COALITION MODELING IN HUMANITARIAN ASSISTANCE OPERATIONS

THESIS

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Abstract

Multinational operations are carried out to achieve military and diplomatic objectives in various regions. Such operations derive a great deal of benefits from sharing budgets, political legitimacy, sharing each national experience and technological resources, and so forth. However, a coalition, one structure of multinational operations, often involves serious challenges in such areas as command and control, logistic support, communication and language, training, and intelligence and information due to its ad hoc characteristics. This research reviews general problems in a coalition operation, and develops the Coalition Operation Planning Model to assist coalition commanders or staff in producing an efficient operational plan. In this model, goal programming is employed to formulate the coalition problems with multiple objectives. The proposed model is composed of three sub-models: the Coalition Mission-Unit Allocation Model, the Coalition Mission-Support Model, and the Coalition Mission-Unit Grouping Model. The first sub-model is designed to find an optimized resource allocation by applying the shortest path problem and effectiveness functions. The second sub-model is developed to obtain an optimized logistics support plan by using the multi-commodity network flow. Finally, the third sub-model is designed to combine small units into one workable independent unit by using the quadratic assignment problem. The models are demonstrated with a notional humanitarian assistance operation.

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COALITION MODELING IN HUMANITARIAN ASSISTANCE OPERATIONS

I. Introduction

In contemporary times, multinational operations have been carried out to achieve military and diplomatic objectives in various regions such as Iraq, Afghanistan and Kosovo. Recent history suggests that the US and its allies will participate in future multinational operations to maintain international stability in various areas of mutual interest around the world. Multinational operations can provide a great deal of benefits like sharing budgets and political legitimacy, but involve various problems ranging from political questions to coordination of military operations. Generally, the high cost of military operations, reduced military budgets after the cold war, global economies, and the need for international legitimacy will often make multinational operations a necessity in the future (Pugh, 2000).

1.1. Background

Multinational operations have different structures; these include coalitions and alliances. However the terms alliance and coalition are often used incorrectly as synonyms. It is therefore necessary to clarify the differences between a coalition and an alliance. In Joint Doctrine for Multinational Operations, the phrase multinational operation is defined as a collective term to describe military actions conducted by forces of two or more nations (DoD, Apr 2000: I-1). Such operations are usually undertaken within the structure of a coalition or alliance. An *alliance* is defined as the result of formal agreements between two or more nations for broad, long-term objectives which further the common interests of the members, while a *coalition* is defined as an ad hoc arrangement between two or more nations for common action (DoD, Apr 2000: I-1). That is, an alliance is an operation conducted by forces of two or more nations in a formal treaty arrangement, with standard agreements for broad, long-term objectives. Alliances often will have common rules of engagement, doctrine, and members who have participated in exercises together. On the other hand, coalitions are operations where the military action is temporary, informal, and usually called for a specific purpose – hence the term ad-hoc (Furlong, 1998). From these aspects, alliances are well organized with stable methods for coordinating between each national force. Coalitions are more flexible, but may be subjected to more political issues than alliances.

The North Atlantic Treaty Organization (NATO) is a good example of an alliance which has existed for over 50 years. Over the years NATO has developed common strategies: NATO guide lines, arrangements, international training, and so on. As previously noted, however, coalitions are temporary organizations formed for certain specific purposes. Therefore coalition operations may have more critical problems than alliances with regard to command and control structure, resource sharing, communication, training, sharing intelligence and other issues that may arise without precedents guidance.

Clearly, multinational operations might be one of the most difficult types of operations for each level commander to conduct due to differences in language, equipment, culture, doctrine, and so forth. Furthermore, coalition partners could be non-alliance members with whom the forces have little in common other than the coalition cause. They may not have previously conducted operations together, thus lacking the experience and understanding an alliance may have developed. For these reasons, operational commanders must consider and attempt to solve the challenges of working in ad hoc coalitions. Nevertheless, multinational operations, including coalition operations, have recently increased in certain regions with various national goals. In addition, future U.S. and allied military operations (from peacekeeping to major conflicts) will almost certainly involve multinational coalitions. A representative list of US participation in multinational operations from 1900 to 1999 is shown in Appendix A.

Given these potential problems, what benefits do multinational operations have? Consider the potential benefits by such criteria as political, economic, and military operational aspects. Regarding political aspects, a coalition can gain political legitimacy, not only international support, but also regional support through their partners who participate in the coalition. Secondly the economics of war will undoubtedly be a key element driving the need for future coalitions since a coalition can provide a broad base of operational and logistical support for military operations. Therefore, a coalition can mitigate certain nations' financial and manpower burdens associated with military operations. In this light, coalition forces are highly desirable. Thirdly, in coalition operations, each nation's experience and technological resources can be shared; this fact can contribute to the ease of coalition operation.

Anyone who is not familiar with the history of warfare might mistakenly think that the Gulf War was the first time that coalition operations were used successfully to fight a war. Multinational operations, however, have been around for quite some time-going at least as far back as Alexander's forces, the ancient battles between Athens and Sparta or the Roman legions in the later stages of the empire (Furlong, 1998). Turner points out that the campaign of the Sixth Coalition against Napoleon is also a good historical example. In studying the operations of the Sixth Coalition, Austria played the prominent role in the success of the allies. Austria's leadership ensured unity of effort and provided the decisive resources to ensure the allies stayed focused on the strategic objective, i.e., the defeat of Napoleon and the threat he posed to other European powers. However, there were the relative failures of the coalition prior to Austria's formal entry into the operations; the coalition did not exercise unity of command or possess a sound operational plan until the integration of Austria into the operations (Turner, 2003: 3).

1.2. Problem Statement

Even though a coalition posses many benefits, the success of coalition operations can not be guaranteed since the coalition involves numerous significant problems. Therefore, it is important to identify possible problems which can occur in coalition operations. Once identified, it is necessary to try to solve or at least ameliorate these problems using operations research and other methods. Unfortunately, there are not many existing models for coalition operations.

In coalition operations, one potential important problem might be to efficiently allocate available resources to required tasks. In reality, available resources are usually limited. Furthermore, there are often restrictions to the allocation of resources in coalition operations due to the coalition's ad hoc nature. Therefore these resources should be allocated to appropriate locations at the proper time to yield the maximum desired effect. This thesis, to illustrate the potential and pitfalls of coalition modeling, aims at developing a model which provides an optimal resource allocation solution in a Coalition Operation. This model is named the Coalition Operation Planning Model and is designed to assist coalition commanders and staff to make an acceptable and potentially optimal operational plan. A notional Coalition Operation conducting Humanitarian Assistance is used to demonstrate the application of this model, and to provide a framework for the mathematical formulations in this thesis.

1.3. Research Approach

In this thesis, a variety of optimization and modeling methods such as shortest path problem, multi-commodity network flow, quadratic assignment problem, and goal programming are used to develop a Coalition Operation Planning Model for humanitarian assistance.

First, the shortest path problem formulation is applied to allocate each available unit to the required task over time periods based on optimizing effectiveness functions. Network flow techniques are employed to represent a directed graph consisting of origin-destination pairs, distances, cost, and effectiveness. In order to find an efficient support plan for each unit's activities, a multi-commodity network flow problem is implemented and several different types of vehicles are used. Next, the quadratic assignment problem is used to coordinate unit's activities to carry out various tasks. Finally, goal programming (GP) techniques are implemented to formulate a Coalition Operation Planning Model with multiple objectives.

1.4. Thesis Outline

The remainder of this thesis is organized as follows: In Chapter II, the general coalition problems and Humanitarian Assistance Operation are reviewed in order to identify significant coalition operation problems which should be considered in Coalition Operation Planning Model formulation. Optimization methods, such as goal programming, shortest path problem, multi-commodity flow problem, and quadratic assignment problem, which are used in the model, are reviewed. In Chapter III, the general procedures of the Coalition Operation Planning Model are demonstrated, and mathematical formulations of this model for coalition operation in Humanitarian Assistance are developed. Chapter IV presents a scenario as an example and the results of this model. Finally, Chapter V presents the conclusions and directions for future research.

II. Literature Review

2.1. General Problem Statement for a Coalition Operation

Coalition Operations are a two-edged sword. While they have a number of benefits, it can be difficult for military commanders and their staff to efficiently carry out coalition operations due to the complexities resulting from the mingling of disparate force. In addition, the situation is exacerbated by the ad hoc nature of coalitions.

