(Donations[s1] * Open1[s1])+
      sum(s2 in Stations)(Donations[s2] * Open2[s2]);
float Total_Distance = max(r in RBCs,s in Stations)(Distance2[r][s] );

execute DISPLAY_RESULTS{
  writeln("Open1=",Open1);
  writeln("Open2=",Open2);
  writeln("Allocation of=",Allocatedof);
  writeln("Storesof=",Storesof);
  writeln(" Sites Opened for station type 1 =",Open_Station1);
  writeln("Total distance between ",TotalDistance_RBC_Hospital);
  writeln("Total distance between ", TotalDistance_Donation_Hospital);
  writeln("Total distance between ", TotalDistance_Donation_RBC);
  writeln("Total distance weighted ", TotalWeightDistanceType1 );
  writeln("Total distance weighted", TotalWeightDistanceType2 );
  writeln("Total donor ", Total_Donor);
  writeln("Total Distance",Total_Distance);
}
```

Appendix I

Visual Basic Code: Location-Allocation model for low-cost blood facilities

```
Imports ILOG.OPL
Imports ILOG.Concert
Imports ILOG.CPLEX

Module Mulprod
 Const DATADIR As String = "../.."

 Sub Main()

  Console.BackgroundColor = ConsoleColor.Red
  Console.ForegroundColor = ConsoleColor.White
  Console.Title = "Location Allocation Problem for Blood Service Facilities"

  Dim status As Integer = 127
  Dim stationName(0 To 75) As String

  Do

   Try

     OplFactory.DebugMode = False 'Default = True

     Dim oplF As OplFactory = New OplFactory

     Dim errorHandler As OplErrorHandler = oplF.CreateOplErrorHandler()

     Dim modelSource As OplModelSource = oplF.CreateOplModelSource(DATADIR + "/LAP.mod")

     Dim settings As OplSettings = oplF.CreateOplSettings(errorHandler)

     Dim def As OplModelDefinition = oplF.CreateOplModelDefinition(modelSource, settings)

     Dim cplex As Cplex = oplF.CreateCplex()

     cplex.SetOut(Nothing)

     Dim opl As OplModel = oplF.CreateOplModel(def, cplex)

     Dim dataSource As OplDataSource = oplF.CreateOplDataSource(DATADIR + "/LAP.dat")
```

```
opl.AddDataSource(dataSource)

Dim masterDataElements As OplDataElements = opl.MakeDataElements()

Dim dblUB, dblPara As Double

Console.Out.Write("Enter the Budget for facilities: ")

dblPara = CDbl(Console.ReadLine())

masterDataElements.GetElement("Budget").AsNumMap().Set(1, dblPara)

cplex.SetOut(Nothing)

opl.AddDataSource(masterDataElements)

opl.Generate()

dblUB = masterDataElements.GetElement("Budget").AsNumMap().Get(1)

Console.Out.Write("BUDGET FOR OPENING BLOOD SERVICE FACILITY = ")

Console.Out.WriteLine(CStr(Format(dblUB, "###,###,###.##")))

stationName(0) = "Bangkok"
stationName(1) = "Krabi"
stationName(2) = "Kanchanaburi"
stationName(3) = "Kalasin"
stationName(4) = "KamphaengPhet"
stationName(5) = "KhonKaen"
stationName(6) = "Chanthaburi"
stationName(7) = "Chachoengsao"
stationName(8) = "Chonburi"
stationName(9) = "Chainat"
stationName(10) = "Chaiyaphum"
stationName(11) = "Chumphon"
stationName(12) = "ChiangRai"
stationName(13) = "ChiangMai"
stationName(14) = "Trang"
stationName(15) = "Trat"
stationName(16) = "Tak"
stationName(17) = "NakhonNayok"
stationName(18) = "NakhonPathom"
stationName(19) = "NakhonPhanom"
stationName(20) = "NakhonRatchasima"
stationName(21) = "NakhonSiThammarat"
stationName(22) = "NakhonSawan"
stationName(23) = "Nonthaburi"
stationName(24) = "Narathiwat"
stationName(25) = "Nan"
stationName(26) = "Buriram"
stationName(27) = "PathumThani"
stationName(28) = "PrachuapKhiriKhan"
stationName(29) = "Prachinburi"
stationName(30) = "Pattani"
stationName(31) = "PhraNakhonSiAyutthaya"
stationName(32) = "Phayao"
stationName(33) = "PhangNga"
stationName(34) = "Phatthalung"
stationName(35) = "Phichit"
stationName(36) = "Phitsanulok"
stationName(37) = "Phetchaburi"
```

```
stationName(38) = "Phetchabun"
stationName(39) = "Phrae"
stationName(40) = "Phuket"
stationName(41) = "MahaSarakham"
stationName(42) = "Mukdahan"
stationName(43) = "MaeHongSon"
stationName(44) = "Yasothon"
stationName(45) = "Yala"
stationName(46) = "RoiEt"
stationName(47) = "Ranong"
stationName(48) = "Rayong"
stationName(49) = "Ratchaburi"
stationName(50) = "Lopburi"
stationName(51) = "Lampang"
stationName(52) = "Lamphun"
stationName(53) = "Loei"
stationName(54) = "Sisaket"
stationName(55) = "SakonNakhon"
stationName(56) = "Songkhla"
stationName(57) = "Satun"
stationName(58) = "SamutPrakan"
stationName(59) = "SamutSongkhram"
stationName(60) = "SamutSakhon"
stationName(61) = "SaKaeo"
stationName(62) = "Saraburi"
stationName(63) = "Singburi"
stationName(64) = "Sukhothai"
stationName(65) = "Suphanburi"
stationName(66) = "SuratThani"
stationName(67) = "Surin"
stationName(68) = "NongKhai"
stationName(69) = "NongBuaLamphu"
stationName(70) = "AngThong"
stationName(71) = "AmnatCharoen"
stationName(72) = "UdonThani"
stationName(73) = "Uttaradit"
stationName(74) = "UthaiThani"
stationName(75) = "UbonRatchathani"

If (cplex.Solve()) Then

 Console.Out.WriteLine("OBJECTIVE: " + CStr(Format(opl.Cplex.ObjValue, "00.#########")))

 opl.PostProcess()

 Dim station1 As OplElement

 Dim station2 As OplElement

 station1 = opl.GetElement("Open1")

 station2 = opl.GetElement("Open2")

 Dim station1Map As IIntMap = station1.AsIntMap

 Dim station2Map As IIntMap = station2.AsIntMap

 Dim i As Integer

 Console.Out.WriteLine()

 Console.Out.WriteLine("SITES FOR OPENING FACILITY TYPE 1 (COLLECTION + DISTRIBUTION)")
```

```
For i = 0 To 75
       If (station1Map.Get(stationName(i))) = 1 Then
           Console.Out.Write(" * ")
           Select Case stationName(i)
               Case "KamphaengPhet"
                   Console.Out.WriteLine("Kamphaeng Phet")
               Case "ChiangRai"
                   Console.Out.WriteLine("Chiang Rai")
               Case "ChiangMai"
                   Console.Out.WriteLine("Chiang Mai")
               Case "NakhonNayok"
                   Console.Out.WriteLine("Nakhon Nayok")
               Case "NakhonPathom"
                   Console.Out.WriteLine("Nakhon Pathom")
               Case "NakhonPhanom"
                   Console.Out.WriteLine("Nakhon Phanom")
               Case "NakhonRatchasima"
                   Console.Out.WriteLine("Nakhon Ratchasima")
               Case "NakhonSiThammarat"
                   Console.Out.WriteLine("Nakhon Si Thammarat")
               Case "NakhonSawan"
                   Console.Out.WriteLine("Nakhon Sawan")
               Case "PrachuapKhiriKhan"
                   Console.Out.WriteLine("Prachuap Khiri Khan")
               Case "PhraNakhonSiAyutthaya"
                   Console.Out.WriteLine("Phra Nakhon Si Ayutthaya")
               Case "PhangNga"
                   Console.Out.WriteLine("Phang Nga")
               Case "MahaSarakham"
                   Console.Out.WriteLine("Maha Sarakham")
               Case "MaeHongSon"
                   Console.Out.WriteLine("Mae Hong Son")
               Case "RoiEt"
                   Console.Out.WriteLine("Roi Et")
               Case "SakonNakhon"
                   Console.Out.WriteLine("Sakon Nakhon")
               Case "SamutPrakan"
                   Console.Out.WriteLine("Samut Prakan")
               Case "SamutSongkhram"
                   Console.Out.WriteLine("Samut Songkhram")
               Case "SamutSakhon"
                   Console.Out.WriteLine("Samut Sakhon")
               Case "SaKaeo"
                   Console.Out.WriteLine("Sa Kaeo")
               Case "SuratThani"
                   Console.Out.WriteLine("Surat Thani")
               Case "NongKhai"
                   Console.Out.WriteLine("Nong Khai")
               Case "NongBuaLamphu"
                   Console.Out.WriteLine("Nong Bua Lamphu")
               Case "AngThong"
                   Console.Out.WriteLine("Ang Thong")
               Case "AmnatCharoen"
                   Console.Out.WriteLine("Amnat Charoen")
               Case "UdonThani"
                   Console.Out.WriteLine("Udon Thani")
               Case "UthaiThani"
                   Console.Out.WriteLine("Uthai Thani")
               Case "Ubon Ratchathani"
                   Console.Out.WriteLine("Ubon Ratchathani")
               Case Else
```

```
                        Console.Out.WriteLine(stationName(i))
                End Select

            End If
        Next

Console.Out.WriteLine()

Console.Out.WriteLine("SITES FOR OPENING FACILITY TYPE 2 (COLLECTION)")

        For i = 0 To 75
            If (station2Map.Get(stationName(i))) = 1 Then
                Console.Out.Write(" * ")
                'Select station1Map.Get(stationName(i))
                'strStation2(i) = station1Map.Get(stationName(i))
                Select Case stationName(i)
                    Case "KamphaengPhet"
                        Console.Out.WriteLine("Kamphaeng Phet")
                    Case "ChiangRai"
                        Console.Out.WriteLine("Chiang Rai")
                    Case "ChiangMai"
                        Console.Out.WriteLine("Chiang Mai")
                    Case "NakhonNayok"
                        Console.Out.WriteLine("Nakhon Nayok")
                    Case "NakhonPathom"
                        Console.Out.WriteLine("Nakhon Pathom")
                    Case "NakhonPhanom"
                        Console.Out.WriteLine("Nakhon Phanom")
                    Case "NakhonRatchasima"
                        Console.Out.WriteLine("Nakhon Ratchasima")
                    Case "NakhonSiThammarat"
                        Console.Out.WriteLine("Nakhon Si Thammarat")
                    Case "NakhonSawan"
                        Console.Out.WriteLine("Nakhon Sawan")
                    Case "PrachuapKhiriKhan"
                        Console.Out.WriteLine("Prachuap Khiri Khan")
                    Case "PhraNakhonSiAyutthaya"
                        Console.Out.WriteLine("Phra Nakhon Si Ayutthaya")
                    Case "PhangNga"
                        Console.Out.WriteLine("Phang Nga")
                    Case "MahaSarakham"
                        Console.Out.WriteLine("Maha Sarakham")
                    Case "MaeHongSon"
                        Console.Out.WriteLine("Mae Hong Son")
                    Case "RoiEt"
                        Console.Out.WriteLine("Roi Et")
                    Case "SakonNakhon"
                        Console.Out.WriteLine("Sakon Nakhon")
                    Case "SamutPrakan"
                        Console.Out.WriteLine("Samut Prakan")
                    Case "SamutSongkhram"
                        Console.Out.WriteLine("Samut Songkhram")
                    Case "SamutSakhon"
                        Console.Out.WriteLine("Samut Sakhon")
                    Case "SaKaeo"
                        Console.Out.WriteLine("Sa Kaeo")
                    Case "SuratThani"
                        Console.Out.WriteLine("Surat Thani")
                    Case "NongKhai"
                        Console.Out.WriteLine("Nong Khai")
                    Case "NongBuaLamphu"
                        Console.Out.WriteLine("Nong Bua Lamphu")
```

```
                                Case "AngThong"
                                    Console.Out.WriteLine("Ang Thong")
                                Case "AmnatCharoen"
                                    Console.Out.WriteLine("Amnat Charoen")
                                Case "UdonThani"
                                    Console.Out.WriteLine("Udon Thani")
                                Case "UthaiThani"
                                    Console.Out.WriteLine("Uthai Thani")
                                Case "Ubon Ratchathani"
                                    Console.Out.WriteLine("Ubon Ratchathani")
                                Case Else
                                    Console.Out.WriteLine(stationName(i))
                            End Select
                        End If
                 Next

          status = 0

     Else

          Console.Out.WriteLine("No solution!")

          status = 1

     End If

          oplF.End()

          Catch ex As ILOG.Concert.Exception

               Console.WriteLine(ex.Message)

               status = 2

   End Try

   Console.Out.WriteLine()

   Console.WriteLine("--------------------Continue--------------------")

   Loop Until MsgBox("Do you want to continue (YES/NO)", vbYesNo, "LAP") = vbNo

   Environment.ExitCode = status

   Console.WriteLine("--Press <Enter> to exit--")

   Console.ReadLine()