Generally at the initial stage of coalition formation and operation, there are many political problems which must be addressed such as “Who will be the coalition commander?” and “Can each national force exchange their own equipment with each other and achieve interoperability?” Since these problems depend on each coalition partners’ national goals and interests, the rest of this section focuses on potential problems associated with the operational parts. These problems should be considered for military operations from the planning stage to the end state. These areas are: Command and Control, Planning Coalition Operations, Logistic Support, Communication and Language, Training, and Intelligence and Information. In this section, general problems which can be involved in a coalition operation are described. Numerous detailed problems can be extracted from these general problems.

2.1.1. Command and Control

Command and Control is one of the most important considerations in forging a unity of effort. However, the command structure in a multinational force can involve different types of structure compared to ordinary established command structure. That is, due to the issue of national sovereignty, coalition operations, at least in the initial stages, often involve a parallel command structure (Furlong, 1998). Therefore, two issues must be faced: “Who will command the multinational force?” and “What authority will the commander have” These issues create tension within the coalition because all contributors to multinational forces struggle with the scope of command authority over their forces granted to another nation’s commander (Marich, 2000).

Coalition Command Structure: In coalition operations, each nation which dispatches their forces may wish to retain more control of their own national forces than is generally associated with alliance operations. Joint Publication 3-16 defines types of coalition command structures. Coalitions are most often characterized by one of three basic structures; parallel, lead nation, or a combination of the two (DoD, Apr 2000: II-10).

The use of truly parallel command structure is dangerous without developing a means for coordination in order to attain and maintain a unity of effort since there is no single force commander. Some coalitions may be rapidly formed to respond to an emergency without enough time to consider a combined command structure. For these reasons, it is more likely for a coalition to use a parallel structure at the initial stage, but the coalition should try to organize coordination centers, to evolve the structure (see Figure II-1). Operation Desert Storm in the Persian Gulf represented this type of structure where nations formed a coalition for a common effort, with many nations retaining control of their own forces (see Figure II-2) (Pugh, 2000).

Another command structure in a coalition is the lead nation command (see Figure II-3). This entails one nation taking the lead or the majority of the responsibility for conducting military operations. In this case, the other nations are placed under the operational control of the lead nation. A coalition operation such as the Korean War used this type of command relationship (Pugh, 2000).

However, many nations are generally reluctant to grant extensive control over their forces to one lead nation. The third command structure is a combination of the two structures. This combination occurs when two or more nations serve as controlling elements for a mix of international forces, such as the command arrangement employed by the Gulf War coalition.

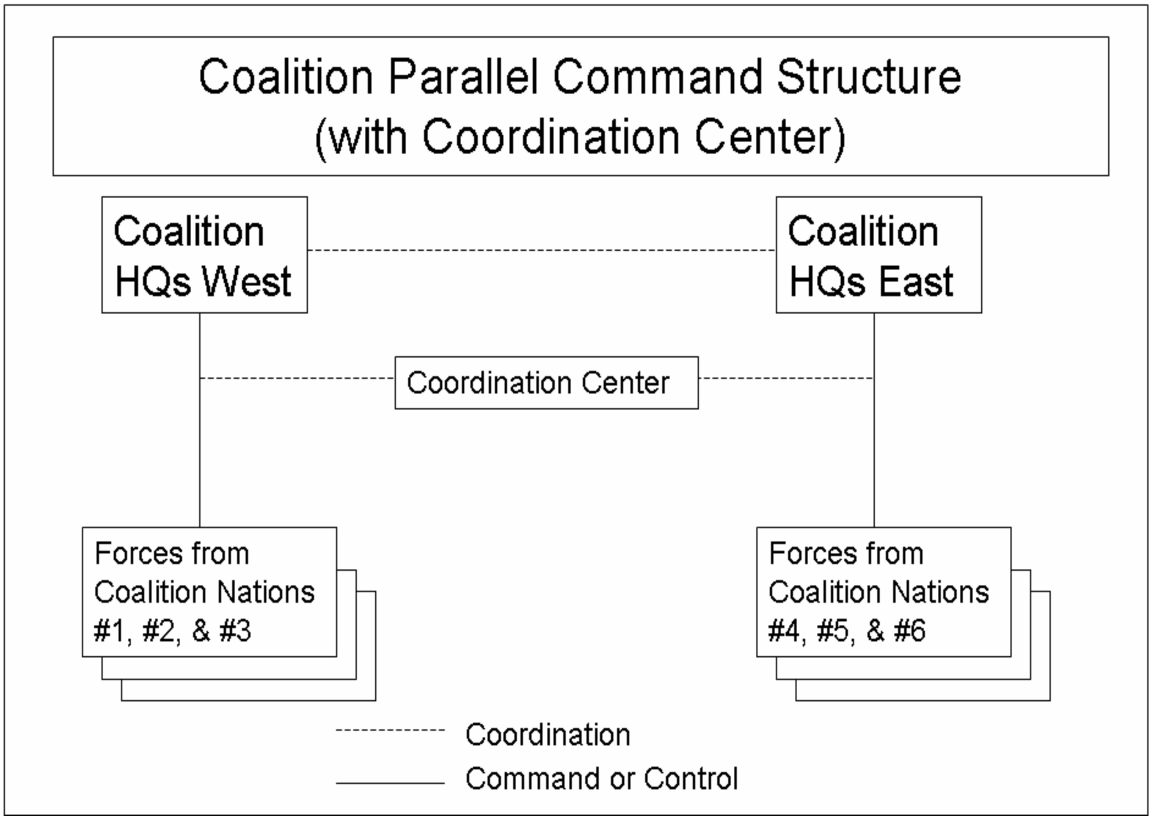


Figure II- 1: Coalition Parallel Command Structure (DoD, Apr 2000: II-11)

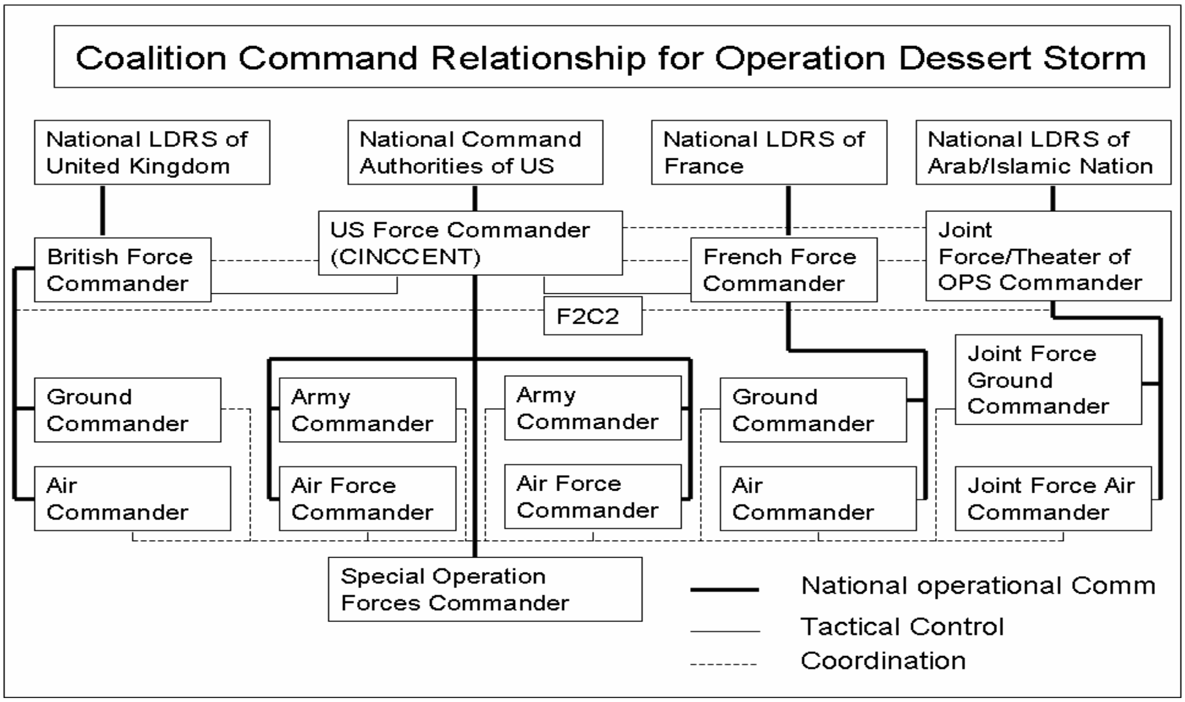


Figure II- 2: Coalition Command Relationship for Operation Dessert Storm (DoD, Apr 2000: II-12)