  End Sub

End Module
```

Appendix J

Results: Nationwide location of low-cost blood collection and distribution centres

J.1 Table: Results of locations proposed for Type 1 and Type 2 by different budgets

Table J.1: Results of a facility location model for donation rooms and distribution sites on various budgets

Maximum budget (Million BAHT)	Location selected		Amount of blood		Demand Weighted Distance	
	Type 1	Type 2	Type 1	Type 2	site - hospital	RBC - hospital
10	63	-	23,608	-	-	98,189,000
	68	-	23,656	-		
	73	-	28,748	-		
Total	3	0	76,012	0	0	98,189,000
20	32	-	22,614	-	-	98,189,000
	39	-	18,709	-		
	63	-	23,608	-		
	67	-	23,138	-		
	68	-	23,656	-		
	73	-	28,748	-		
Total	6	0	140,473	0	0	98,189,000
30	32	-	22,614	-	-	98,189,000
	39	-	18,709	-		
	40	-	12,903	-		
	55	-	18,343	-		
	56	-	16,614	-		
	63	-	23,608	-		
	67	-	23,138	-		
	68	-	23,656	-		
	73	-	28,748	-		
Total	9	0	112,791	0	0	98,189,000
40	13	-	21,131	-	-	98,189,000
	27	-	18,999	-		
	32	-	22,614	-		
	39	-	18,709	-		
	47	-	18,818	-		
	49	-	18,964	-		
	52	-	22,301	-		
	63	-	23,608	-		

Continued on next page

Table J.1: Results of a facility location model for donation rooms and distribution sites on various budgets

Maximum budget (Million BAHT)	Location selected		Amount of blood		Demand Weighted Distance	
	Type 1	Type 2	Type 1	Type 2	site - hospital	RBC - hospital
	67	-	23,138	-		
	68	-	23,656	-		
	73	-	28,748	-		
Total	11	0	240,686	0	0	98,189,000
	7	-	15,900	-		
	13	-	21,131	-		
	27	-	18,999	-		
	32	-	22,614	-		
	39	-	18,709	-		
	47	-	18,818	-		
50	49	-	18,964	-	-	98,189,000
	52	-	22,301	-		
	55	-	18,343	-		
	56	-	16,614	-		
	63	-	23,608	-		
	67	-	23,138	-		
	68	-	23,656	-		
	73	-	28,748	-		
Total	14	0	291,543	0	0	98,189,000
	4	-	14,265	-		
	7	-	15,900	-		
60	8	-	15,258	-		
	13	-	21,131	-		
	27	-	18,999	-		
	32	-	22,614	-		
	39	-	18,709	-		
	42	-	14,795	-		
	47	-	18,818	-	-	98,189,000
	49	-	18,964	-		
60	52	-	22,301	-		
	55	-	18,343	-		
	56	-	16,614	-		
	63	-	23,608	-		
	67	-	23,138	-		
	68	-	23,656	-		
	73	-	28,748	-		
Total	17	0	335,861	0	0	98,189,000
	7	13	15,900	21,131		
	8	-	15,258	-		
	27	-	18,999	-		
	32	-	22,614	-		
	39	-	18,709	-		
	42	-	14,795	-		
	47	-	18,818	-		
70	49	-	18,964	-	3,782,200	86,334,000
	52	-	22,301	-		
	55	-	18,343	-		
	56	-	16,614	-		
	63	-	23,608	-		
	67	-	23,138	-		
	68	-	23,656	-		
	73	-	28,748	-		
Total	15	1	300,465	21,131	3,782,200	86,334,000
	4	13	14,265	21,131	3,782,200	86,334,000
	7	-	15,900	-		
	8	-	15,258	-		

Continued on next page

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Table J.1: Results of a facility location model for donation rooms and distribution sites on various budgets

Maximum budget	**Location selected**		**Amount of blood**		**Demand Weighted Distance**	
(Million BAHT)	**Type 1**	**Type 2**	**Type 1**	**Type 2**	**site - hospital**	**RBC - hospital**
	27	-	18,999	-		
	32	-	22,614	-		
	39	-	18,709	-		
	40	-	12,903	-		
	42	-	14,795	-		
	47	-	18,818	-		
	49	-	18,964	-		
	52	-	22,301	-		
	55	-	18,343	-		
	56	-	16,614	-		
	63	-	23,608	-		
	67	-	23,138	-		
	68	-	23,656	-		
	69	-	13,568	-		
	73	-	28,748	-		
Total	18	1	341,201	21,131	3,782,200	86,334,000
	4	12	14,265	13,814		
	7	13	15,900	21,131		
	8	-	15,258	-		
	27	-	18,999	-		
90	32	-	22,614	-		
	39	-	18,709	-		
	42	-	14,795	-		
	47	-	18,818	-	4,930,400	78,069,000
	49	-	18,964	-		
	52	-	22,301	-		
	55	-	18,343	-		
	56	-	16,614	-		
90	63	-	23,608	-		
	67	-	23,138	-		
	68	-	23,656	-		
	73	-	28,748	-		
Total	16	2	314,730	34,945	4,930,400	78,069,000
	4	12	14,265	13,814		
	7	13	15,900	21,131		
	8	-	15,258	-		
	26	-	13,991	-		
	27	-	18,999	-		
	32	-	22,614	-		
	39	-	18,709	-		
	40	-	12,903	-		
	42	-	14,795	-		
100	47	-	18,818	-	4,930,400	78,069,000
	49	-	18,964	-		
	52	-	22,301	-		
	55	-	18,343	-		
	56	-	16,614	-		
	63	-	23,608	-		
	67	-	23,138	-		
	68	-	23,656	-		
	69	-	13,568	-		
	73	-	28,748	-		
Total	19	2	355,192	34,945	4,930,400	78,069,000

Appendix K

Results: Clustering by K-Means and Fuzzy C-Means algorithms

K.1 Table: Results of Clustering by K-Means and Fuzzy C-Means algorithms

Table K.1: Comparison of results for fixed route blood distribution of hospitals

Hospital code	**Cluster no.**	
	K-Means algorithm	**Fuzzy C-Means algorithm**
1	2	2
2	1	3
3	2	2
4	2	2
5	2	2
6	3	2
7	2	1
8	2	2
9	1	1
10	1	3
11	3	2
12	2	2
13	2	2
14	1	1
15	2	2
16	2	2
17	2	2
18	2	2
19	2	2

Continued on next page

Table K.1: Comparison of results for fixed route blood distribution of hospitals

Hospital code	Cluster no.	
	K-Means algorithm	**Fuzzy C-Means algorithm**
20	1	1
21	2	2
22	2	2
23	1	1
24	2	2
25	2	2
26	3	3
27	2	2
28	2	2
29	2	2
30	1	1
31	2	2
32	2	2
33	1	1
34	2	2
35	2	2
36	2	2
37	2	2
38	1	1
39	3	2
40	3	2
41	1	1
42	2	2
43	3	2
44	3	2
45	3	2
46	2	2
47	2	2
48	3	2
49	3	3
50	1	1
51	2	2
52	1	1
53	1	3

Continued on next page

Table K.1: Comparison of results for fixed route blood distribution of hospitals

Hospital code	**Cluster no.**	
	K-Means algorithm	**Fuzzy C-Means algorithm**
54	2	2
55	2	2
56	2	2
57	1	1
58	2	2
59	2	2
60	1	1
61	1	1
62	2	2
63	2	2
64	2	2
65	2	2
66	2	2
67	3	3
68	1	3
69	2	2
70	1	3
71	2	2
72	1	1
73	2	2
74	2	2
75	1	1
76	1	1
77	1	1
78	1	1
79	3	3
80	3	3
81	2	2
82	1	1
83	1	3
84	2	2
85	2	2
86	2	2
87	2	2

Continued on next page

Table K.1: Comparison of results for fixed route blood distribution of hospitals

Hospital code	**Cluster no.**	
	K-Means algorithm	**Fuzzy C-Means algorithm**
88	2	2
89	2	2
90	1	3
91	2	2
92	2	2
93	2	2
94	2	2
95	1	1
96	2	2
97	3	3
98	1	3
99	1	1
100	3	2
101	1	1
102	1	3
103	3	2
104	3	2
105	1	1
106	2	2
107	1	1
108	1	1
109	1	1
110	1	3
111	2	2
112	2	2

K.2 Figure: Fuzzy C-Means using MATLAB

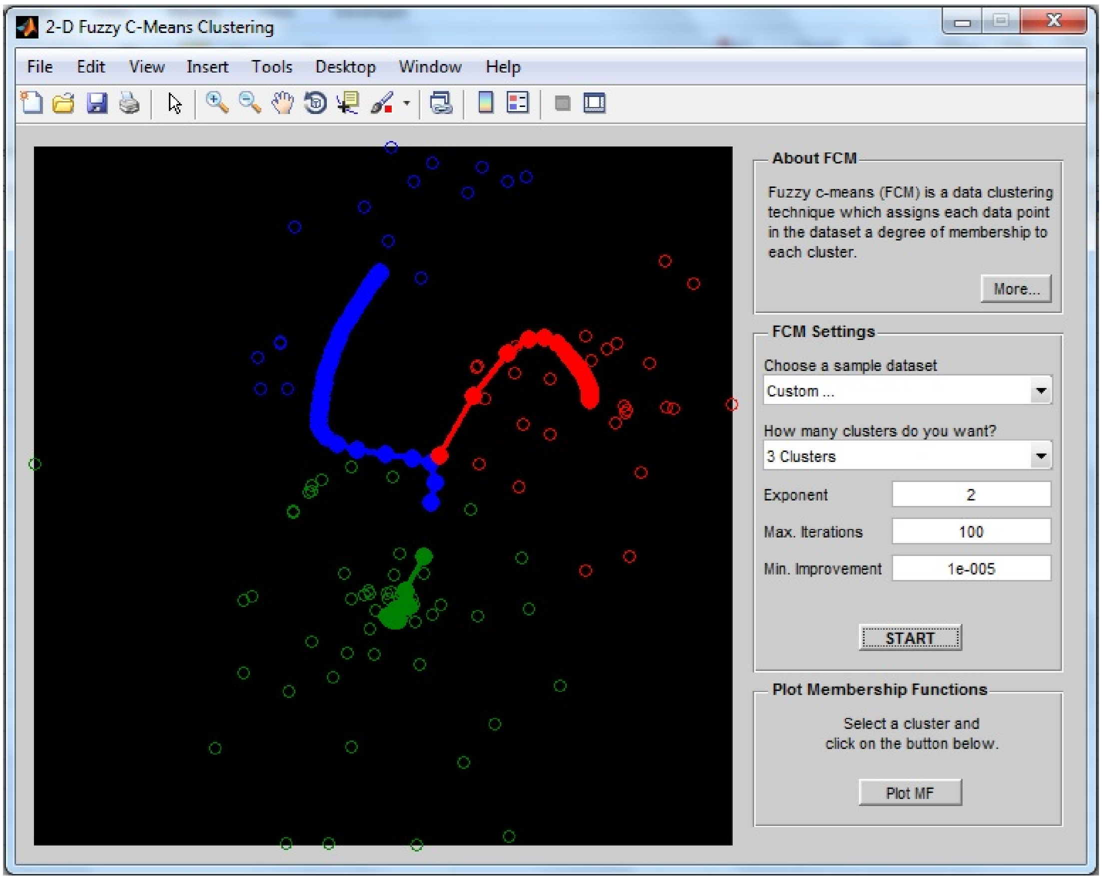

Figure K.1: Fuzzy C-Means algorithm

Appendix L

Formulation of Vehicle Routing Problem with multi-frequency blood deliveries

This problem is similar to the PVRP described in Chapter 3, Section 3.3.2. However, in this model, a pre-defined visit frequency is given, rather than use of "visit combinations" as in the PVRP.

L.1 Model assumptions

- The number of hospitals is known in advance
- The period of planning horizon is defined in advance
- Each hospital can be supplied by only one RBC and one vehicle in each day
- Each route starts and stops at the same RBC
- The capacity of each vehicle is predefined
- The total blood delivered on the route must not exceed the capacity of the vehicle
- The maximum daily operation time for the driver in each route must not exceed 8 hours
- The quantity blood demand is greater than quantity blood supply
- Blood supply available on each day is known in advance
- The visit frequency for hospitals is predefined

L.2 Notation

Paramter	Description
T	set of horizon planning days
M	set of nodes (RBC and Hospitals)
N	set of hospitals
K	set of vehicles
f_i	visit frequency assigned to hospital i in the period of time, $i \in N$
d_{ij}	distance between the i^{th} node and the j^{th} node, $i \in M, j \in M$
m	maximum travel distance in each day
q_{it}	quantity of blood targeted for hospital i on day t, $i \in N, t \in T$
Q_k	maximum capacity of the vehicle k, $k \in K$
g_t	total amount of available blood supply on day t, $t \in T$

Decision variables

Variable	**Description**
s_{ik}	= auxiliary variable for sub-tour elimination constraints in the vehicle k, $i \in N, k \in K$
x_{ijkt}	$= \begin{cases} 1, & \text{if vehicle } k \text{ visits node } i \text{ before node } j \text{ on day } t, \\ & i \in M, j \in M, k \in K, t \in T, \\ 0, & \text{otherwise.} \end{cases}$
y_{ikt}	= amount of blood allocated to hospital i and delivered by vehicle k on day t, $i \in N, k \in K, t \in T$

L.3 Model formulation

The objective function (L.1) in the model minimises the total distance for blood distribution to all hospitals in the period of time. The model formulation is as follows:
Minimise

$$\sum_{i\in M}\sum_{j\in M}\sum_{k\in K}\sum_{t\in T} d_{ij}x_{ijkt} \tag{L.1}$$

Subject to

$$\sum_{i\in M}\sum_{j\in M} d_{ij}x_{ijkt} \leq m, \quad \forall k \in K, \quad \forall t \in T, \tag{L.2}$$

$$\sum_{j\in M}\sum_{k\in K}\sum_{t\in T} x_{ijkt} \geq f_i, \quad \forall i \in N, \tag{L.3}$$

$$\sum_{j\in M}\sum_{k\in K} x_{ijkt} \leq 1, \quad \forall i \in N, \quad \forall t \in T, \tag{L.4}$$

$$\sum_{j\in M}\sum_{k\in K} x_{0jkt} \leq |K|, \quad \forall t \in T, \tag{L.5}$$

$$\sum_{j\in M}\sum_{k\in K} x_{j0kt} \leq |K|, \quad \forall t \in T, \tag{L.6}$$

$$\sum_{j\in M} x_{0jkt} = 1, \forall k \in K, \quad \forall t \in T, \tag{L.7}$$

$$\sum_{j\in M} x_{j0kt} = 1, \forall k \in K, \quad \forall t \in T, \tag{L.8}$$

$$\sum_{j\in M} x_{ijkt} - \sum_{j\in M} x_{jikt} = 0, \forall i \in M, \quad \forall k \in K, \quad \forall t \in T, \tag{L.9}$$

$$\sum_{i\in N}\sum_{k\in K} y_{ikt} \leq g_t, \quad \forall t \in T, \tag{L.10}$$

$$\sum_{k\in K} y_{ikt} = \sum_{j\in M}\sum_{k\in K} x_{ijkt} q_{it}, \forall i \in N, \quad \forall t \in T, \tag{L.11}$$

$$\sum_{i\in N} y_{ikt} \leq Q_k, \quad \forall k \in K, \quad \forall t \in T, \tag{L.12}$$

$$x_{ijkt} = 0, \quad \forall i \in M, \quad \forall j \in M, \quad \forall k \in K, \quad \forall t \in T, \quad i \neq j, \tag{L.13}$$

$$s_{ik} - s_{jk} + |N| x_{ijkt} \leq |N| - 1, \quad \forall i \in N, \quad \forall j \in N, \quad \forall k \in K, \quad \forall t \in T, \tag{L.14}$$

$$x_{ijkt} \in \{0, 1\}, \quad \forall i \in M, \quad \forall j \in M, \quad \forall k \in K, \quad \forall t \in T, \tag{L.15}$$

$$y_{ikt} \in \mathbb{I}^+, \quad \forall i \in N, \quad \forall k \in K, \quad \forall t \in T, \tag{L.16}$$

$$s_{ik} \in \mathbb{I}^+, \quad \forall i \in N, \quad \forall k \in K. \tag{L.17}$$