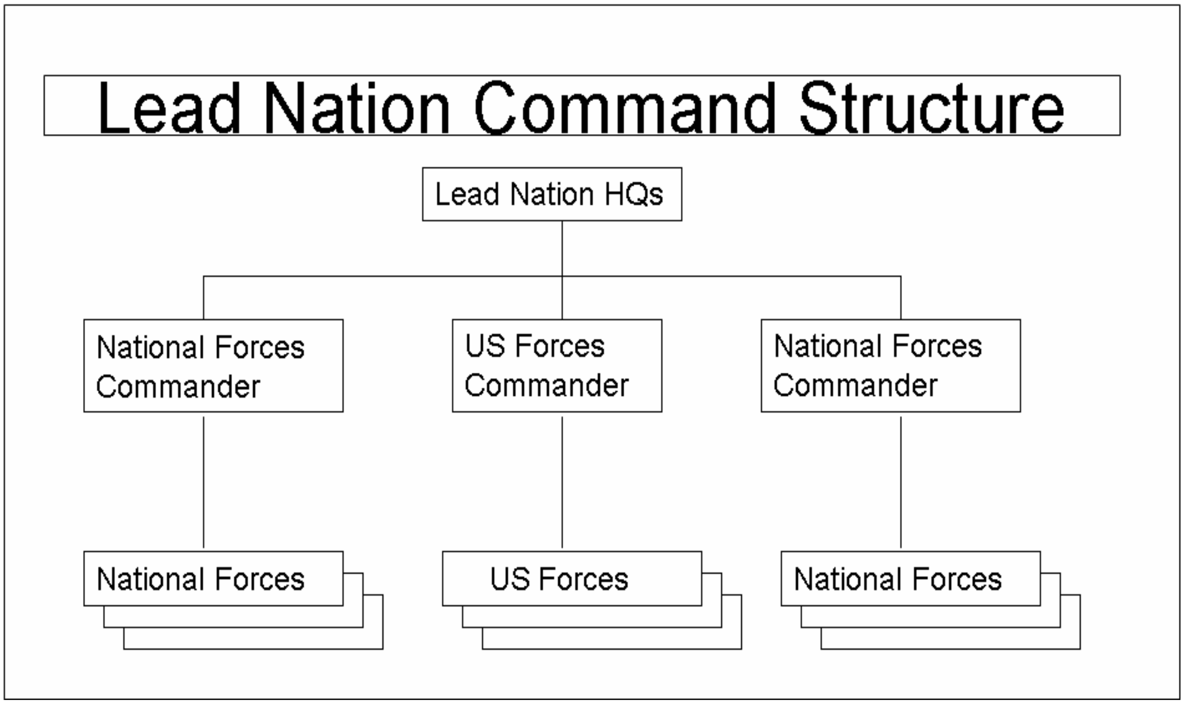


Figure II- 3: Lead Nation Command Structure (DoD, Apr 2000: II-10)

Control: Since differences in organization, equipment, training, language and culture make control of multinational forces difficult, Coalition HQ should consider various means to improve the control of their forces. A liaison network and coordination centers are recommended to make the control of the coalition efficient (DoD, Apr 2000: II-11).

Rationalization, Standardization, and Interoperability (RSI): When one considers command and control problems, RSI of multinational forces is one of the most important factors. Rationalization is any action that increases the effectiveness of allied and/or coalition forces through more efficient or effective use of defense resources (DoD, Apr 2000: I-10). The purpose of standardization is to achieve the closest practical cooperation among multinational forces (MNFs) through the efficient use of resources and the reduction of operational, logistic, technical, and procedural obstacles in multinational military operations (DoD, Apr 2000: I-10). Since coalitions, however, are usually formed at an uncertain time, often in a rapid manner compared to an alliance, the effort to increase interoperability is more desirable than other efforts. For this reason, a further focus on interoperability is explored.

Interoperability is the ability of the systems, units, or forces to provide services to and accept services from other systems, units, or forces, and to use the services so exchanged to enable them to operate effectively together (Black, 2000: 8). That is, it is a measure of the degree to which various organizations or individuals are able to operate together to achieve a common goal. Therefore, interoperability is an essential RSI requirement for multinational operations; national forces cannot operate effectively together unless their forces are interoperable. The most important areas for interoperability include language, communications, doctrine and exchanges of information (DoD, Apr 2000: I-12). Interoperability is often situation-dependent, comes in various forms and degrees, and can occur at various levels-strategic, operational, and tactical as well as technological (Hura *et al.*, 2000:7).

2.1.2. Planning Coalition Operations

Mission Analysis: As an initial stage of planning operations, mission analysis should be done before assigning tasks to various elements of the coalition forces. Regardless of the source of the strategic guidance, a detailed mission analysis must be accomplished. It is one of the most important tasks in planning multinational operations. This analysis should result in a mission statement and campaign plan for the MNF as a whole and a restated mission for each national element of the force (DoD, Apr 2000: III-1).

Assigning sub-missions: Sub-missions which result from the mission analysis must be assigned to appropriate multinational forces, but the characteristics of each national force varies. Therefore, the types of multinational forces must be identified. Factors include training level and logistic support (including deployment, sustainment, and redeployment capabilities), any limit on forces use, funding requests, certification procedures, and so on. That is, when planning missions, a commander must be aware of operational limitations that may be imposed on his subordinate units (Marich, 2000:12). Due to these factors, simplicity, one principle of war, is important when working with and planning major operations that involve coalition forces. Another necessary consideration when assigning tasks to multinational forces is each nation’s contribution.

In the Joint Doctrine for Multinational Operations, it is stated that if there are several elements that can complete the task, the multinational forces commander (MNFC) should consider assigning that task in a manner that ensures that all elements can make meaningful contributions to the desired end state (DoD, Apr 2000: III-1).

2.1.3. Logistics Support

Logistics may be the most important ingredient for coalition success since partner nations have various degrees of military and logistics capabilities. That is, to be successful, multinational operations should be well planned and coordinated, especially with regard to logistical support with a rapidly forming coalition (DoD, Apr 2000:III-6). However, such support can be difficult. Joint Publications 4-08 defines multinational logistics as any coordinated logistic activity involving two or more nations supporting a multinational force conducting military operations under the auspices of an alliance or coalition, including those conducted under a United Nation (UN) mandate (DoD, 2002: I-2).

From multinational operation's general characteristics, multinational logistics involves the complexities of sustaining multinational forces comprising many different nations in both War and Military Operations Other Than War (MOOTW). In large-scale war, well organized logistical planning might be more necessary than in a MOOTW setting since the nature of war require extensive movement of material and personnel, consumption of large amount of various resources. Furthermore logistical policy must be different depending on types of military operation (War or MOOTW), each national political interest, geography and climate, and so on.

In coalition operations, logistic support is more complex and necessary than other multinational operations due to its ad-hoc formation. It is therefore critical for the coalition commander and his staff to find the most appropriate logistical policy and planning.

According to JP 4-08, successful multinational logistic operations are governed by several unique principles. First, multinational logistic operations are a collective responsibility of participating nations and the MNFC, although nations are inherently responsible for supporting their forces. A second principle is that MNFCs should be given sufficient authority over logistic resources to ensure that the force is supported in the most efficient and effective manner. Third, cooperation and coordination are necessary among participating nations and forces. Finally synergy results from the use of integrated multinational logistic support (DoD, 2002: I-6).

Responsibility: Often, a coalition is driven by political rather than military considerations. That is, due to political interests, the coalition often invites small units of foreign forces into coalition operations, even though they may offer only token forces. For example, of the 34 countries participating in the “coalition of the willing” in Iraq, 25 nations have provided a force of less than 500 military personnel and ten of these have provided less than 100 personnel (Brich, 2004:2). Given the small size, the coalition HQ should consider the logistics problems for these multinational forces as they often have logistics limitations. According to Joint Publication 3-16, the responsibility for providing logistic support to national component forces ultimately resides with their nations, unless previously agreed to in accordance with alliance implementing arrangements (IAs) or coalition ISAs (International Standardization Agreement) (DoD, Apr 2000: III-7).