Since the number of hours which can be spent driving in each day is limited, Constraints (L.2) mandate that the total daily travel distance must not exceed the maximum distance corresponding to the total driving time. Constraints (L.3) determine the delivery frequency for the hospital during the period of time. Constraints (L.4) ensure that each hospital is visited no more than once per day. The number of vehicles used to deliver blood for hospitals in each day must not exceed the available vehicle numbers through Constraints (L.5) and (L.6). Constraints (L.7) and (L.8) ensure that every route must start and end at the Regional Blood Centre. Constraints (L.9) are the flow conservation constraints. Constraints (L.10) limit of the quantity of blood which can be supplied to the hospitals in each day. Constraints (L.11) are used to determine the quantity of blood allocated to each hospital. Constraints (L.12) are used to guarantee that the quantity of blood in each route must not exceed the vehicle capacity. No path between the same nodes is assigned in the route through Constraints (L.13). Constraints (L.14) are the subtour elimination constraints (Miller et al., 1960).

Appendix M

Results of Vehicle Routing Problem with multi-frequency blood deliveries

Table M.1 gives results for the VRP with multi-frequency blood deliveries. Column "Freq." gives the assigned number of visits to each hospital. Numbers of blood bags delivered each day are listed, with the total over the planning period. This total is equal to the target amount for each hospital. However, hospitals request larger amounts of blood, as shown in the final column.

Table M.1: An allocation for blood distribution

Hospital code	**Freq.**	**Mon.**	**Tue.**	**Wed.**	**Thu.**	**Fri.**	**Sat.**	**Total**	**Average weekly blood requests**
1	2	5	4	0	0	0	0	9	15
2	1	0	0	0	1	0	0	1	1
3	2	0	5	4	0	0	0	9	14
4	1	0	0	0	0	7	0	7	7
5	1	1	0	0	0	0	0	1	1
6	1	1	0	0	0	0	0	1	1
7	1	8	0	0	0	0	0	8	8
8	2	5	4	0	0	0	0	9	14
9	1	0	1	0	0	0	0	1	1
10	1	0	0	0	1	0	0	1	1
11	1	1	0	0	0	0	0	1	1
12	1	1	0	0	0	0	0	1	1
13	1	1	0	0	0	0	0	1	1
14	1	0	1	0	0	0	0	1	1
15	1	0	0	0	9	0	0	9	9
16	1	1	0	0	0	0	0	1	1
17	2	5	5	0	0	0	0	10	16
18	1	1	0	0	0	0	0	1	1
19	1	1	0	0	0	0	0	1	1
20	1	0	1	0	0	0	0	1	1
21	1	2	0	0	0	0	0	2	2
22	3	0	10	10	10	0	0	30	50
23	1	0	6	0	0	0	0	6	6
24	1	1	0	0	0	0	0	1	1
25	1	1	0	0	0	0	0	1	1
26	1	1	0	0	0	0	0	1	1

Continued on next page

Table M.1: An allocation for blood distribution

Hospital code	Freq.	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.	Total	Average weekly blood requests
27	1	10	0	0	0	0	0	10	11
28	1	0	9	0	0	0	0	9	14
29	2	0	0	4	5	0	0	9	15
30	1	0	1	0	0	0	0	1	1
31	1	1	0	0	0	0	0	1	1
32	1	1	0	0	0	0	0	1	1
33	2	15	15	0	0	0	0	30	46
34	1	2	0	0	0	0	0	2	2
35	3	0	7	0	7	7	0	21	35
36	2	5	4	0	0	0	0	9	14
37	1	0	0	0	17	0	0	17	17
38	1	0	1	0	0	0	0	1	1
39	1	5	0	0	0	0	0	5	5
40	1	8	0	0	0	0	0	8	8
41	1	0	1	0	0	0	0	1	1
42	1	0	0	1	0	0	0	1	1
43	3	5	6	0	7	0	0	18	30
44	1	1	0	0	0	0	0	1	1
45	1	1	0	0	0	0	0	1	1
46	2	4	4	0	0	0	0	8	13
47	2	4	3	0	0	0	0	7	11
48	1	7	0	0	0	0	0	7	7
49	1	1	0	0	0	0	0	1	1
50	2	7	7	0	0	0	0	14	22
51	1	0	0	0	10	0	0	10	11
52	1	0	1	0	0	0	0	1	1
53	1	0	0	0	1	0	0	1	1
54	1	1	0	0	0	0	0	1	1
55	1	0	0	4	0	0	0	4	4
56	1	0	0	0	3	0	0	3	3
57	1	0	1	0	0	0	0	1	1
58	3	0	6	6	6	0	0	18	29
59	2	4	4	0	0	0	0	8	13
60	1	0	1	0	0	0	0	1	1
61	1	3	0	0	0	0	0	3	3
62	1	0	0	6	0	0	0	6	6
63	1	0	0	0	0	12	0	12	19
64	3	0	0	8	0	16	15	39	60
65	4	0	15	15	0	16	13	59	98
66	1	1	0	0	0	0	0	1	1
67	1	0	1	0	0	0	0	1	1
68	1	0	1	0	0	0	0	1	1
69	5	0	4	6	11	34	58	113	188
70	1	0	0	0	1	0	0	1	1
71	1	9	0	0	0	0	0	9	9
72	1	0	1	0	0	0	0	1	1
73	1	0	0	9	0	0	0	9	9
74	4	10	10	10	9	0	0	39	65
75	1	0	1	0	0	0	0	1	1
76	1	0	1	0	0	0	0	1	1
77	1	0	1	0	0	0	0	1	1
78	1	0	1	0	0	0	0	1	1

Continued on next page

Table M.1: An allocation for blood distribution

Hospital code	Freq.	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.	Total	Average weekly blood requests
79	1	1	0	0	0	0	0	1	1
80	1	8	0	0	0	0	0	8	8
81	3	7	7	7	0	0	0	21	34
82	1	1	0	0	0	0	0	1	1
83	1	2	0	0	0	0	0	2	3
84	2	0	4	0	4	0	0	8	13
85	1	1	0	0	0	0	0	1	1
86	1	7	0	0	0	0	0	7	7
87	1	0	3	0	0	0	0	3	3
88	4	0	14	14	14	15	0	57	92
89	1	0	0	0	13	0	0	13	13
90	1	1	0	0	0	0	0	1	1
91	5	10	1	14	12	25	0	62	105
92	1	1	0	0	0	0	0	1	1
93	1	1	0	0	0	0	0	1	1
94	1	0	0	2	0	0	0	2	2
95	1	0	1	0	0	0	0	1	1
96	1	0	0	2	0	0	0	2	2
97	1	1	0	0	0	0	0	1	1
98	1	0	0	0	1	0	0	1	1
99	1	0	1	0	0	0	0	1	1
100	1	7	0	0	0	0	0	7	7
101	1	0	1	0	0	0	0	1	1
102	1	0	0	0	1	0	0	1	1
103	1	3	0	0	0	0	0	3	3
104	1	1	0	0	0	0	0	1	1
105	1	1	0	0	0	0	0	1	1
106	1	1	0	0	0	0	0	1	1
107	1	0	1	0	0	0	0	1	1
108	1	0	1	0	0	0	0	1	1
109	2	4	0	4	0	0	0	8	12
110	1	0	1	0	0	0	0	1	1
111	1	0	0	6	0	0	0	6	6
112	1	1	0	0	0	0	0	1	1
Total		200	179	132	143	132	86	872	1,276

Appendix N

Results: Online variable routes

N.1 Schedule plan for blood distribution

N.1.1 Fixed routes

Cluster 1

Table N.1: Amount of blood distributed to hospitals in cluster 1

Hospital name	Type	Distance (km)	Request	Target supply
Ban Hong Hospital	Community(30 beds)	126.33	3	3
Chomthong Hospital	Community(90 beds)	120.21	17	15
Doi Tao Hospital	Community(30 beds)	184.25	6	5
Hod Hospital	Community(30 beds)	149.98	3	3
Lee Hospital	Community(60 bed)	183.85	3	3
Mae Chaem Hospital	Community(30 beds)	178.18	5	5
Mae La Noi Hospital	Community(10 beds)	281.22	3	3
Maesariang Hospital	Community(90 beds)	251.60	6	5
Omkoi Hospital	Community(30 beds)	237.11	4	3
Thung Hua Chang Hospital	Community(30 beds)	162.05	2	2
Total			52	47

Cluster 2

Table N.2: Amount of blood distributed to hospitals in cluster 2

Hospital name	Type	Distance (km)	Request	Target supply
Chiang Kham Hospital	Public	163.69	28	28
Chiangkhong Crown Prince Hospital	Community(90 beds)	217.56	1	1
Chiangsaen Hospital	Community(60 beds)	143.73	5	5
Chun Hospital	Community(30 beds)	124.53	3	3
Dok Khamtai Hospital	Community(30 beds)	106.75	2	2
Fang Hospital	Community(90 beds)	130.69	18	15
Kasemrad Sriburin Hospital	Private	121.14	14	14
Khun Tan Hospital	Community(30 beds)	160.50	2	2
Mae Ai Hospital	Community(30 beds)	136.35	4	4
Mae Chai Hospital	Community(30 beds)	106.47	1	1
Mae Sai Hospital	Community(90 beds)	182.68	6	5
Maechan Hospital	Community(90 beds)	148.39	7	5
Maelao Hospital	Community(10 beds)	113.09	1	1
Padad Hospital	Community(30 beds)	131.05	2	2

Continued on next page

Table N.2: Amount of blood distributed to hospitals in cluster 2

Hospital name	**Type**	**Distance (km)**	**Request**	**Target supply**
Phan Hospital	Community(90 beds)	122.51	7	5
Phaya Mengrai Hospital	Community(30 beds)	160.09	2	2
Phayao Hospital	Public	97.36	40	25
Phayao Ram Hospital	Private	85.74	4	4
Pong Hospital	Community(30 beds)	97.47	1	1
Somdet Prayannasungworn Hospital	Community(30 beds)	125.11	2	2
The Overbrook Hospital	Private	122.84	20	20
Thoeng Hospital	Community(30 beds)	165.05	1	1
Wiang Chiang Rung Hospital	Community(30 beds)	150.96	1	1
Wiang Kaen Hospital	Community(30 beds)	225.50	1	1
Total			173	150

Cluster 3

Table N.3: Amount of blood distributed to hospitals in cluster 3

Hospital name	**Type**	**Distance (km)**	**Request**	**Target supply**
Central Lamphun Memorial Hospital	Private	80.23	1	1
Chaehom Hospital	Community(60 beds)	84.97	4	3
Chiangmai Klaimor Hospital	Private	78.19	1	1
Dara Rassami Hospital	Military	73.64	1	1
Doi Lo Hospital	Community(30 beds)	106.98	6	3
Hariphunchai Memorial Hospital	Private	81.53	6	6
Lamphun Hospital	Public	92.78	50	30
Mae Tha Hospital	Community(30 beds)	103.57	1	1
Maewang Hospital	Community(30 beds)	97.69	3	2
Pasang Hospital	Community(60 beds)	80.38	7	5
Rhuampath Chiangmai Hospital	Private	72.19	3	3
Samoeng Hospital	Community(30 beds)	106.67	2	2
Sanpatong Hospital	Community(60 beds)	87.13	16	15
Sansai Hospital	Community(30 beds)	71.03	2	2
Saraphi Hospital	Community(30 beds)	70.19	32	25
Sirivej Lamphun Hospital	Private	84.34	2	2
Total			137	105

Cluster 4

Table N.4: Amount of blood distributed to hospitals in cluster 4

Hospital name	**Type**	**Distance (km)**	**Request**	**Target supply**
Chaiprakarn Hospital	Community(30 beds)	127.93	1	1
Chiangdao Hospital	Community(30 beds)	120.98	1	1
Khunyuam Hospital	Community(30 beds)	276.65	2	2
Mae Taeng Hospital	Community(30 beds)	95.23	13	10
Pai Hospital	Community(60 beds)	182.15	4	4
Phrao Hospital	Community(30 beds)	84.58	12	10
Srisangwal Hospital	Public	289.28	10	10
Wat Chan 80^{th} Celebrations Hospital	Community(10 beds)	194.74	1	1
Wianghaeng Hospital	Community(30 beds)	177.46	2	2
Total			46	41

Cluster 5

Table N.5: Amount of blood distributed to hospitals in cluster 5

Hospital name	Type	Distance (km)	Request	Target supply
Chiang Mai Heath Promotion Hospital	Community(90 beds)	111.22	1	1
Denchai Crown Prince Hospital	Community(30 beds)	216.20	2	2
Khai Surasak Montree Hospital	Military	138.67	1	1
Khelangnakorn-Ram Hospital	Private	138.10	3	3
Ko Kha Hospital	Community(30 beds)	144.25	11	10
Lampang Cancer Centrel	Others	139.06	8	5
Lampang Hospital	Public	142.50	115	80
Long Hospital	Community(60 beds)	216.74	1	1
Phrae Christain Hospital	Private	208.17	1	1
Phrae Hospital	Public	207.73	82	40
Sung Men Hospital	Community(30 beds)	223.64	2	2
Thep Panya Hospital	Private	326.25	3	3
Van Santvoord Hospital	Private	136.35	1	1
Total			79	61

Cluster 6

Table N.6: Amount of blood distributed to hospitals in cluster 6

Hospital name	Type	Distance (km)	Request	Target supply
Banluang Hospital	Community(30 beds)	173.58	1	1
Chiang Klang Hospital	Community(30 beds)	257.31	1	1
Mae Charim Hospital	Community(30 beds)	258.00	1	1
Na Muen Hospital	Community(30 beds)	270.34	2	1
Na Noi Hospital	Community(30 beds)	243.89	2	1