Although each nation is responsible for the logistic support of its national forces, a centralized control and coordination of common services and common funding for logistics is necessary to reduce overall cost since separate logistic plans would be inefficient, expensive and hinder the MNFC's ability to influence operations logistically. There are good examples of integrated multinational logistic support from World War II. These examples include (Pugh, 2000):

- Britain and the US provided logistical support to the USSR because the USSR was contributing to the defeat of Germany on the eastern front. The allies believed that providing support accelerated the defeat of Germany (Pugh, 2000: 17).
- The US established a program to rearm eight French Divisions in North Africa. To the US, arming the French divisions would reduce its need for more manpower; US industry was requesting the "release of additional soldiers for work in tire and heavy ammunition plants" (Pugh, 2000:18).
- Each nation had its own supply and transport structure on the continent. However, strategic and operational planning and the allocation of supplies were shared.

Table II- 1: Planning for Bulk Supply (Pugh, 2000:21)

Type of Product	Department Responsible
Fuels and lubricants of Naval Supply	Admiralty [British]
All M.T.[Mechanical Transport] fuels, lubricants, fog oil kerosene and F.T.F.[flame thrower fuels], consigned to US controlled ports on the continent.	European theater of Operations, US Army
ALL M.T. fuels, lubricants, fog oil, and F.T.F., consigned to British controlled ports on the continent	War Office
All aviation fuels an aircraft engine lubricants for both British and US controlled ports	Air Ministry [British]

For example, the allocation of responsibilities for the provision, supply and distribution of fuel was managed in the European theater as early as 1943 (see Table II-1) (Pugh, 2000: 20).

- The India force received almost all of its equipment from the US and Britain. Although the Government of India did not have the capability to supply critical arms and munitions, it provided US forces supplies such as clothing and foodstuffs under the reciprocal aid program. Therefore, logistics was entirely a collective responsibility (Pugh, 2000: 32).

In sum, these examples suggest that multinational forces must capitalize on the strengths of their partners, and that a collective approach to providing logistical support can achieve economies of scale. It further highlights the need of military officers to become familiar with the procedures of its fellow national forces.

Difference: As mentioned previously, a coalition operation is an ad hoc arrangement which can be formed for a short term compared to an alliance. It is clearly possible that Non-alliance nations will participate in the coalition and will have differences in logistics. Like NATO, Alliances try to standardize their equipments and procedures, and to develop arrangements about logistics during peacetime. A coalition, however, has to figure out this problem as or after it is formed, so the characteristics of difference in the logistics are more significant in a coalition than in an alliance.

According to the JP 3-16, among the participating nations, there will be differences in logistics doctrine, organizational capabilities, Standing Operating Procedures (SOPs), terminology and definitions, methods for computing requirements, organizational policies, and automated data processing (ADP) support systems (DoD, Apr 2000: III-7). These differences must be understood by all, harmonized where realistically possible, and accounted for during OPLAN formulation.

Many lessons learned exist from war history. Consider that during WW II, the French military could understand US supply procedures, especially requisitioning, due to the multinational logistical operations conducted between the French and Americans during WW I. These experiences enabled them to better solve multinational logistical problems when they occurred. For example, French quartermaster officers ensured that only certain American rations were sent to French colonial soldiers because of cultural and religious preferences. This increased efficiency by reducing backhauls of unwanted food items, and also reduced waste (Pugh, 2000: 25). As a secondary effect, it also avoided offending a coalition partner due to a cultural lapse.

Multinational logistic support arrangements: The coalition members can agree to lead or participate in a variety of support arrangements to ease individual national burdens and achieve operational efficiencies. According to the JP 4-08, these arrangements include (DoD, 2002: III-4 – III-12):

- Lead Nation (LN) logistic support: One nation agrees to assume responsibility for procuring and providing a range of logistic support services for either all or part of a multinational force. Such services may include transportation, medical support, medical evacuation, rear area security, Port of Debarkation (POD) operations, engineering, and movement control. Compensation and reimbursement will then be subject to agreements of the parties involved. The U.S. provided selected lead nation logistic support to coalition partners in Somalia and Haiti.

- Role Specialist Nation (RSN) logistic support: Under a RSN arrangement, one nation assumes responsibility for providing a particular class of supply or service for all or part of a multinational force, usually at a determined rate of reimbursement. Provision of bulk fuel in Bosnia and Kosovo by the U.S. and France, are examples of RSN support.
- National Logistics Units: Individual nations can provide to a coalition a particular logistic unit such as engineer battalions or a composite logistic unit that performs several logistic functions, such as medical transportation and engineer units.
- Host-Nation Support (HNS): HNS is defined as civil and/or military assistance rendered by a host nation to foreign forces within its territory during peacetime, crises or emergencies, or war based on agreements mutually concluded between nations. These include transportation, civilian labor, services, rear area protection, petroleum, telecommunications, supplies, health services, facilities and real estate, and contracting. In some cases, reimbursement may not be required because the providing nation recognizes the importance of coalition/alliance forces deployed on its territory and/or considers HNS to be its contribution to the security arrangement. Saudi Arabia provided extensive HNS during Operation Desert Storm including the use of airports and seaports, port operations, transportation, fuel, water and rations.
- Contractor Support: There are three kinds of contractor support – systems support, theater contractor support, and external theater support. In cases where a nation operates foreign-acquired equipment, some or all of the support for such equipment may be provided by foreign contractors and hence could be "multinational."

Implementation of multinational logistic support arrangements may involve a range of legal, administrative, or financial mechanisms which include mutual support agreements, memoranda of agreement (MOAs), standardization agreements, and common funding (DoD, 2002: III-13). However, these agreements negotiated among participants do not provide sufficient legal authority for exchanging support with multinational partners. For example, specific and additional agreements between the US and coalition partners (e.g., Acquisition and Cross-Serving Agreements Authority (ACSA) or Foreign Military Sales (FMS) agreements may be required to allow US forces to provide logistic support to other nations.

Acquisition and Cross-Serving Agreements Authority: There are some US legal Authorities including Acquisition and Cross-Servicing Agreement Authority (ACSA), Arms Export Control Act (AECA), Foreign Assistance Act (FAA), and so on. US participation in multinational logistic support arrangements must be undertaken in accordance with these US legal authorities (DoD, 2002: III-15). Other nations will also have their own specific agreements and procedure. Normally, acquisitions must be accomplished by means of a Federal Acquisition Regulation contract. Transfers of defense goods and services to foreign nations must generally be done through a foreign military sales (FMS) agreement. In coalition operations, however, these methods might be cumbersome, time consuming, and inefficient. Under ACSA authority, the Secretary of Defense can enter into agreements for the acquisition of cross-servicing of logistic support, supplies, and services on a reimbursable, replacement-in-kind, or exchange for equal value basis (DoD, Apr 2000: III-10). Even though there are restrictions on the types of defense articles and services that can be provided to or purchased from other nations through ACSAs, this method constitutes an operationally flexible authority for exchanging logistic support between US and multinational forces, particularly in emergencies and unforeseen circumstances (DoD, 2002: III-15).

Host-Nation Support (HNS) Infrastructure: Availability of HNS infrastructure is critical to plan coalition logistic support since these resources, which can affect coalition operations significantly, are limited at certain levels. According to the JP 3-16, three steps are recommended: First, assess the ability of the HN to receive US and/or MNF personnel and equipment (e.g., ports and airfields). Second, determine the capability of transportation systems to move forces once they arrive in theater. Third, evaluate availability of logistic support. These must be recognized and addressed during the planning process. Generally Host nation militaries can grant the essential permission for the coalition not only to operate in ports, airfields, rail networks, road, and assembly areas but also to use fuel pipelines and other indispensable logistics infrastructures (Brich, 2004:5).

Authority: According to JP 3-16, the degree of authority assigned to MNFCs on the logistic support will depend upon existing agreements and ad hoc arrangements negotiated with participating nations and/or as identified in the campaign plan and/or OPLAN. Therefore, the authority is various depending on situations.

2.1.4. Communication and Language

Communications: Communications are an essential requirement for all operations and are especially critical for successful multinational operations due to different languages, different procedures, and different equipment. Planning considerations include frequency management, equipment compatibility, procedural compatibility, cryptographic and information security, identification friend or foe, and data-link protocols (DoD, Apr 2000: III-16). Therefore, the coalition commanders should address the following common problems: common or understandable language, common terms of reference, common procedures, and interoperable means to deliver the messages. According to the JP 3-16, many communications issues can be resolved through equipment exchange and liaison teams. A MNF planning and technical communications systems control centers should be established as soon as possible to coordinate all communications and information operations. Since communications requirements, however, vary with the mission, size, composition, geography, and location of the MNF, MNFCs should consider various situations before deciding these methods to solve communications problems (DoD, Apr 2000: III-16).

Languages: Different languages among participants in a coalition make a unity of effort difficult. In addition, the time required to receive information, process it, develop operational plans from it, translate it, and distribute them to multinational partners can adversely impact the speed and tempo of operations (DoD, Apr 2000: III-13). Operating in an environment of multiple languages also makes translation errors more likely. Special Operations Forces (SOF) who receive language training as part of their professional development, and contracted linguists, along with limited numbers of linguist trained soldiers, sailors and Marines, provide the coalition with the limited ability to overcome language barriers (Marich, 2000:17). The coalition commanders and staff should not only identify the available translator supports and multilingual liaison personnel, including contractors and HN resources, but should also consider how well these resources can be distributed to each national force. This can be a key consideration in any moderate to large size coalition effort.

2.1.5. Training

When the situation permits, MNFCs should seek opportunities to improve the contributions of member nation forces through training assistance and sharing resources consistent with agreements between alliance and coalition members, such as the loan of equipment (e.g., radios, vehicles, or weapons) (DoD, Apr 2000: III-20). Training is one of the next logical steps to coalition interoperability after the design and acquisition process (Black, 2000:10). In the case of coalition operations, training is critical for successful operations since multinational forces might have to carry out an assigned mission under unfamiliar environments with non-alliance countries. Therefore, a significant amount of time and major training effort are required for multinational forces to reach an operating standard that is acceptable to all participating nations. However, there are limitations on available time and place for training. Because of these circumstances, MNFCs and their staffs should schedule each national force's training in combined manners, considering many types of training (command post exercises, field training exercises, and simulation) as dictated by the operational situation.

2.1.6. Intelligence and Information

Intelligence tells commanders what their adversaries or potential adversaries are doing, what they are capable of doing, and what they may do in the future. Without efficient intelligence operations, commanders can not expect the success of military operations. Therefore, commanders are ultimately responsible for ensuring that intelligence is fully integrated into their plans and operations (DoD, Mar 2000: vi). In coalition operations, it is very important to share intelligence with foreign military forces and to coordinate receiving intelligence from those forces. That is, a shared situational awareness of the battle space is necessary for unity of command and unity of effort, mission deconfliction, and avoidance of duplication of effort. In coalition operations, however, sharing intelligence is one of the most difficult problems since there are no existing international standardization agreements. Nevertheless, each coalition must develop its own intelligence procedures, utilizing available assets that are tailored to the mission (DoD, Apr 2000: III-3).

Integrated policy and procedure: There is a great deal of doctrinal guidance and policy on intelligence. The release of classified information to MNFs is governed by national disclosure policy (NDP). Key among these policies is Director of Central Intelligence Directive (DCID) 5/6 and “National Policy and Procedures for the Disclosure of Classified Military Information to Foreign Governments and International Organizations” (also known as National Disclosure Policy or NDP-1) (Gramer, 1999:1). NDP-1 provides policy and procedures in the form of specific disclosure criteria and limitations, definition of terms, release arrangements, and other guidance. The following general principles provide a starting point for creating the necessary policy and procedures for coalition operations (DoD, Mar 2000: A-1):

- Maintain Unity of Effort: Intelligence personnel of each nation should think of a threat to one element of an alliance or coalition by the common adversary as a threat to all alliance or coalition elements.

- Make Adjustments: The differences in intelligence doctrine and procedures among the coalition partners, including procedures for sharing information, the degree of security afforded by different communications systems and procedures, classification levels, and personnel security clearance standards, are required to be solved.
- Plan Early and Plan Concurrently: It is needed to determine what intelligence may be shared with the forces of other nations early in the planning process.
- Share All Necessary Information: Coalition members should share all relevant and pertinent intelligence about the situation and adversary consistent with NDP and theater guidance. However, information about intelligence sources and methods can not be shared with coalition members until approved by the appropriate national-level agency since nations are reluctant to share all of their sources and methods of obtaining intelligence.
- Conduct Complementary Operations: Intelligence efforts of the nations must be complementary since each nation will have intelligence system strengths and limitations and unique and valuable capabilities.

Communications and Processing Architectures: It is imperative that an intelligence system should be devised for and by the MNF members that is capable of transmitting the most important intelligence rapidly to units due to the perishable nature of pertinent, releasable intelligence. Therefore, developing a standardized methodology for disseminating and exchanging intelligence is critical to the multinational architecture (DoD, Mar 2000: A-3). That is, the distribution of standardized equipment by one country's forces might be important to ensure commonality.

Coordination: Coalitions are frequently ad hoc organizations, created and disbanded relatively quickly. Therefore, it is imperative to compensate for the lack of standardization through coordination. The essential elements which need to be coordinated include communications architectures, friendly use of the electromagnetic spectrum, use of space and/or space assets, geographical location of intelligence collection assets, and targets of intelligence collection (DoD, Apr 2000: III-5). In order to carry out coordination about intelligence problems, MNFCs should consider organizing a multinational intelligence center, an intelligence liaison team, and multinational processing centers, particularly in the case of ad hoc coalitions (DoD, Mar 2000: A-3).

2.2. Military Operations Other Than War (MOOTW)

The types of military operations (War and Military Operations Other Than War) also affect the characteristics of the coalition operation, including common goals, command and control, logistics, and so on. Therefore, it is useful to understand the differences between War and MOOTW, and the types of MOOTW, in order to define characteristics of the coalition.

When instruments of national power are unable to achieve national objectives or protect national interests any other way, the national leadership may decide to conduct large-scale, sustained combat operations to achieve national objectives or protect national interests. In such cases, the goal is to win as quickly and with as few casualties as possible while achieving national objectives (DoD, 1995: I-1). But MOOTW focus on deterring war, resolving conflict, promoting peace, and supporting civil authorities in response to domestic crises (DoD, 1995: I-1). MOOTW may involve elements of both combat and noncombat operations in peacetime, conflict, and war situations. All military operations are driven by political considerations. However, MOOTW are more sensitive to such considerations due to the overriding goal to prevent, preempt or limit potential hostilities (DoD, Apr 2000: I-1).

In Joint Doctrine for MOOTW, 16 types of MOOTW are listed (DoD, 1995: III-1 – III-15). Some of these include:

- Arms Control: Arms control is a concept that connotes any plan, arrangement, or process, resting upon explicit or implicit international agreement. Arms control governs any aspect of the following: the numbers, types, and performance characteristics of weapon systems; and the numerical strength, organization, equipment, deployment or employment of the armed forces retained by the parties. Although it may be viewed as a diplomatic mission, the military can play an important role. For example, US military personnel may be involved in verifying an arms control treaty; seizing WMD (nuclear, biological and chemical or conventional); escorting authorized deliveries of weapons and other materials (such as enriched uranium) to preclude loss or unauthorized use of these assets; or dismantling, destroying, or disposing of weapons and hazardous material. All of these actions help reduce threats to regional security.
- Combatting Terrorism: Combatting terrorism involves actions taken to oppose terrorism from wherever the threat. It includes antiterrorism (defensive measures taken to reduce vulnerability to terrorist acts) and counterterrorism (offensive measures taken to prevent, deter, and respond to terrorism).

- Enforcing Exclusion Zones: An exclusion zone is established by a sanctioning body to prohibit specified activities in a specific geographic area. The purpose may be to persuade nations or groups to modify their behavior to meet the desires of the sanctioning body or face continued imposition of sanctions, or use or threat of force.
- Humanitarian Assistance (HA): HA operations relieve or reduce the results of natural or manmade disasters or other endemic conditions such as human pain, disease, hunger, or privation. Examples of humanitarian assistance are Operations SEA ANGEL I, conducted in 1991, and SEA ANGEL II, conducted in 1992, to provide assistance in the aftermath of devastating natural disasters in Bangladesh. More recently, Operation Unified Assistance for the Tsunami in December 2004 and the recent Pakistan Earthquake Relief Effort in 2005 are examples of coalition humanitarian assistance operations.
- Peace Operations (PO): POs are military operations to support diplomatic efforts to reach a long-term political settlement and categorized as peacekeeping operations (PKO) and peace enforcement operations (PEO). PKO are military operations undertaken with the consent of all major parties to a dispute, designed to monitor and facilitate implementation of an agreement and support diplomatic efforts to reach a long term political settlement. An example of a PKO is the US commitment to the Multinational Force Observers in the Sinai since 1982. PEO are the application of military force, or threat of its use, normally pursuant to international authorization, to compel compliance with resolutions or sanctions designed to maintain or restore peace and order. Examples

of PEO are Operation POWER PACK conducted in the Dominican Republic in 1965 and the secondary effort in Somalia (UNITAF), 1992-1993.