Nan Hospital	Public	233.53	48	30
Pua Crown Prince Hospital	Community(90 beds)	276.01	15	15
Santi Suk Hospital	Community(30 beds)	251.97	2	2
Thawangpha Hospital	Community(30 beds)	255.89	1	1
Thung Chang Hospital	Community(30 beds)	268.30	1	1
Wiang Sa Hospital	Community(60 beds)	240.39	5	5
Total			79	61

N.1.2 Initial plan for variable routes

Table N.7: Initial Plan of the dynamic route

Hospital name	Target supply	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Banthi Hospital	3	0	0	0	0	3	0
Central Chiangmai Memorial Hospital	3	0	0	0	0	0	3
Chang Phuak Hospital	4	0	0	0	4	0	0
Chiang Mai Provincial	1	0	0	0	0	0	1
Chiangmai Municipal Hospital	1	0	0	0	1	0	0
Chiangmai Neurological Hospital	1	0	1	0	0	0	0
Chiangmai Ram Hospital	4	0	0	4	0	0	0
Chiangrai Prachanukroh Hospital	82	0	0	0	0	81	1
Children Hospital and Medical Clinic	2	0	0	0	2	0	0
Clinics for Kidney Diseases	1	0	0	0	0	0	1
Doisaket Hospital	4	0	0	0	0	0	4
Dr. Wong Hospital	1	0	0	0	0	0	1

Continued on next page

Table N.7: Initial Plan of the dynamic route

Hospital name	Target supply	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Faculty of Medicine, ChiangMai	1	0	0	0	0	0	1
Fort Kawila Hospital	1	0	0	0	0	0	1
Hangdong Hospital	4	4	0	0	0	0	0
Lanna Hospital	16	0	0	0	16	0	0
Mae Hia Hospital	1	0	0	0	1	0	0
Mae On Hospital	2	0	0	0	0	0	2
Maharaj Nakorn Chiang Mai Hospital	107	44	28	23	12	0	0
McCormick Hospital	19	0	0	0	19	0	0
Mcken Hospital	1	0	0	0	0	1	0
Nakornping Hospital	49	0	0	0	24	0	25
Rajavej Chiang Mai Hospital	1	0	0	0	1	0	0
San Kamphaeng Hospital	2	0	0	0	0	0	2
Si Phum Hospital	1	0	0	0	1	0	0
Siamrad Chiang Mai Hospital	1	0	0	0	1	0	0
Wangnua Hospital	1	0	0	0	0	0	1
Wiang Pa Pao Hospital	2	0	0	0	0	0	2
Wing 41 Hospital	1	1	0	0	0	0	0
Total	317	49	29	27	82	85	45

N.2 Online schedule for blood distribution

N.2.1 Rescheduled Plan on Monday

N.2.1.1 Policy 1

Table N.8: Monday Plan of the dynamic route based on Policy 1

Hospital name	Target supply	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Banthi Hospital	3	0	0	0	3	0	0
Central Chiangmai Memorial Hospital	3	0	0	0	0	3	0
Chang Phuak Hospital	4	0	0	4	0	0	0
Chiang Mai Provincial	1	0	0	0	0	0	1
Chiangmai Municipal Hospital	1	0	0	0	0	1	0
Chiangmai Neurological Hospital	1	0	0	1	0	0	0
Chiangmai Ram Hospital	4	0	0	4	0	0	0
Chiangrai Prachanukroh Hospital	82	0	0	0	78	4	0
Children Hospital and Medical Clinic	2	0	0	2	0	0	0
Clinics for Kidney Diseases	1	0	0	0	0	1	0
Doisaket Hospital	4	0	0	0	0	4	0
Dr. Wong Hospital	1	0	0	0	0	1	0
Faculty of Medicine, ChiangMai	1	0	0	0	0	0	1
Fort Kawila Hospital	1	0	0	0	0	1	0
Hangdong Hospital	4	4	0	0	0	0	0
Lanna Hospital	16	0	0	16	0	0	0
Mae Hia Hospital	1	0	0	1	0	0	0
Mae On Hospital	2	0	0	0	0	2	0
Maharaj Nakorn Chiang Mai Hospital	107	84	23	0	0	0	0
McCormick Hospital	19	0	0	3	0	16	0
Mcken Hospital	1	0	0	0	1	0	0
Nakornping Hospital	49	0	0	0	0	49	0
Rajavej Chiang Mai Hospital	1	0	0	0	0	1	0
San Kamphaeng Hospital	2	0	0	0	0	2	0
Si Phum Hospital	1	0	0	1	0	0	0
Siamrad Chiang Mai Hospital	1	0	0	1	0	0	0
Wangnua Hospital	1	0	0	0	0	0	1
Wiang Pa Pao Hospital	2	0	0	0	0	0	2

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Table N.8: Monday Plan of the dynamic route based on Policy 1

Hospital name	Target supply	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Wing 41 Hospital	1	1	0	0	0	0	0
Total	317	89	0	56	82	85	5

N.2.1.2 Policy 2

Table N.9: Monday Plan of the dynamic route based on Policy 2

Hospital name	Target supply	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Banthi Hospital	3	3	0	0	0	0	0
Central Chiangmai Memorial Hospital	3	0	0	0	3	0	0
Chang Phuak Hospital	4	4	0	0	0	0	0
Chiang Mai Provincial	1	0	0	0	0	0	1
Chiangmai Municipal Hospital	1	0	0	0	1	0	0
Chiangmai Neurological Hospital	1	1	0	0	0	0	0
Chiangmai Ram Hospital	4	4	0	0	0	0	0
Chiangrai Prachanukroh Hospital	82	24	0	0	7	51	0
Children Hospital and Medical Clinic	2	2	0	0	0	0	0
Clinics for Kidney Diseases	1	0	0	0	0	1	0
Doisaket Hospital	4	0	0	0	0	4	0
Dr. Wong Hospital	1	0	0	0	1	0	0
Faculty of Medicine, ChiangMai	1	0	0	0	0	0	1
Fort Kawila Hospital	1	0	0	0	1	0	0
Hangdong Hospital	4	4	0	0	0	0	0
Lanna Hospital	16	0	0	0	16	0	0
Mae Hia Hospital	1	0	1	0	0	0	0
Mae On Hospital	2	0	0	0	0	2	0
Maharaj Nakorn Chiang Mai Hospital	107	44	28	23	12	0	0
McCormick Hospital	19	0	0	4	15	0	0
Mcken Hospital	1	1	0	0	0	0	0
Nakornping Hospital	49	0	0	0	24	25	0
Rajavej Chiang Mai Hospital	1	0	0	0	1	0	0
San Kamphaeng Hospital	2	0	0	0	0	2	0
Si Phum Hospital	1	0	0	0	1	0	0
Siamrad Chiang Mai Hospital	1	1	0	0	0	0	0
Wangnua Hospital	1	0	0	0	0	0	1
Wiang Pa Pao Hospital	2	0	0	0	0	0	2
Wing 41 Hospital	1	1	0	0	0	0	0
Total	317	89	29	27	82	85	5

N.2.1.3 Policy 3

Table N.10: Monday Plan of the dynamic route based on Policy 3

Hospital name	Target supply	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Banthi Hospital	3	3	0	0	0	0	0
Central Chiangmai Memorial Hospital	3	0	0	3	0	0	0
Chang Phuak Hospital	4	0	0	4	0	0	0
Chiang Mai Provincial	1	0	0	0	1	0	0
Chiangmai Municipal Hospital	1	0	1	0	0	0	0
Chiangmai Neurological Hospital	1	1	0	0	0	0	0
Chiangmai Ram Hospital	4	0	4	0	0	0	0
Chiangrai Prachanukroh Hospital	82	82	0	0	0	0	0
Children Hospital and Medical Clinic	2	0	2	0	0	0	0
Clinics for Kidney Diseases	1	0	0	0	1	0	0
Doisaket Hospital	4	0	0	0	4	0	0

Continued on next page

Table N.10: Monday Plan of the dynamic route based on Policy 3

Hospital name	Target supply	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Dr. Wong Hospital	1	0	0	0	1	0	0
Faculty of Medicine, ChiangMai	1	0	0	0	1	0	0
Fort Kawila Hospital	1	0	0	0	1	0	0
Hangdong Hospital	4	0	0	4	0	0	0
Lanna Hospital	16	0	0	16	0	0	0
Mae Hia Hospital	1	0	1	0	0	0	0
Mae On Hospital	2	0	0	0	2	0	0
Maharaj Nakorn Chiang Mai Hospital	107	0	0	0	17	85	28
McCormick Hospital	19	0	19	0	0	0	0
Mcken Hospital	1	1	0	0	0	0	0
Nakornping Hospital	49	0	0	0	49	0	0
Rajavej Chiang Mai Hospital	1	0	1	0	0	0	0
San Kamphaeng Hospital	2	0	0	0	2	0	0
Si Phum Hospital	1	0	1	0	0	0	0
Siamrad Chiang Mai Hospital	1	1	0	0	0	0	0
Wangnua Hospital	1	0	0	0	1	0	0
Wiang Pa Pao Hospital	2	0	0	0	2	0	0
Wing 41 Hospital	1	1	0	0	0	0	0
Total	317	89	29	27	82	85	28

N.2.1.4 Policy 4

Table N.11: Monday Plan of the dynamic route based on Policy 4

Hospital name	Target supply	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Banthi Hospital	3	0	0	0	0	3	0
Central Chiangmai Memorial Hospital	3	0	0	0	0	0	4
Chang Phuak Hospital	4	0	0	0	5	0	0
Chiang Mai Provincial	1	0	0	0	0	0	1
Chiangmai Municipal Hospital	1	0	0	0	1	0	0
Chiangmai Neurological Hospital	1	0	1	0	0	0	0
Chiangmai Ram Hospital	4	0	0	5	0	0	0
Chiangrai Prachanukroh Hospital	82	0	0	0	0	81	7
Children Hospital and Medical Clinic	2	0	0	0	2	0	0
Clinics for Kidney Diseases	1	0	0	0	0	0	1
Doisaket Hospital	4	0	0	0	0	0	4
Dr. Wong Hospital	1	0	0	0	0	0	1
Faculty of Medicine, ChiangMai	1	0	0	0	0	0	1
Fort Kawila Hospital	1	0	0	0	0	0	1
Hangdong Hospital	4	4	0	0	0	0	0
Lanna Hospital	16	0	0	0	19	0	0
Mae Hia Hospital	1	0	0	0	1	0	0
Mae On Hospital	2	0	0	0	0	0	2
Maharaj Nakorn Chiang Mai Hospital	107	84	28	18	0	0	0
McCormick Hospital	19	0	0	0	23	0	0
Mcken Hospital	1	0	0	0	0	1	0
Nakornping Hospital	49	0	0	0	31	0	18
Rajavej Chiang Mai Hospital	1	0	0	0	1	0	0
San Kamphaeng Hospital	2	0	0	0	0	0	3
Si Phum Hospital	1	0	0	0	1	0	0
Siamrad Chiang Mai Hospital	1	0	0	0	1	0	0
Wangnua Hospital	1	0	0	0	0	0	1
Wiang Pa Pao Hospital	2	0	0	0	0	0	2
Wing 41 Hospital	1	1	0	0	0	0	0
Total	317	89	29	23	86	85	45

N.2.1.5 Policy 5

Table N.12: Monday Plan of the dynamic route based on Policy 5

Hospital name	Target supply	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Banthi Hospital	3	3	0	0	0	0	0
Central Chiangmai Memorial Hospital	3	3	0	0	0	0	0
Chang Phuak Hospital	4	5	0	0	0	0	0
Chiang Mai Provincial	1	1	0	0	0	0	0
Chiangmai Municipal Hospital	1	1	0	0	0	0	0
Chiangmai Neurological Hospital	1	1	0	0	0	0	0
Chiangmai Ram Hospital	4	5	0	0	0	0	0
Chiangrai Prachanukroh Hospital	82	0	0	0	89	0	0
Children Hospital and Medical Clinic	2	2	0	0	0	0	0
Clinics for Kidney Diseases	1	1	0	0	0	0	0
Doisaket Hospital	4	4	0	0	0	0	0
Dr. Wong Hospital	1	1	0	0	0	0	0
Faculty of Medicine, ChiangMai	1	1	0	0	0	0	0
Fort Kawila Hospital	1	1	0	0	0	0	0
Hangdong Hospital	4	4	0	0	0	0	0
Lanna Hospital	16	19	0	0	0	0	0
Mae Hia Hospital	1	1	0	0	0	0	0
Mae On Hospital	2	2	0	0	0	0	0
Maharaj Nakorn Chiang Mai Hospital	107	0	0	0	0	0	130
McCormick Hospital	19	23	0	0	0	0	0
Mcken Hospital	1	1	0	0	0	0	0
Nakornping Hospital	49	0	0	49	0	0	0
Rajavej Chiang Mai Hospital	1	1	0	0	0	0	0
San Kamphaeng Hospital	2	2	0	0	0	0	0
Si Phum Hospital	1	1	0	0	0	0	0
Siamrad Chiang Mai Hospital	1	1	0	0	0	0	0
Wangnua Hospital	1	1	0	0	0	0	0
Wiang Pa Pao Hospital	2	2	0	0	0	0	0
Wing 41 Hospital	1	1	0	0	0	0	0
Total	317	89	0	49	89	0	130

N.2.2 Rescheduled Plan on Tuesday

N.2.2.1 Policy 1

Table N.13: Tuesday Plan of the dynamic route based on Policy 1

Hospital name	Target supply	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Banthi Hospital	3	0	0	0	3	0	0
Central Chiangmai Memorial Hospital	3	0	0	0	0	3	0
Chang Phuak Hospital	4	0	0	4	0	0	0
Chiang Mai Provincial	1	0	0	0	0	1	0
Chiangmai Municipal Hospital	1	0	0	0	0	1	0
Chiangmai Neurological Hospital	1	0	0	1	0	0	0
Chiangmai Ram Hospital	4	0	0	4	0	0	0
Chiangrai Prachanukroh Hospital	82	0	0	0	78	4	0
Children Hospital and Medical Clinic	2	0	0	2	0	0	0
Clinics for Kidney Diseases	1	0	0	0	0	1	0
Doisaket Hospital	4	0	0	0	0	4	0
Dr. Wong Hospital	1	0	0	0	0	1	0
Faculty of Medicine, ChiangMai	1	0	0	0	0	1	0
Fort Kawila Hospital	1	0	0	0	0	1	0
Hangdong Hospital	4	4	0	0	0	0	0

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Table N.13: Tuesday Plan of the dynamic route based on Policy 1