In addition to these examples, there are other types of MOOTW; DOD Support to Counterdrug Operations, Enforcement of Sactions/Maritime Intercept Operations, Ensuring Freedom of Navigation and Overflight, Military Support to Civil Authorities (MSCA), Nation Assistance/Support to Counterinsurgency, Noncombatant Evacuation Operations (NEO), Protection of Shipping, Recovery Operations, Show of Force Operations, Strikes and Raids, and Support to Insurgency

2.3. Coalition Operation for Humanitarian Assistance

If a Humanitarian Emergency exceeds the capability of HN, a Coalition could be formed to conduct HA Operations. These could be due to various reasons including political interests. For example, on 26 December 2004, the Indian Ocean earthquake struck off the northwest coast of the Indonesian island of Sumatra and spawned a tsunami that wreaked havoc along much of the rim of the Indian Ocean. Particularly hard-hit were the countries of India, Indonesia, Sri Lanka and Thailand. Over 280,000 people were killed, tens of thousands more were injured and over one million were made homeless. In the wake of the disaster, Australia, India, Japan and the United States formed a coalition to coordinate aid efforts to streamline immediate assistance (Wikipedia). As doctrine points out, even though HA operation is one type of MOOTW, the Coalition Operation for HA can be prepared in a similar manner as a general Coalition Operation (DoD, Apr 2000: IV-1).

2.3.1. Humanitarian Emergency and Required tasks

There is no universally accepted definitions of Humanitarian Emergency, but Lynch defined Humanitarian Emergency as

> An acute situation affecting a large population where through disruption or displacement neither the population nor its government is capable of providing for all of the basic needs (Lynch: 3).

This can be classified as natural disaster, technological disaster and complex humanitarian emergencies.

- Natural Disasters are life-threatening events that include floods, typhoons, earthquakes, tsunamis, volcanic eruptions, epidemics, famine, and fire (Davidson *et al.*, 1996: 4).
- Technological Disasters are manmade and include such events as chemical spills, radiological releases, and oil spills. The 1986 reactor disaster at Chernobyl is one example of this type of disaster (Davidson *et al.*, 1996: 4).
- Complex Humanitarian Emergency is a term used to describe the human disaster that follows war and civil strife (Lynch: 4).

The timing of climatic and geologic emergency is unpredictable. Unregulated industrialization, inadequate safety standards, and terrorist acts continue to create an increasing potential for industrial disasters. In addition, there has been a global increase in civil/ethnic strife which cause complex emergency (Lynch: 4). Furthermore, since these emergencies generally cause large damage which often overwhelm the Host Nation's capability, an international assistance response is more often required to deal with this situation.

Every disaster/emergency is unique in terms of the triggering event, climate, geography, culture/social structure and pre-existing status of the population affected. Therefore, required tasks and their priorities in the HA operation vary depending on the emergency situation; therefore a rapid assessment of the situation is desirable before determining which tasks are required.

2.3.2. Participants and Coordination Centers

Numerous organizations and agencies can participate in a coalition for HA. These can generally be divided by such criteria as Non-Governmental Organizations (NGO) and Governmental Organizations, or the Civilian organizations and the Military organizations (Davidson *et al.*, 1996; Lynch). Table II-2 represents possible participants in HA operation divided into two types; the Civilian players and the Military players.

Table II- 2: Potential Participants for HA Operation (Davidson *et al.*, 1996:34)

The Civilian Players	The Military Players
- United Nations Humanitarian Agencies • UNHCR, WFP, UNICEF, DHA.... - International Organizations (IOs) • ICRC, IFRC, IOM⋯. • NGOs: IRC, World Vision, ADRA⋯. • Donor Agencies: OFDA, ECHO⋯. • Host Government Authorities	- UN, NATO, Coalition • UNPROFOR / PRF / IFOR - Multinational - National / Indigenous Forces - Quasi-Military: UNMO, UNMP, CIVPOL

During recent military operations other than war (MOOTW), the U.S. military has become increasingly involved in humanitarian assistance efforts throughout the world. Assuming this trend continues, mission success may well depend upon effective interaction between the military and other HA organizations (Hinson, 1998: 2). However, each NGO is often unique with regard to its organizational structures, size and origin of resources, national ties, focus of activities, as well as access to and use of technology. These organizations often do not welcome or accept the military role in HA and will work to achieve their own goals and objectives, regardless of military support or coordination. Furthermore, NGOs are placing increased emphasis on emergency relief, especially in complex humanitarian emergencies. For example, 28 NGOs were involved in providing humanitarian aid during the Kurdish crisis in 1991, 170 NGOs were involved in Rwanda, and over 400 NGOs in Haiti (Davidson *et al.*, 1996:14). In view of these numbers, it is more important, but more difficult, to make a unity of efforts in a HA operation. The coalition needs to interact with the various NGOs, but they may not welcome such interaction, or they may choose to accept it only on their own terms.

Operation Provide Comfort, the 1991 operation to provide humanitarian relief to Kurds in northern Iraq, was a watershed in NGO/Interagency cooperation. It marked the first time that government agencies, NGOs and the military, despite different methods and motivations, worked so closely together in pursuit of a common goal. In addition, the experiences in Somalia (Operation Provide Relief), Haiti (Operation Restore Democracy), Bosnia (Operation Joint Endeavor), and Rwanda have proven that closer coordination among NGOs and the military can more effectively serve the goal of delivering humanitarian assistance (Davidson *et al.*, 1996:14; Hinson, 1998:5-12). Figure II-4 depicts the general pattern of coordination among the UN agencies, donor agencies, NGOs, and the military that has evolved in recent experience.

In Figure II-4, the mechanism for coordinating between “official” entities (national governments and UN agencies) and the NGO community is the Humanitarian Operations Center (HOC), which was first used in Somalia; the same function was performed by the On-Site Operations Coordination Center (OSOCC) in Rwanda and a Humanitarian Affairs Center (HAC) in Haiti (Davidson *et al.*, 1996; Hinson, 1998). The Civil Military Operations Center (CMOC) also had its origins in Operation Provide Comfort. Through coordination, the military gained efficiency and economy of effort from the NGOs, and the NGOs received logistical support, security, and information from the military and from other NGOs.