Hospital name	Target supply	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Lanna Hospital	16	0	0	16	0	0	0
Mae Hia Hospital	1	0	0	1	0	0	0
Mae On Hospital	2	0	0	0	0	2	0
Maharaj Nakorn Chiang Mai Hospital	107	84	23	0	0	0	0
McCormick Hospital	19	0	0	10	0	9	0
Mcken Hospital	1	0	0	0	1	0	0
Nakornping Hospital	49	0	0	0	0	51	0
Rajavej Chiang Mai Hospital	1	0	0	0	0	1	0
San Kamphaeng Hospital	2	0	0	0	0	2	0
Si Phum Hospital	1	0	0	1	0	0	0
Siamrad Chiang Mai Hospital	1	0	0	1	0	0	0
Wangnua Hospital	1	0	0	0	0	1	0
Wiang Pa Pao Hospital	2	0	0	0	0	2	0
Wing 41 Hospital	1	1	0	0	0	0	0
Total	317	89	0	63	82	85	0

N.2.2.2 Policy 2

Table N.14: Tuesday Plan of the dynamic route based on Policy 2

Hospital name	Target supply	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Banthi Hospital	3	3	0	0	0	0	0
Central Chiangmai Memorial Hospital	3	0	0	0	3	0	0
Chang Phuak Hospital	4	4	0	0	0	0	0
Chiang Mai Provincial	1	0	0	0	0	1	0
Chiangmai Municipal Hospital	1	0	0	0	1	0	0
Chiangmai Neurological Hospital	1	1	0	0	0	0	0
Chiangmai Ram Hospital	4	4	0	0	0	0	0
Chiangrai Prachanukroh Hospital	82	24	0	0	7	53	0
Children Hospital and Medical Clinic	2	2	0	0	0	0	0
Clinics for Kidney Diseases	1	0	0	0	0	1	0
Doisaket Hospital	4	0	0	0	2	2	0
Dr. Wong Hospital	1	0	0	0	1	0	0
Faculty of Medicine, ChiangMai	1	0	0	0	0	1	0
Fort Kawila Hospital	1	0	0	0	1	0	0
Hangdong Hospital	4	4	0	0	0	0	0
Lanna Hospital	16	0	0	0	16	0	0
Mae Hia Hospital	1	0	1	0	0	0	0
Mae On Hospital	2	0	0	0	2	0	0
Maharaj Nakorn Chiang Mai Hospital	107	44	28	23	12	0	0
McCormick Hospital	19	0	7	4	8	0	0
Mcken Hospital	1	1	0	0	0	0	0
Nakornping Hospital	49	0	0	0	24	25	0
Rajavej Chiang Mai Hospital	1	0	0	0	1	0	0
San Kamphaeng Hospital	2	0	0	0	2	0	0
Si Phum Hospital	1	0	0	0	1	0	0
Siamrad Chiang Mai Hospital	1	1	0	0	0	0	0
Wangnua Hospital	1	0	0	0	0	1	0
Wiang Pa Pao Hospital	2	0	0	0	0	2	0
Wing 41 Hospital	1	1	0	0	0	0	0
Total	317	89	36	27	82	85	0

N.2.2.3 Policy 3

Table N.15: Tuesday Plan of the dynamic route based on Policy 3

Hospital name	Target supply	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Banthi Hospital	3	3	0	0	0	0	0
Central Chiangmai Memorial Hospital	3	0	3	0	0	0	0
Chang Phuak Hospital	4	0	4	0	0	0	0
Chiang Mai Provincial	1	0	0	0	1	0	0
Chiangmai Municipal Hospital	1	0	1	0	0	0	0
Chiangmai Neurological Hospital	1	1	0	0	0	0	0
Chiangmai Ram Hospital	4	0	4	0	0	0	0
Chiangrai Prachanukroh Hospital	82	82	0	0	0	0	0
Children Hospital and Medical Clinic	2	0	2	0	0	0	0
Clinics for Kidney Diseases	1	0	0	1	0	0	0
Doisaket Hospital	4	0	0	0	4	0	0
Dr. Wong Hospital	1	0	0	1	0	0	0
Faculty of Medicine, ChiangMai	1	0	0	0	1	0	0
Fort Kawila Hospital	1	0	0	1	0	0	0
Hangdong Hospital	4	0	0	4	0	0	0
Lanna Hospital	16	0	0	16	0	0	0
Mae Hia Hospital	1	0	1	0	0	0	0
Mae On Hospital	2	0	0	2	0	0	0
Maharaj Nakorn Chiang Mai Hospital	107	0	0	0	24	85	21
McCormick Hospital	19	0	19	0	0	0	0
Mcken Hospital	1	1	0	0	0	0	0
Nakornping Hospital	49	0	0	0	49	0	0
Rajavej Chiang Mai Hospital	1	0	1	0	0	0	0
San Kamphaeng Hospital	2	0	0	2	0	0	0
Si Phum Hospital	1	0	1	0	0	0	0
Siamrad Chiang Mai Hospital	1	1	0	0	0	0	0
Wangnua Hospital	1	0	0	0	1	0	0
Wiang Pa Pao Hospital	2	0	0	0	2	0	0
Wing 41 Hospital	1	1	0	0	0	0	0
Total	317	89	36	27	82	85	21

N.2.2.4 Policy 4

Table N.16: Tuesday Plan of the dynamic route based on Policy 4

Hospital name	Target supply	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Banthi Hospital	3	0	0	0	0	3	0
Central Chiangmai Memorial Hospital	3	0	0	0	0	0	4
Chang Phuak Hospital	4	0	0	0	5	0	0
Chiang Mai Provincial	1	0	0	0	0	0	1
Chiangmai Municipal Hospital	1	0	0	0	1	0	0
Chiangmai Neurological Hospital	1	0	1	0	0	0	0
Chiangmai Ram Hospital	4	0	0	5	0	0	0
Chiangrai Prachanukroh Hospital	82	0	0	0	0	81	14
Children Hospital and Medical Clinic	2	0	0	0	2	0	0
Clinics for Kidney Diseases	1	0	0	0	0	0	1
Doisaket Hospital	4	0	0	0	0	0	4
Dr. Wong Hospital	1	0	0	0	0	0	1
Faculty of Medicine, ChiangMai	1	0	0	0	0	0	1
Fort Kawila Hospital	1	0	0	0	0	0	1
Hangdong Hospital	4	4	0	0	0	0	0
Lanna Hospital	16	0	0	0	19	0	0
Mae Hia Hospital	1	0	0	0	1	0	0

Continued on next page

Table N.16: Tuesday Plan of the dynamic route based on Policy 4

Hospital name	Target supply	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Mae On Hospital	2	0	0	0	0	0	2
Maharaj Nakorn Chiang Mai Hospital	107	84	35	11	0	0	0
McCormick Hospital	19	0	0	0	23	0	0
Mcken Hospital	1	0	0	0	0	1	0
Nakornping Hospital	49	0	0	0	39	0	10
Rajavej Chiang Mai Hospital	1	0	0	0	1	0	0
San Kamphaeng Hospital	2	0	0	0	0	0	3
Si Phum Hospital	1	0	0	0	1	0	0
Siamrad Chiang Mai Hospital	1	0	0	0	1	0	0
Wangnua Hospital	1	0	0	0	0	0	1
Wiang Pa Pao Hospital	2	0	0	0	0	0	2
Wing 41 Hospital	1	1	0	0	0	0	0
Total	317	89	36	16	93	85	45

N.2.2.5 Policy 5

Table N.17: Tuesday Plan of the dynamic route based on Policy 5

Hospital name	Target supply	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Banthi Hospital	3	3	0	0	0	0	0
Central Chiangmai Memorial Hospital	3	3	0	0	0	0	0
Chang Phuak Hospital	4	5	0	0	0	0	0
Chiang Mai Provincial	1	1	0	0	0	0	0
Chiangmai Municipal Hospital	1	1	0	0	0	0	0
Chiangmai Neurological Hospital	1	1	0	0	0	0	0
Chiangmai Ram Hospital	4	5	0	0	0	0	0
Chiangrai Prachanukroh Hospital	82	0	0	0	96	0	0
Children Hospital and Medical Clinic	2	2	0	0	0	0	0
Clinics for Kidney Diseases	1	1	0	0	0	0	0
Doisaket Hospital	4	4	0	0	0	0	0
Dr. Wong Hospital	1	1	0	0	0	0	0
Faculty of Medicine, ChiangMai	1	1	0	0	0	0	0
Fort Kawila Hospital	1	1	0	0	0	0	0
Hangdong Hospital	4	4	0	0	0	0	0
Lanna Hospital	16	19	0	0	0	0	0
Mae Hia Hospital	1	1	0	0	0	0	0
Mae On Hospital	2	2	0	0	0	0	0
Maharaj Nakorn Chiang Mai Hospital	107	0	0	0	0	0	130
McCormick Hospital	19	23	0	0	0	0	0
Mcken Hospital	1	1	0	0	0	0	0
Nakornping Hospital	49	0	0	49	0	0	0
Rajavej Chiang Mai Hospital	1	1	0	0	0	0	0
San Kamphaeng Hospital	2	2	0	0	0	0	0
Si Phum Hospital	1	1	0	0	0	0	0
Siamrad Chiang Mai Hospital	1	1	0	0	0	0	0
Wangnua Hospital	1	1	0	0	0	0	0
Wiang Pa Pao Hospital	2	2	0	0	0	0	0
Wing 41 Hospital	1	1	0	0	0	0	0
Total	317	89	0	49	96	0	130

N.2.3 Rescheduled Plan on Wednesday

N.2.3.1 Policy 1

Table N.18: Wednesday Plan of the dynamic route based on Policy 1

Hospital name	Target supply	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Banthi Hospital	3	0	0	0	3	0	0
Central Chiangmai Memorial Hospital	3	0	0	0	0	4	0
Chang Phuak Hospital	4	0	0	4	0	0	0
Chiang Mai Provincial	1	0	0	0	0	1	0
Chiangmai Municipal Hospital	1	0	0	1	0	0	0
Chiangmai Neurological Hospital	1	0	0	1	0	0	0
Chiangmai Ram Hospital	4	0	0	4	0	0	0
Chiangrai Prachanukroh Hospital	82	0	0	0	78	13	0
Children Hospital and Medical Clinic	2	0	0	2	0	0	0
Clinics for Kidney Diseases	1	0	0	0	0	1	0
Doisaket Hospital	4	0	0	0	0	4	0
Dr. Wong Hospital	1	0	0	0	0	1	0
Faculty of Medicine, ChiangMai	1	0	0	0	0	1	0
Fort Kawila Hospital	1	0	0	0	0	1	0
Hangdong Hospital	4	4	0	0	0	0	0
Lanna Hospital	16	0	0	16	0	0	0
Mae Hia Hospital	1	0	0	1	0	0	0
Mae On Hospital	2	0	0	0	0	2	0
Maharaj Nakorn Chiang Mai Hospital	107	84	0	23	0	0	0
McCormick Hospital	19	0	0	19	0	0	0
Mcken Hospital	1	0	0	0	1	0	0
Nakornping Hospital	49	0	0	3	0	52	0
Rajavej Chiang Mai Hospital	1	0	0	1	0	0	0
San Kamphaeng Hospital	2	0	0	0	0	2	0
Si Phum Hospital	1	0	0	1	0	0	0
Siamrad Chiang Mai Hospital	1	0	0	1	0	0	0
Wangnua Hospital	1	0	0	0	0	1	0
Wiang Pa Pao Hospital	2	0	0	0	0	2	0
Wing 41 Hospital	1	1	0	0	0	0	0
Total	317	89	0	77	82	85	0

N.2.3.2 Policy 2

Table N.19: Wednesday Plan of the dynamic route based on Policy 2

Hospital name	Target supply	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Banthi Hospital	3	3	0	0	0	0	0
Central Chiangmai Memorial Hospital	3	0	0	0	3	0	0
Chang Phuak Hospital	4	4	0	0	0	0	0
Chiang Mai Provincial	1	0	0	0	1	0	0
Chiangmai Municipal Hospital	1	0	0	1	0	0	0
Chiangmai Neurological Hospital	1	1	0	0	0	0	0
Chiangmai Ram Hospital	4	4	0	0	0	0	0
Chiangrai Prachanukroh Hospital	82	24	0	0	7	67	0
Children Hospital and Medical Clinic	2	2	0	0	0	0	0
Clinics for Kidney Diseases	1	0	0	0	1	0	0
Doisaket Hospital	4	0	0	0	4	0	0
Dr. Wong Hospital	1	0	0	0	1	0	0
Faculty of Medicine, ChiangMai	1	0	0	0	1	0	0
Fort Kawila Hospital	1	0	0	0	1	0	0
Hangdong Hospital	4	4	0	0	0	0	0
Lanna Hospital	16	0	0	0	16	0	0

Continued on next page

Table N.19: Wednesday Plan of the dynamic route based on Policy 2

Hospital name	**Target supply**	**Mon.**	**Tue.**	**Wed.**	**Thu.**	**Fri.**	**Sat.**
Mae Hia Hospital	1	0	1	0	0	0	0
Mae On Hospital	2	0	0	0	2	0	0
Maharaj Nakorn Chiang Mai Hospital	107	44	28	23	12	0	0
McCormick Hospital	19	0	7	4	8	0	0
Mcken Hospital	1	1	0	0	0	0	0
Nakornping Hospital	49	0	0	11	20	18	0
Rajavej Chiang Mai Hospital	1	0	0	1	0	0	0
San Kamphaeng Hospital	2	0	0	0	2	0	0
Si Phum Hospital	1	0	0	1	0	0	0
Siamrad Chiang Mai Hospital	1	1	0	0	0	0	0
Wangnua Hospital	1	0	0	0	1	0	0
Wiang Pa Pao Hospital	2	0	0	0	2	0	0
Wing 41 Hospital	1	1	0	0	0	0	0
Total	317	89	36	41	82	69	0

N.2.3.3 Policy 3

Table N.20: Wednesday Plan of the dynamic route based on Policy 3

Hospital name	**Target supply**	**Mon.**	**Tue.**	**Wed.**	**Thu.**	**Fri.**	**Sat.**
Banthi Hospital	3	3	0	0	0	0	0
Central Chiangmai Memorial Hospital	3	0	3	0	0	0	0
Chang Phuak Hospital	4	0	4	0	0	0	0
Chiang Mai Provincial	1	0	0	1	0	0	0
Chiangmai Municipal Hospital	1	0	1	0	0	0	0
Chiangmai Neurological Hospital	1	1	0	0	0	0	0
Chiangmai Ram Hospital	4	0	4	0	0	0	0
Chiangrai Prachanukroh Hospital	82	82	0	0	0	0	0
Children Hospital and Medical Clinic	2	0	2	0	0	0	0
Clinics for Kidney Diseases	1	0	0	1	0	0	0
Doisaket Hospital	4	0	0	4	0	0	0
Dr. Wong Hospital	1	0	0	1	0	0	0
Faculty of Medicine, ChiangMai	1	0	0	1	0	0	0
Fort Kawila Hospital	1	0	0	1	0	0	0
Hangdong Hospital	4	0	0	4	0	0	0
Lanna Hospital	16	0	0	16	0	0	0
Mae Hia Hospital	1	0	1	0	0	0	0
Mae On Hospital	2	0	0	2	0	0	0
Maharaj Nakorn Chiang Mai Hospital	107	0	0	0	38	85	7
McCormick Hospital	19	0	19	0	0	0	0
Mcken Hospital	1	1	0	0	0	0	0
Nakornping Hospital	49	0	0	0	49	0	0
Rajavej Chiang Mai Hospital	1	0	1	0	0	0	0
San Kamphaeng Hospital	2	0	0	2	0	0	0
Si Phum Hospital	1	0	1	0	0	0	0
Siamrad Chiang Mai Hospital	1	1	0	0	0	0	0
Wangnua Hospital	1	0	0	1	0	0	0
Wiang Pa Pao Hospital	2	0	0	2	0	0	0
Wing 41 Hospital	1	1	0	0	0	0	0
Total	317	89	36	36	82	85	12

N.2.3.4 Policy 4

Table N.21: Wednesday Plan of the dynamic route based on Policy 4

Hospital name	Target supply	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Banthi Hospital	3	0	0	0	0	3	0
Central Chiangmai Memorial Hospital	3	0	0	0	0	0	4
Chang Phuak Hospital	4	0	0	0	5	0	0
Chiang Mai Provincial	1	0	0	0	0	0	1
Chiangmai Municipal Hospital	1	0	0	0	1	0	0
Chiangmai Neurological Hospital	1	0	1	0	0	0	0
Chiangmai Ram Hospital	4	0	0	5	0	0	0
Chiangrai Prachanukroh Hospital	82	0	0	0	0	85	15
Children Hospital and Medical Clinic	2	0	0	0	2	0	0
Clinics for Kidney Diseases	1	0	0	0	0	0	1
Doisaket Hospital	4	0	0	0	0	0	4
Dr. Wong Hospital	1	0	0	0	0	0	1
Faculty of Medicine, ChiangMai	1	0	0	0	0	0	1
Fort Kawila Hospital	1	0	0	0	0	0	1
Hangdong Hospital	4	4	0	0	0	0	0
Lanna Hospital	16	0	0	0	19	0	0
Mae Hia Hospital	1	0	0	0	1	0	0
Mae On Hospital	2	0	0	0	0	0	2
Maharaj Nakorn Chiang Mai Hospital	107	84	35	11	0	0	0
McCormick Hospital	19	0	0	0	23	0	0
Mcken Hospital	1	0	0	0	0	1	0
Nakornping Hospital	49	0	0	0	49	0	9
Rajavej Chiang Mai Hospital	1	0	0	0	1	0	0
San Kamphaeng Hospital	2	0	0	0	0	0	3
Si Phum Hospital	1	0	0	0	1	0	0
Siamrad Chiang Mai Hospital	1	0	0	0	1	0	0
Wangnua Hospital	1	0	0	0	0	0	1
Wiang Pa Pao Hospital	2	0	0	0	0	0	2
Wing 41 Hospital	1	1	0	0	0	0	0
Total	317	89	36	16	103	89	45

N.2.3.5 Policy 5

Table N.22: Wednesday Plan of the dynamic route based on Policy 5

Hospital name	Target supply	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Banthi Hospital	3	3	0	0	0	0	0
Central Chiangmai Memorial Hospital	3	3	0	0	0	0	0
Chang Phuak Hospital	4	5	0	0	0	0	0
Chiang Mai Provincial	1	1	0	0	0	0	0
Chiangmai Municipal Hospital	1	1	0	0	0	0	0
Chiangmai Neurological Hospital	1	1	0	0	0	0	0
Chiangmai Ram Hospital	4	5	0	0	0	0	0
Chiangrai Prachanukroh Hospital	82	0	0	0	100	0	0
Children Hospital and Medical Clinic	2	2	0	0	0	0	0
Clinics for Kidney Diseases	1	1	0	0	0	0	0
Doisaket Hospital	4	4	0	0	0	0	0
Dr. Wong Hospital	1	1	0	0	0	0	0
Faculty of Medicine, ChiangMai	1	1	0	0	0	0	0
Fort Kawila Hospital	1	1	0	0	0	0	0
Hangdong Hospital	4	4	0	0	0	0	0
Lanna Hospital	16	19	0	0	0	0	0
Mae Hia Hospital	1	1	0	0	0	0	0

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Table N.22: Wednesday Plan of the dynamic route based on Policy 5

Hospital name	Target supply	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Mae On Hospital	2	2	0	0	0	0	0
Maharaj Nakorn Chiang Mai Hospital	107	0	0	0	0	0	130
McCormick Hospital	19	23	0	0	0	0	0
Mcken Hospital	1	1	0	0	0	0	0
Nakornping Hospital	49	0	0	59	0	0	0
Rajavej Chiang Mai Hospital	1	1	0	0	0	0	0
San Kamphaeng Hospital	2	2	0	0	0	0	0
Si Phum Hospital	1	1	0	0	0	0	0
Siamrad Chiang Mai Hospital	1	1	0	0	0	0	0
Wangnua Hospital	1	1	0	0	0	0	0
Wiang Pa Pao Hospital	2	2	0	0	0	0	0
Wing 41 Hospital	1	1	0	0	0	0	0
Total	317	89	0	59	100	0	130

N.2.4 Rescheduled Plan on Thursday

N.2.4.1 Policy 1

Table N.23: Thursday Plan of the dynamic route based on Policy 1

Hospital name	Target supply	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Banthi Hospital	3	0	0	0	0	3	0
Central Chiangmai Memorial Hospital	3	0	0	0	0	3	0
Chang Phuak Hospital	4	0	0	4	0	0	0
Chiang Mai Provincial	1	0	0	0	0	0	1
Chiangmai Municipal Hospital	1	0	0	1	0	0	0
Chiangmai Neurological Hospital	1	0	0	1	0	0	0
Chiangmai Ram Hospital	4	0	0	4	0	0	0
Chiangrai Prachanukroh Hospital	82	0	0	0	0	82	0
Children Hospital and Medical Clinic	2	0	0	2	0	0	0
Clinics for Kidney Diseases	1	0	0	0	0	0	1
Doisaket Hospital	4	0	0	0	0	0	4
Dr. Wong Hospital	1	0	0	0	0	0	1
Faculty of Medicine, ChiangMai	1	0	0	0	0	0	1
Fort Kawila Hospital	1	0	0	0	0	0	1
Hangdong Hospital	4	4	0	0	0	0	0
Lanna Hospital	16	0	0	16	0	0	0
Mae Hia Hospital	1	0	0	1	0	0	0
Mae On Hospital	2	0	0	0	0	0	2
Maharaj Nakorn Chiang Mai Hospital	107	84	0	23	0	0	0
McCormick Hospital	19	0	0	19	0	0	0
Mcken Hospital	1	0	0	0	0	1	0
Nakornping Hospital	49	0	0	3	0	36	21
Rajavej Chiang Mai Hospital	1	0	0	1	0	0	0
San Kamphaeng Hospital	2	0	0	0	0	0	2
Si Phum Hospital	1	0	0	1	0	0	0
Siamrad Chiang Mai Hospital	1	0	0	1	0	0	0
Wangnua Hospital	1	0	0	0	0	0	1
Wiang Pa Pao Hospital	2	0	0	0	0	0	2
Wing 41 Hospital	1	1	0	0	0	0	0
Total	317	89	0	77	0	125	36

N.2.4.2 Policy 2

Table N.24: Thursday Plan of the dynamic route based on Policy 2

Hospital name	Target supply	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Banthi Hospital	3	3	0	0	0	0	0
Central Chiangmai Memorial Hospital	3	0	0	0	3	0	0
Chang Phuak Hospital	4	4	0	0	0	0	0
Chiang Mai Provincial	1	0	0	0	0	0	1
Chiangmai Municipal Hospital	1	0	0	1	0	0	0
Chiangmai Neurological Hospital	1	1	0	0	0	0	0
Chiangmai Ram Hospital	4	4	0	0	0	0	0
Chiangrai Prachanukroh Hospital	82	24	0	0	0	58	0
Children Hospital and Medical Clinic	2	2	0	0	0	0	0
Clinics for Kidney Diseases	1	0	0	0	0	0	1
Doisaket Hospital	4	0	0	0	0	0	4
Dr. Wong Hospital	1	0	0	0	0	0	1
Faculty of Medicine, ChiangMai	1	0	0	0	0	0	1
Fort Kawila Hospital	1	0	0	0	0	0	1
Hangdong Hospital	4	4	0	0	0	0	0
Lanna Hospital	16	0	0	0	6	0	13
Mae Hia Hospital	1	0	1	0	0	0	0
Mae On Hospital	2	0	0	0	0	0	2
Maharaj Nakorn Chiang Mai Hospital	107	44	28	23	12	0	0
McCormick Hospital	19	0	7	4	8	0	0
Mcken Hospital	1	1	0	0	0	0	0
Nakornping Hospital	49	0	0	11	11	27	0
Rajavej Chiang Mai Hospital	1	0	0	1	0	0	0
San Kamphaeng Hospital	2	0	0	0	0	0	2
Si Phum Hospital	1	0	0	1	0	0	0
Siamrad Chiang Mai Hospital	1	1	0	0	0	0	0
Wangnua Hospital	1	0	0	0	0	0	1
Wiang Pa Pao Hospital	2	0	0	0	0	0	2
Wing 41 Hospital	1	1	0	0	0	0	0
Total	317	89	36	41	40	85	29

N.2.4.3 Policy 3

Table N.25: Thursday Plan of the dynamic route based on Policy 3

Hospital name	Target supply	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Banthi Hospital	3	3	0	0	0	0	0
Central Chiangmai Memorial Hospital	3	0	3	0	0	0	0
Chang Phuak Hospital	4	0	4	0	0	0	0
Chiang Mai Provincial	1	0	0	1	0	0	0
Chiangmai Municipal Hospital	1	0	1	0	0	0	0
Chiangmai Neurological Hospital	1	1	0	0	0	0	0
Chiangmai Ram Hospital	4	0	4	0	0	0	0
Chiangrai Prachanukroh Hospital	82	82	0	0	0	0	0
Children Hospital and Medical Clinic	2	0	2	0	0	0	0
Clinics for Kidney Diseases	1	0	0	1	0	0	0
Doisaket Hospital	4	0	0	4	0	0	0
Dr. Wong Hospital	1	0	0	1	0	0	0
Faculty of Medicine, ChiangMai	1	0	0	1	0	0	0
Fort Kawila Hospital	1	0	0	1	0	0	0
Hangdong Hospital	4	0	0	4	0	0	0
Lanna Hospital	16	0	0	16	0	0	0
Mae Hia Hospital	1	0	1	0	0	0	0

Continued on next page

Table N.25: Thursday Plan of the dynamic route based on Policy 3

Hospital name	**Target supply**	**Mon.**	**Tue.**	**Wed.**	**Thu.**	**Fri.**	**Sat.**
Mae On Hospital	2	0	0	2	0	0	0
Maharaj Nakorn Chiang Mai Hospital	107	0	0	0	45	36	45
McCormick Hospital	19	0	19	0	0	0	0
Mcken Hospital	1	1	0	0	0	0	0
Nakornping Hospital	49	0	0	0	0	49	0
Rajavej Chiang Mai Hospital	1	0	1	0	0	0	0
San Kamphaeng Hospital	2	0	0	2	0	0	0
Si Phum Hospital	1	0	1	0	0	0	0
Siamrad Chiang Mai Hospital	1	1	0	0	0	0	0
Wangnua Hospital	1	0	0	1	0	0	0
Wiang Pa Pao Hospital	2	0	0	2	0	0	0
Wing 41 Hospital	1	1	0	0	0	0	0
Total	317	89	36	36	45	85	45

N.2.4.4 Policy 4

Table N.26: Thursday Plan of the dynamic route based on Policy 4

Hospital name	**Target supply**	**Mon.**	**Tue.**	**Wed.**	**Thu.**	**Fri.**	**Sat.**
Banthi Hospital	3	0	0	0	0	3	0
Central Chiangmai Memorial Hospital	3	0	0	0	0	0	3
Chang Phuak Hospital	4	0	0	0	4	0	0
Chiang Mai Provincial	1	0	0	0	0	0	1
Chiangmai Municipal Hospital	1	0	0	0	1	0	0
Chiangmai Neurological Hospital	1	0	1	0	0	0	0
Chiangmai Ram Hospital	4	0	0	5	0	0	0
Chiangrai Prachanukroh Hospital	82	0	0	0	0	81	1
Children Hospital and Medical Clinic	2	0	0	0	2	0	0
Clinics for Kidney Diseases	1	0	0	0	0	0	1
Doisaket Hospital	4	0	0	0	0	0	4
Dr. Wong Hospital	1	0	0	0	0	0	1
Faculty of Medicine, ChiangMai	1	0	0	0	0	0	1
Fort Kawila Hospital	1	0	0	0	0	0	1
Hangdong Hospital	4	4	0	0	0	0	0
Lanna Hospital	16	0	0	0	16	0	0
Mae Hia Hospital	1	0	0	0	1	0	0
Mae On Hospital	2	0	0	0	0	0	2
Maharaj Nakorn Chiang Mai Hospital	107	84	35	11	0	0	0
McCormick Hospital	19	0	0	0	19	0	0
Mcken Hospital	1	0	0	0	0	1	0
Nakornping Hospital	49	0	0	0	19	0	25
Rajavej Chiang Mai Hospital	1	0	0	0	1	0	0
San Kamphaeng Hospital	2	0	0	0	0	0	3
Si Phum Hospital	1	0	0	0	1	0	0
Siamrad Chiang Mai Hospital	1	0	0	0	1	0	0
Wangnua Hospital	1	0	0	0	0	0	1
Wiang Pa Pao Hospital	2	0	0	0	0	0	2
Wing 41 Hospital	1	1	0	0	0	0	0
Total	317	89	36	16	65	85	45

N.2.4.5 Policy 5

Table N.27: Thursday Plan of the dynamic route based on Policy 5

Hospital name	Target supply	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Banthi Hospital	3	3	0	0	0	0	0
Central Chiangmai Memorial Hospital	3	3	0	0	0	0	0
Chang Phuak Hospital	4	5	0	0	0	0	0
Chiang Mai Provincial	1	1	0	0	0	0	0
Chiangmai Municipal Hospital	1	1	0	0	0	0	0
Chiangmai Neurological Hospital	1	1	0	0	0	0	0
Chiangmai Ram Hospital	4	5	0	0	0	0	0
Chiangrai Prachanukroh Hospital	82	0	0	0	0	0	81
Children Hospital and Medical Clinic	2	2	0	0	0	0	0
Clinics for Kidney Diseases	1	1	0	0	0	0	0
Doisaket Hospital	4	4	0	0	0	0	0
Dr. Wong Hospital	1	1	0	0	0	0	0
Faculty of Medicine, ChiangMai	1	1	0	0	0	0	0
Fort Kawila Hospital	1	1	0	0	0	0	0
Hangdong Hospital	4	4	0	0	0	0	0
Lanna Hospital	16	19	0	0	0	0	0
Mae Hia Hospital	1	1	0	0	0	0	0
Mae On Hospital	2	2	0	0	0	0	0
Maharaj Nakorn Chiang Mai Hospital	107	0	0	0	0	107	0
McCormick Hospital	19	23	0	0	0	0	0
Mcken Hospital	1	1	0	0	0	0	0