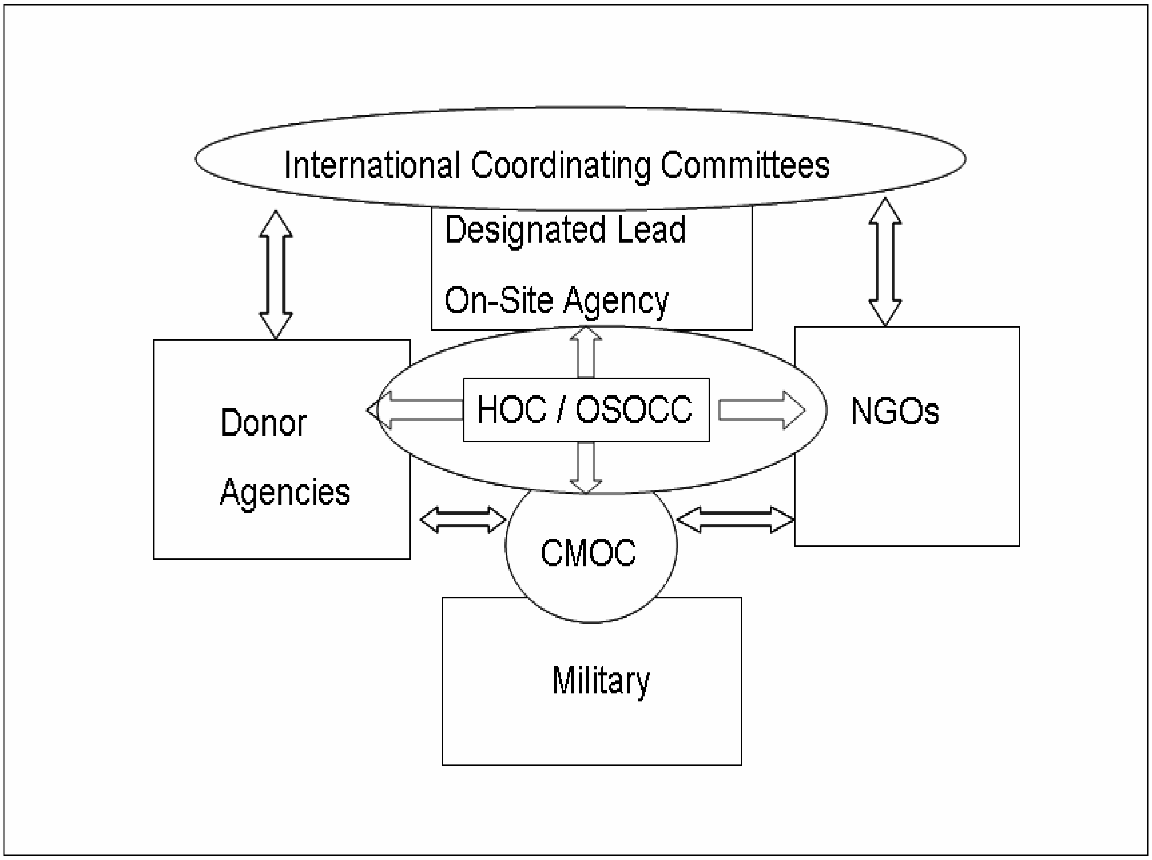
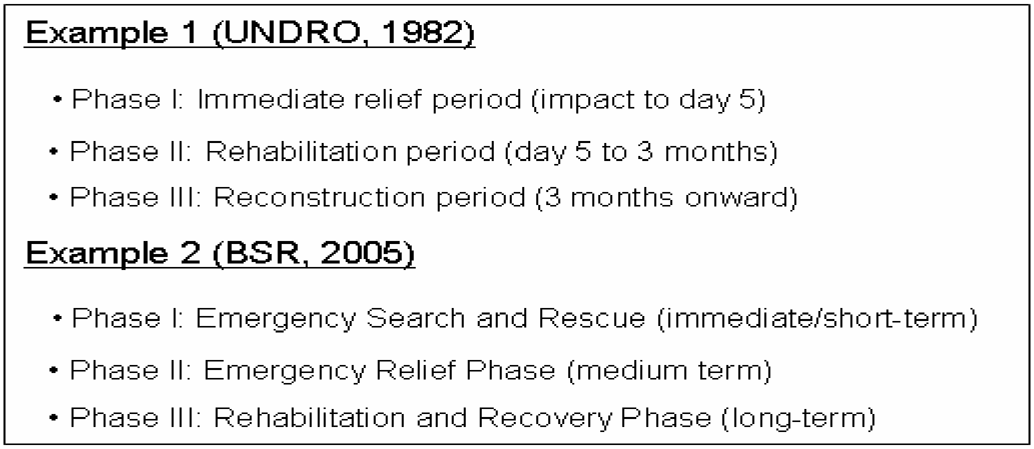


Figure II- 4: Coordination Structures in HA Operation (Davidson *et al.*, 1996:15)

2.3.3. Operational Phase in Humanitarian Assistance

The goals of a HA operation vary depending on operation phases. It is therefore useful to divide the entire operation into several phases which can help to define objectives and their priorities. In some references (UNDRO, 1982; BSR, 2005), the HA operation is divided into three phases. Figure II-5 represents examples of operation phases in HA. Time phases will vary depending on the local conditions, type of disaster, and so on.



Example 1 (UNDRO, 1982)

- Phase I: Immediate relief period (impact to day 5)
- Phase II: Rehabilitation period (day 5 to 3 months)
- Phase III: Reconstruction period (3 months onward)

Example 2 (BSR, 2005)

- Phase I: Emergency Search and Rescue (immediate/short-term)
- Phase II: Emergency Relief Phase (medium term)
- Phase III: Rehabilitation and Recovery Phase (long-term)

Figure II- 5: Example of phases in HA Operation

2.3.4. Existing Model

After required tasks are identified through a mission analysis in the HA Operation Center, one of the most important missions in the operation planning step may be to find the best assignment of available resources to operational tasks. The coalition commander must try to find an optimal way for assigning resources in both space and time to address the required tasks. Since emergency situations have various needs depending on type of disaster, degree of damage, geography, climate, and so on, different tasks are required to carry out a HA Operation in a Humanitarian Emergency. Furthermore, available resources in the Coalition have different characteristics with regard to quality and quantity, and may have different limitations as the coalition is usually composed of various multinational forces and organizations. The coalition commander should identify attributes for both required tasks and available resources before allocating available resources to tasks.

2.3.4.1. ARES Model

Brown and Vassiliou (1993) introduced a real-time decision support system, named ARES for the Greek god of war, which uses optimization methods, simulation, and the judgement of the decision maker for operational assignment of units to tasks, and for tactical allocation of units to task requirements. In this model, a scenario starts with the determination of tasks and task attributes derived in large part from standard cataloged data for similar tasks. Next, units are identified which might perform the tasks and unit attributes are established (Brown and Vassiliou, 1993:4). ARES is coordinated by a time-interval decision support simulator which scales and manipulates scenario data in a fashion transparent to the decision maker and employs a georeference system, a mobility system, a decision maker simulator, and extensive user interface and user override and control facilities (Brown and Vassiliou, 1993:3). As an example of the kind of problem ARES can address, a scenario following an earthquake is presented using some construction battalions as operational units, and some rehabilitation areas (road, bridges, drinking water systems, and so on) as tasks with the goal of completing repairs as quickly as possible.

ARES is composed of two sub-models, the Operational Assignment Model and the Tactical Allocation Model. It follows several steps.

- Step 1. Solve Operational Assignment Model: The Operational Assignment Model is designed to find operational assignments of tasks to units by using integer programming.

In this model, the objective is to minimize total cost of moving a distance. A general assignment algorithm is used, but logistical considerations are included in the constraints using goal programming with linear penalties (Brown and Vassiliou, 1993:6-9).

- Step 2. If the result of the Operational Assignment Model is acceptable to the decision maker, then go to step 3, otherwise modify the result manually and go to step 3, or restate the condition for the original operational assignment scenario and go to step 1.
- Step 3. Solve Tactical Allocation Model: The Tactical Allocation Model is designed to allocate the resources of each unit to the requirement of its assigned tasks by using a linear program with an objective of maximizing the efficiency of each resource used for each task (Brown and Vassiliou, 1993:9-10). Through the Operational Assignment Model in step 1, unit and task assignment, and unit movement are determined. Therefore, the tactical allocation model allocates resources using any logistic efficiency function of assigned distance, and of other attributes induced only from assignments such as weather effects, speed of unit movement, and so on.
- Step 4. The decision maker is presented with a complete immediate operational and tactical plan, which he can accept, or modify, or reject outright and reconstruct.

2.3.4.2. ALLOCATE Model

Fiedrich *et al.* (2000) presented the ALLOCATE Model which is designed to find the optimal schedule of available resources in order to minimize total fatalities from several operational areas for emergency response after earthquake disasters. In ALLOCATE, operational areas, which influence the number of fatalities, are identified as tasks, and resources are defined as the machines and equipment which can be used to work at the different operational areas. The different work tasks which influence the number of fatalities in ALLOCATE are (Fiedrich *et al.*, 2000:43):

- Search and rescue (SAR) work to rescue people out of collapsed buildings;
- Stabilizing work to prevent secondary disasters (e.g. dam failure, fire, etc.);
- Immediate rehabilitation of the transportation lifelines to improve the accessibility of relevant areas, such as hospitals, SAR areas or potential secondary disaster areas.

Therefore, three different operational areas are determined in this model; SAR areas, Stabilizing areas, and Immediate Rehabilitation areas.