Nakornping Hospital	49	0	0	59	0	0	0
Rajavej Chiang Mai Hospital	1	1	0	0	0	0	0
San Kamphaeng Hospital	2	2	0	0	0	0	0
Si Phum Hospital	1	1	0	0	0	0	0
Siamrad Chiang Mai Hospital	1	1	0	0	0	0	0
Wangnua Hospital	1	1	0	0	0	0	0
Wiang Pa Pao Hospital	2	2	0	0	0	0	0
Wing 41 Hospital	1	1	0	0	0	0	0
Total	317	89	0	59	0	107	81

N.2.5 Rescheduled Plan on Friday

N.2.5.1 Policy 1

Table N.28: Friday Plan of the dynamic route based on Policy 1

Hospital name	Target supply	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Banthi Hospital	3	0	0	0	0	3	0
Central Chiangmai Memorial Hospital	3	0	0	0	0	3	0
Chang Phuak Hospital	4	0	0	4	0	0	0
Chiang Mai Provincial	1	0	0	0	0	0	1
Chiangmai Municipal Hospital	1	0	0	1	0	0	0
Chiangmai Neurological Hospital	1	0	0	1	0	0	0
Chiangmai Ram Hospital	4	0	0	4	0	0	0
Chiangrai Prachanukroh Hospital	82	0	0	0	0	82	0
Children Hospital and Medical Clinic	2	0	0	2	0	0	0
Clinics for Kidney Diseases	1	0	0	0	0	0	0
Doisaket Hospital	4	0	0	0	0	0	0
Dr. Wong Hospital	1	0	0	0	0	0	1
Faculty of Medicine, ChiangMai	1	0	0	0	0	0	0
Fort Kawila Hospital	1	0	0	0	0	0	1
Hangdong Hospital	4	4	0	0	0	0	0

Continued on next page

Table N.28: Friday Plan of the dynamic route based on Policy 1

Hospital name	Target supply	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Lanna Hospital	16	0	0	16	0	0	0
Mae Hia Hospital	1	0	0	1	0	0	0
Mae On Hospital	2	0	0	0	0	0	0
Maharaj Nakorn Chiang Mai Hospital	107	84	0	23	0	0	0
McCormick Hospital	19	0	0	19	0	0	0
Mcken Hospital	1	0	0	0	0	1	0
Nakornping Hospital	49	0	0	3	0	1	43
Rajavej Chiang Mai Hospital	1	0	0	1	0	0	0
San Kamphaeng Hospital	2	0	0	0	0	0	0
Si Phum Hospital	1	0	0	1	0	0	0
Siamrad Chiang Mai Hospital	1	0	0	1	0	0	0
Wangnua Hospital	1	0	0	0	0	0	0
Wiang Pa Pao Hospital	2	0	0	0	0	0	0
Wing 41 Hospital	1	1	0	0	0	0	0
Total	317	89	0	77	0	90	45

N.2.5.2 Policy 2

Table N.29: Friday Plan of the dynamic route based on Policy 2

Hospital name	Target supply	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Banthi Hospital	3	3	0	0	0	0	0
Central Chiangmai Memorial Hospital	3	0	0	0	3	0	0
Chang Phuak Hospital	4	4	0	0	0	0	0
Chiang Mai Provincial	1	0	0	0	0	0	1
Chiangmai Municipal Hospital	1	0	0	1	0	0	0
Chiangmai Neurological Hospital	1	1	0	0	0	0	0
Chiangmai Ram Hospital	4	4	0	0	0	0	0
Chiangrai Prachanukroh Hospital	82	24	0	0	0	23	19
Children Hospital and Medical Clinic	2	2	0	0	0	0	0
Clinics for Kidney Diseases	1	0	0	0	0	0	1
Doisaket Hospital	4	0	0	0	0	0	4
Dr. Wong Hospital	1	0	0	0	0	0	1
Faculty of Medicine, ChiangMai	1	0	0	0	0	0	1
Fort Kawila Hospital	1	0	0	0	0	0	1
Hangdong Hospital	4	4	0	0	0	0	0
Lanna Hospital	16	0	0	0	6	0	10
Mae Hia Hospital	1	0	1	0	0	0	0
Mae On Hospital	2	0	0	0	0	0	2
Maharaj Nakorn Chiang Mai Hospital	107	44	28	23	12	0	0
McCormick Hospital	19	0	7	4	8	0	0
Mcken Hospital	1	1	0	0	0	0	0
Nakornping Hospital	49	0	0	11	11	27	0
Rajavej Chiang Mai Hospital	1	0	0	1	0	0	0
San Kamphaeng Hospital	2	0	0	0	0	0	2
Si Phum Hospital	1	0	0	1	0	0	0
Siamrad Chiang Mai Hospital	1	1	0	0	0	0	0
Wangnua Hospital	1	0	0	0	0	0	1
Wiang Pa Pao Hospital	2	0	0	0	0	0	2
Wing 41 Hospital	1	1	0	0	0	0	0
Total	317	89	36	41	40	50	45

N.2.5.3 Policy 3

Table N.30: Friday Plan of the dynamic route based on Policy 3

Hospital name	Target supply	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Banthi Hospital	3	3	0	0	0	0	0
Central Chiangmai Memorial Hospital	3	0	3	0	0	0	0
Chang Phuak Hospital	4	0	4	0	0	0	0
Chiang Mai Provincial	1	0	0	1	0	0	0
Chiangmai Municipal Hospital	1	0	1	0	0	0	0
Chiangmai Neurological Hospital	1	1	0	0	0	0	0
Chiangmai Ram Hospital	4	0	4	0	0	0	0
Chiangrai Prachanukroh Hospital	82	82	0	0	0	0	0
Children Hospital and Medical Clinic	2	0	2	0	0	0	0
Clinics for Kidney Diseases	1	0	0	1	0	0	0
Doisaket Hospital	4	0	0	4	0	0	0
Dr. Wong Hospital	1	0	0	1	0	0	0
Faculty of Medicine, ChiangMai	1	0	0	1	0	0	0
Fort Kawila Hospital	1	0	0	1	0	0	0
Hangdong Hospital	4	0	0	4	0	0	0
Lanna Hospital	16	0	0	16	0	0	0
Mae Hia Hospital	1	0	1	0	0	0	0
Mae On Hospital	2	0	0	2	0	0	0
Maharaj Nakorn Chiang Mai Hospital	107	0	0	0	45	0	46
McCormick Hospital	19	0	19	0	0	0	0
Mcken Hospital	1	1	0	0	0	0	0
Nakornping Hospital	49	0	0	0	0	49	0
Rajavej Chiang Mai Hospital	1	0	1	0	0	0	0
San Kamphaeng Hospital	2	0	0	2	0	0	0
Si Phum Hospital	1	0	1	0	0	0	0
Siamrad Chiang Mai Hospital	1	1	0	0	0	0	0
Wangnua Hospital	1	0	0	1	0	0	0
Wiang Pa Pao Hospital	2	0	0	2	0	0	0
Wing 41 Hospital	1	1	0	0	0	0	0
Total	317	89	36	36	45	49	46

N.2.5.4 Policy 4

Table N.31: Friday Plan of the dynamic route based on Policy 4

Hospital name	Target supply	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Banthi Hospital	3	0	0	0	0	3	0
Central Chiangmai Memorial Hospital	3	0	0	0	0	0	3
Chang Phuak Hospital	4	0	0	0	4	0	0
Chiang Mai Provincial	1	0	0	0	0	0	1
Chiangmai Municipal Hospital	1	0	0	0	1	0	0
Chiangmai Neurological Hospital	1	0	1	0	0	0	0
Chiangmai Ram Hospital	4	0	0	5	0	0	0
Chiangrai Prachanukroh Hospital	82	0	0	0	0	46	25
Children Hospital and Medical Clinic	2	0	0	0	2	0	0
Clinics for Kidney Diseases	1	0	0	0	0	0	1
Doisaket Hospital	4	0	0	0	0	0	4
Dr. Wong Hospital	1	0	0	0	0	0	1
Faculty of Medicine, ChiangMai	1	0	0	0	0	0	1
Fort Kawila Hospital	1	0	0	0	0	0	1
Hangdong Hospital	4	4	0	0	0	0	0
Lanna Hospital	16	0	0	0	16	0	0
Mae Hia Hospital	1	0	0	0	1	0	0

Continued on next page

Table N.31: Friday Plan of the dynamic route based on Policy 4

Hospital name	Target supply	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Mae On Hospital	2	0	0	0	0	0	2
Maharaj Nakorn Chiang Mai Hospital	107	84	35	11	0	0	0
McCormick Hospital	19	0	0	0	19	0	0
Mcken Hospital	1	0	0	0	0	1	0
Nakornping Hospital	49	0	0	0	19	0	1
Rajavej Chiang Mai Hospital	1	0	0	0	1	0	0
San Kamphaeng Hospital	2	0	0	0	0	0	3
Si Phum Hospital	1	0	0	0	1	0	0
Siamrad Chiang Mai Hospital	1	0	0	0	1	0	0
Wangnua Hospital	1	0	0	0	0	0	1
Wiang Pa Pao Hospital	2	0	0	0	0	0	2
Wing 41 Hospital	1	1	0	0	0	0	0
Total	317	89	36	16	65	50	45

N.2.5.5 Policy 5

Table N.32: Friday Plan of the dynamic route based on Policy 5

Hospital name	Target supply	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Banthi Hospital	3	3	0	0	0	0	0
Central Chiangmai Memorial Hospital	3	3	0	0	0	0	0
Chang Phuak Hospital	4	5	0	0	0	0	0
Chiang Mai Provincial	1	1	0	0	0	0	0
Chiangmai Municipal Hospital	1	1	0	0	0	0	0
Chiangmai Neurological Hospital	1	1	0	0	0	0	0
Chiangmai Ram Hospital	4	5	0	0	0	0	0
Chiangrai Prachanukroh Hospital	82	0	0	0	0	0	46
Children Hospital and Medical Clinic	2	2	0	0	0	0	0
Clinics for Kidney Diseases	1	1	0	0	0	0	0
Doisaket Hospital	4	4	0	0	0	0	0
Dr. Wong Hospital	1	1	0	0	0	0	0
Faculty of Medicine, ChiangMai	1	1	0	0	0	0	0
Fort Kawila Hospital	1	1	0	0	0	0	0
Hangdong Hospital	4	4	0	0	0	0	0
Lanna Hospital	16	19	0	0	0	0	0
Mae Hia Hospital	1	1	0	0	0	0	0
Mae On Hospital	2	2	0	0	0	0	0
Maharaj Nakorn Chiang Mai Hospital	107	0	0	0	0	107	0
McCormick Hospital	19	23	0	0	0	0	0
Mcken Hospital	1	1	0	0	0	0	0
Nakornping Hospital	49	0	0	59	0	0	0
Rajavej Chiang Mai Hospital	1	1	0	0	0	0	0
San Kamphaeng Hospital	2	2	0	0	0	0	0
Si Phum Hospital	1	1	0	0	0	0	0
Siamrad Chiang Mai Hospital	1	1	0	0	0	0	0
Wangnua Hospital	1	1	0	0	0	0	0
Wiang Pa Pao Hospital	2	2	0	0	0	0	0
Wing 41 Hospital	1	1	0	0	0	0	0
Total	317	89	0	59	0	107	46

N.2.6 Rescheduled Plan on Saturday

N.2.6.1 Policy 1

Table N.33: Saturday Plan of the dynamic route based on Policy 1

Hospital name	Target supply	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Banthi Hospital	3	0	0	0	0	3	0
Central Chiangmai Memorial Hospital	3	0	0	0	0	3	0
Chang Phuak Hospital	4	0	0	4	0	0	0
Chiang Mai Provincial	1	0	0	0	0	0	1
Chiangmai Municipal Hospital	1	0	0	1	0	0	0
Chiangmai Neurological Hospital	1	0	0	1	0	0	0
Chiangmai Ram Hospital	4	0	0	4	0	0	0
Chiangrai Prachanukroh Hospital	82	0	0	0	0	82	0
Children Hospital and Medical Clinic	2	0	0	2	0	0	0
Clinics for Kidney Diseases	1	0	0	0	0	0	1
Doisaket Hospital	4	0	0	0	0	0	5
Dr. Wong Hospital	1	0	0	0	0	0	1
Faculty of Medicine, ChiangMai	1	0	0	0	0	0	1
Fort Kawila Hospital	1	0	0	0	0	0	1
Hangdong Hospital	4	4	0	0	0	0	0
Lanna Hospital	16	0	0	16	0	0	0
Mae Hia Hospital	1	0	0	1	0	0	0
Mae On Hospital	2	0	0	0	0	0	2
Maharaj Nakorn Chiang Mai Hospital	107	84	0	23	0	0	0
McCormick Hospital	19	0	0	19	0	0	0
Mcken Hospital	1	0	0	0	0	1	0
Nakornping Hospital	49	0	0	3	0	1	56
Rajavej Chiang Mai Hospital	1	0	0	1	0	0	0
San Kamphaeng Hospital	2	0	0	0	0	0	3
Si Phum Hospital	1	0	0	1	0	0	0
Siamrad Chiang Mai Hospital	1	0	0	1	0	0	0
Wangnua Hospital	1	0	0	0	0	0	1
Wiang Pa Pao Hospital	2	0	0	0	0	0	2
Wing 41 Hospital	1	1	0	0	0	0	0
Total	317	89	0	77	0	90	74

N.2.6.2 Policy 2

Table N.34: Saturday Plan of the dynamic route based on Policy 2

Hospital name	Target supply	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Banthi Hospital	3	3	0	0	0	0	0
Central Chiangmai Memorial Hospital	3	0	0	0	3	0	0
Chang Phuak Hospital	4	4	0	0	0	0	0
Chiang Mai Provincial	1	0	0	0	0	0	1
Chiangmai Municipal Hospital	1	0	0	1	0	0	0
Chiangmai Neurological Hospital	1	1	0	0	0	0	0
Chiangmai Ram Hospital	4	4	0	0	0	0	0
Chiangrai Prachanukroh Hospital	82	24	0	0	0	23	53
Children Hospital and Medical Clinic	2	2	0	0	0	0	0
Clinics for Kidney Diseases	1	0	0	0	0	0	1
Doisaket Hospital	4	0	0	0	0	0	4
Dr. Wong Hospital	1	0	0	0	0	0	1
Faculty of Medicine, ChiangMai	1	0	0	0	0	0	1
Fort Kawila Hospital	1	0	0	0	0	0	1
Hangdong Hospital	4	4	0	0	0	0	0
Lanna Hospital	16	0	0	0	6	0	13

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Table N.34: Saturday Plan of the dynamic route based on Policy 2

Hospital name	Target supply	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Mae Hia Hospital	1	0	1	0	0	0	0
Mae On Hospital	2	0	0	0	0	0	2
Maharaj Nakorn Chiang Mai Hospital	107	44	28	23	12	0	0
McCormick Hospital	19	0	7	4	8	0	0
Mcken Hospital	1	1	0	0	0	0	0
Nakornping Hospital	49	0	0	11	11	27	0
Rajavej Chiang Mai Hospital	1	0	0	1	0	0	0
San Kamphaeng Hospital	2	0	0	0	0	0	2
Si Phum Hospital	1	0	0	1	0	0	0
Siamrad Chiang Mai Hospital	1	1	0	0	0	0	0
Wangnua Hospital	1	0	0	0	0	0	1
Wiang Pa Pao Hospital	2	0	0	0	0	0	2
Wing 41 Hospital	1	1	0	0	0	0	0
Total	317	89	36	41	40	50	82

N.2.6.3 Policy 3

Table N.35: Saturday Plan of the dynamic route based on Policy 3

Hospital name	Target supply	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Banthi Hospital	3	3	0	0	0	0	0
Central Chiangmai Memorial Hospital	3	0	3	0	0	0	0
Chang Phuak Hospital	4	0	4	0	0	0	0
Chiang Mai Provincial	1	0	0	1	0	0	0
Chiangmai Municipal Hospital	1	0	1	0	0	0	0
Chiangmai Neurological Hospital	1	1	0	0	0	0	0
Chiangmai Ram Hospital	4	0	4	0	0	0	0
Chiangrai Prachanukroh Hospital	82	82	0	0	0	0	0
Children Hospital and Medical Clinic	2	0	2	0	0	0	0
Clinics for Kidney Diseases	1	0	0	1	0	0	0
Doisaket Hospital	4	0	0	4	0	0	0
Dr. Wong Hospital	1	0	0	1	0	0	0
Faculty of Medicine, ChiangMai	1	0	0	1	0	0	0
Fort Kawila Hospital	1	0	0	1	0	0	0
Hangdong Hospital	4	0	0	4	0	0	0
Lanna Hospital	16	0	0	16	0	0	0
Mae Hia Hospital	1	0	1	0	0	0	0
Mae On Hospital	2	0	0	2	0	0	0
Maharaj Nakorn Chiang Mai Hospital	107	0	0	0	45	0	85
McCormick Hospital	19	0	19	0	0	0	0
Mcken Hospital	1	1	0	0	0	0	0
Nakornping Hospital	49	0	0	0	0	49	0
Rajavej Chiang Mai Hospital	1	0	1	0	0	0	0
San Kamphaeng Hospital	2	0	0	2	0	0	0
Si Phum Hospital	1	0	1	0	0	0	0
Siamrad Chiang Mai Hospital	1	1	0	0	0	0	0
Wangnua Hospital	1	0	0	1	0	0	0
Wiang Pa Pao Hospital	2	0	0	2	0	0	0
Wing 41 Hospital	1	1	0	0	0	0	0
Total	317	89	36	36	45	49	85

N.2.6.4 Policy 4

Table N.36: Saturday Plan of the dynamic route based on Policy 4

Hospital name	Target supply	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Banthi Hospital	3	0	0	0	0	3	0
Central Chiangmai Memorial Hospital	3	0	0	0	0	0	3
Chang Phuak Hospital	4	0	0	0	4	0	0
Chiang Mai Provincial	1	0	0	0	0	0	1
Chiangmai Municipal Hospital	1	0	0	0	1	0	0
Chiangmai Neurological Hospital	1	0	1	0	0	0	0
Chiangmai Ram Hospital	4	0	0	5	0	0	0
Chiangrai Prachanukroh Hospital	82	0	0	0	0	46	37
Children Hospital and Medical Clinic	2	0	0	0	2	0	0
Clinics for Kidney Diseases	1	0	0	0	0	0	1
Doisaket Hospital	4	0	0	0	0	0	4
Dr. Wong Hospital	1	0	0	0	0	0	1
Faculty of Medicine, ChiangMai	1	0	0	0	0	0	1
Fort Kawila Hospital	1	0	0	0	0	0	1
Hangdong Hospital	4	4	0	0	0	0	0
Lanna Hospital	16	0	0	0	16	0	0
Mae Hia Hospital	1	0	0	0	1	0	0
Mae On Hospital	2	0	0	0	0	0	2
Maharaj Nakorn Chiang Mai Hospital	107	84	35	11	0	0	0
McCormick Hospital	19	0	0	0	19	0	0
Mcken Hospital	1	0	0	0	0	1	0
Nakornping Hospital	49	0	0	0	19	0	30
Rajavej Chiang Mai Hospital	1	0	0	0	1	0	0
San Kamphaeng Hospital	2	0	0	0	0	0	2
Si Phum Hospital	1	0	0	0	1	0	0
Siamrad Chiang Mai Hospital	1	0	0	0	1	0	0
Wangnua Hospital	1	0	0	0	0	0	1
Wiang Pa Pao Hospital	2	0	0	0	0	0	2
Wing 41 Hospital	1	1	0	0	0	0	0
Total	317	89	36	16	65	50	86

N.2.6.5 Policy 5

Table N.37: Saturday Plan of the dynamic route based on Policy 5

Hospital name	Target supply	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Banthi Hospital	3	3	0	0	0	0	0
Central Chiangmai Memorial Hospital	3	3	0	0	0	0	0
Chang Phuak Hospital	4	5	0	0	0	0	0
Chiang Mai Provincial	1	1	0	0	0	0	0
Chiangmai Municipal Hospital	1	1	0	0	0	0	0
Chiangmai Neurological Hospital	1	1	0	0	0	0	0
Chiangmai Ram Hospital	4	5	0	0	0	0	0
Chiangrai Prachanukroh Hospital	82	0	0	0	0	0	87
Children Hospital and Medical Clinic	2	2	0	0	0	0	0
Clinics for Kidney Diseases	1	1	0	0	0	0	0
Doisaket Hospital	4	4	0	0	0	0	0
Dr. Wong Hospital	1	1	0	0	0	0	0
Faculty of Medicine, ChiangMai	1	1	0	0	0	0	0
Fort Kawila Hospital	1	1	0	0	0	0	0
Hangdong Hospital	4	4	0	0	0	0	0
Lanna Hospital	16	19	0	0	0	0	0
Mae Hia Hospital	1	1	0	0	0	0	0

Continued on next page

Table N.37: Saturday Plan of the dynamic route based on Policy 5

Hospital name	**Target supply**	**Mon.**	**Tue.**	**Wed.**	**Thu.**	**Fri.**	**Sat.**
Mae On Hospital	2	2	0	0	0	0	0
Maharaj Nakorn Chiang Mai Hospital	107	0	0	0	0	107	0
McCormick Hospital	19	23	0	0	0	0	0
Mcken Hospital	1	1	0	0	0	0	0
Nakornping Hospital	49	0	0	59	0	0	0
Rajavej Chiang Mai Hospital	1	1	0	0	0	0	0
San Kamphaeng Hospital	2	2	0	0	0	0	0
Si Phum Hospital	1	1	0	0	0	0	0
Siamrad Chiang Mai Hospital	1	1	0	0	0	0	0
Wangnua Hospital	1	1	0	0	0	0	0
Wiang Pa Pao Hospital	2	2	0	0	0	0	0
Wing 41 Hospital	1	1	0	0	0	0	0
Total	317	89	0	59	0	107	87

Glossary

A

ABO blood group A classification system for the antigens of human blood used in blood transfusion therapy; the four groups are A and B and AB and O.

Antibodies An immunoglobulin molecule reacts with a specific antigen that induced its synthesis and with similar molecules; classified according to mode of action as agglutinin, bacteriolysin, hemolysin, opsonin, or precipitin. Antibodies are synthesized by B lymphocytes that have been activated by the binding of an antigen to a cell-surface receptor.

B

bloodmobiles A vehicle equipped with everything necessary for a blood donation procedure.

C

Chemiluminescence Microparticle Immuno Assay An immunoassay technique in which the antigen or antibody is labelled with a molecule capable of emitting light during a chemical reaction; this light is used to measure the formation of the antigen-antibody complex.

cross-matching blood A test applied to determine that blood of donors is compatible with blood of recipients.

Cryoprecipitate A frozen blood product prepared from plasma. It is often transfused as a four to six unit pool instead of as a single product. Many uses of the product have been replaced by factor concentrates, but it is still routinely stocked by many hospital blood banks.

D

Dried Cryo-Removed Plasma Plasma from which the cryoprecipitate has been removed.

F

Fibrin Glue A formulation used to create a fibrin clot.

Fresh Dried Plasma A lyophilized form of fresh frozen plasma can be stored at +4 °C, whereas fresh frozen plasma must be stored at −20 °C.

Fresh Frozen Plasma The product of choice for patients specifically requires replacement of the labile clotting factors or other proteins with poor storage stability because the other plasma products may be deficient in these factors during liquid storage; deficiencies due to consumption/hemodilution rarely fall to levels that are inadequately treated with non-FFP plasma components; consultation with a hematologist or transfusion medicine physician is recommended for assistance with indications 3-6.

H

Heat Treated Freeze Dried Cryoprecipitate Cryoprecipitate can be stored at +4 °C.

Hepatitis B Immunoglobulin A human immune globulin that is used to prevent the development of hepatitis B.

Human Albumin Solution The most abundant protein in human blood plasma. It is produced in the liver. Albumin constitutes about half of the blood serum protein. It is soluble and monomeric.

Human Rabies Immunoglobulin This product is prepared from plasma from screened donors. It contains human protein, 40-180 g/L of which at least 95% is IgG. The concentration of specific IgG to Rabies virus is not less than 150 IU/mL in nominal 500 IU vials. The correct volume to give the stated potency is overprinted on the label.

L

Leukocyte-Poor Packed Red Cells This product is obtained by employing a filter to remove white blood cells (leukocytes) from a unit of packed red blood cells. This type of transfusion is used to prevent febrile (fever) reactions in patients who have had multiple febrile transfusion reactions in the past, presumably to white blood cell antigens.

Leukocyte-Poor Platelet Concentrates This product obtained by conventional techniques, ie, centrifugation, frequently has a high level of remaining leukocytes. Cotton wool filter Imugard IG 500 can be used to obtain leukocyte-poor cellular blood products. The technique is easy to perform, even in an emergency, and can be used with either packed red blood cells or platelet concentrates.

N

Nucleic Acid Testing A biochemical technique is used to detect a virus or a bacterium.

P

Packed Red Blood Cells Red blood cells are made from a unit of whole blood by centrifugation and removal of most of the plasma, leaving a unit with a hematocrit of about 60%. One unit will raise the hematocrit of a standard adult patient by 3% (or about 1%/mL/kg in a child - 12%/25 kg with the standard 300 mL unit). They are used to replace red cell mass when tissue oxygenation is impaired by acute or chronic anemia.

plasma The yellow liquid contains the blood cells.

Platelet Concentrates Unrefrigerated whole blood is centrifuged at low speed (soft spin) to separate platelet rich plasma.

platelets Blood cells whose function (along with the coagulation factors) is to stop bleeding.

R

reagent A substance which acts on another in a chemical reaction.

red blood cells Red corpuscles carry oxygen around the body.

Rhesus blood group The extensive, genetically determined system of red blood cell antigens is defined by the immune serum of rabbits injected with rhesus monkey erythrocytes, or by human antisera. Also known as rhesus blood group.

S

sepsis A severe medical condition in which bacteria enter the blood after an operation or accident.

serology The study of blood serum and other bodily fluids.

W

Whole Blood Blood that is unmodified except for the presence of an anticoagulant. Whole blood may be used for transfusion. Various components and factors may be separated from whole blood for infusion to replace or to augment a deficient or non-functional component or factor.