For each operational area, different functions are used to estimate the number of fatalities depending on the effectiveness of assigned resources. The number of fatalities for each area is calculated using the following functions from Fiedrich *et al.*:

- Fatalities due to secondary disasters: To calculate the number of fatalities in a stabilizing area i for time interval (T^{m-1}, T^m), the failure probability, $\hat{p}_i$, has to be multiplied by the average number of people, $N_i(T^m)$, staying in the endangered area and by the probability α_i^{killed} of being killed. In addition, the percentage of completed work, $\hat{q}_i$, has to be considered. Therefore, the total number of fatalities due to a secondary disaster area i, $X_1(T^m)$, is calculated by the following function in ALLOCATE (Fiedrich *et al.*, 2000:50):

$$X_1(T^m) = \sum_i p_i\, q_i\, \alpha_i^{killed} N_i(T^M), where \quad i \in Secondary \quad disaster \quad areas$$

• Fatalities due to the duration of the rescue operation: A SAR area i has unique attributes; the initial number of victims n_i^0 and total initial workload V_i^0 which has to be removed or lifted to rescue all trapped persons. The average number of people being rescued in time interval (T^{m-1}, T^m) in SAR area i, $\Delta n_i(T^m)$, can be estimated using the function $\Delta n_i(T^m) = \frac{P_i}{V_i^0} n_i^0 (T^m - T^{m-1})$ where P_i is the performance of the assigned resources. Even though people in collapsed structures are rescued, some of them might already be dead, and some rescued people are seriously injured. Therefore, the number of persons rescued alive $X_{2,i}^{alive}(T^m)$ and dead $X_{2,i}^{killed}(T^m)$ is calculated for each SAR area in ALLOCATE by (Fiedrich *et al.*, 2000:50):

$X_{2,i}^{alive}(T^m) = G_i(0.5T^{m-1} + 0.5T^m)\Delta n_i(T^m), \quad \forall i \in SARarea$, where function $G_i(T)$ is the probability of surviving over time, $X_{2,i}^{killed}(T^m) = \Delta n_i(T^m) - X_{SAR,i}^{alive}(T^m), \quad \forall i \in SAR\ area$

The percentage of rescued persons with deadly injuries is estimated with $\alpha = 0.2$. Fiedrich *et al.* (2000:50) note that Kirchhoff's work suggests the use of an α of 0.2, which was the value used in ALLOCATE. Therefore, the total number of fatalities in SAR area is (Fiedrich *et al.*, 2000:50):

$X_2(T^m) = \sum_i X_{2,i}^{killed}(T^m) + \alpha X_{2,i}^{alive}(T^m)$, where $i \in SAR\ areas$

• Fatalities due to lack of rescue attempts: All persons who have not been rescued until the end of the SAR period T^{end} are assumed to be dead. Therefore, the number of unrescued persons can be calculated for each SAR area i by (Fiedrich *et al.*, 2000:51):

$$X_3 = \sum_i n_i^o - \sum_{T=T^0}^{T^{end}} \Delta n_i(T), where\ i \in SAR\ area$$

In addition to the above three types of fatalities, there are other fatalities caused by delayed transport, duration of transport, and lack of transport.

Fiedrich *et al* 's ALLOCATE Model is formalized as a dynamic combinatorial optimized model with an objective to minimize the total fatalities due to the several factors mentioned above. Because of the complexity of this model, heuristic solution procedures have been applied. Simulated Annealing (SA) led to the best results among different tested procedures (Fiedrich *et al.*, 2000:55).

2.4. Goal Programming

In coalition operations there might be multiple, potentially conflicting, objectives required to carry out the coalition missions; for example, minimizing completion time, minimizing resource consumption, or minimizing casualties. Multiple Criteria Decision Making (MCDM) techniques, like those in ARES, show promise as a methodology to formulate a statement of the coalition problems.

Goal programming (GP) is a powerful approach that has been proposed for the modeling, analysis and solution of multi-criteria optimization problems. Ignizio suggested that any problem that is a candidate for analysis by mathematical programming is suitable for GP. He presented a procedure which converts a baseline programming model into a GP model (Ignizio, 1985:15). This procedure is:

- Step 1: All objectives are transformed into goals. Any objective may be transformed into a goal by means of citing a specific target value or aspiration level associated with the goal. For example, an objective function, $Min \quad or \quad Max \quad f_i(x)$, can be converted as $f_i(x) \leq b_i$, $f_i(x) = b_i$, or $f_i(x) \geq b_i$, where b_i is the desired aspiration level of the decision maker, which may or may not be achieved. Therefore, goals may be further classified as either “hard” (i.e., rigid or inflexible) or “soft” (i.e., flexible) depending upon just how firm the desire is to achieve the target value.

- Step 2: Each goal is then rank ordered according to importance. As a result, the set of hard goals (i.e., rigid constraints) is always assigned the top priority or rank (designated typically as P_1). All remaining goals are then ranked, in order of their perceived importance, below the rigid constraint set.
- Step 3: Given that the solution procedure used in solving GP models requires a set of simultaneous linear equations, all of the goals must be converted into equations through the addition of logical variables. In LP, such logical variables are known as slack and surplus variables (and, when needed, artificial variables). In GP, these logical variables are termed deviation variables (Ignizio, 1985:24).

Goal programming focuses on minimizing the deviations between the goals themselves and what can be achieved within the given set of constraints rather than trying to maximize or minimize the objective criterion directly. These deviational variables are most often two dimensional, represented as both positive and negative deviations from each goal. In GP, the objective function minimizes these deviations based on the relative importance or preemptive priority weights assigned to them (Wise and Perushek, 2000:167).

Schniederjans suggests six basic steps in the formulation of a preemptive linear goal programming model. These steps are similar to that of a regular linear program but with slight additions. The steps are:

1. Define decision variables
2. State constraints
3. Determine the preemptive priorities (if need be)
4. Determine the relative weights (if need be)
5. State the objective function
6. State the nonnegativity or given requirements. (Schniederjans, 1995:21)

There are many applications of goal programming in the literature. Azaiez and Sharif (2005) developed a computerized nurse-scheduling model using 0-1 linear goal programming. In the nurse scheduling problem, there are multiple objectives which could be hospital objectives, nurses' preferences, and recommended policies. Given that satisfying all preferences while making an effective utilization of nurses seems infeasible, a number of priority levels are considered in developing the scheduling system, and required policies are formulated as model constraints while the remaining policies are modeled as soft constraints with different importance weights. Wise and Perushek (2000) demonstrate how goal programming can be used to provide an optimal allocation solution for the acquisitions funds in academic libraries within the context of conflicting and incommensurate goals. Hajidimitriou and Georgiou (2002) developed a goal programming model for partner selection decisions in international joint ventures.

2.5. Network Flow Problem

2.5.1. Minimum Cost Flow Problem

The minimum cost flow problem is the most fundamental of all network flow problems, and the objective of this problem is to determine a least cost movement of a commodity through a network in order to satisfy demands at certain nodes from available supplies at other nodes (Ahuja, *et al.*, 1993: 4; Bazaraa, *et al.*, 1997:420). The Minimum cost flow problem might arise in (Bazaraa, *et al.*, 1997:420):

- Logistics network where people and materials are being moved between various points in the world
- Movement of locomotives between points in a railroad network to satisfy power for trains at least travel cost
- Design and analysis of communication systems, oil pipeline systems, tanker scheduling problems, and a variety of other areas.

Let $G = (N, A)$ be a directed network with a flow cost c_{ij} and a capacity u_{ij} associated with every arc $(i, j) \in A$ (Ahuja, *et al.*, 1993: 296; Bazaraa, *et al.*, 1997:420; Bertsekas, 1998:9). Each node $i \in N$, has an associated supply, demand, or transshipment requirement $b(i)$, depending on whether $b(i) > 0$, $b(i) < 0$, or $b(i) = 0$, respectively (Ahuja, *et al.*, 1993: 296; Bazaraa, *et al.*, 1997:420; Bertsekas, 1998:6). The general formulation of minimum cost flow problems with the assumption that the data are integer is as follows (Ahuja, *et al.*, 1993:296; Bazaraa, *et al.*, 1997:420; Bertsekas, 1998:9):

$$\text{Minimize} \sum_{(i,j)\in A} c_{ij} x_{ij} \tag{4-1}$$

Subject to

$$\sum_{\{j:(i,j)\in A\}} x_{ij} - \sum_{\{j:(j,i)\in A} x_{ji} = b(i) \text{ for all } i \in N, \tag{4-2}$$

$$0 \le x_{ij} \le u_{ij} \text{ for all } (i,j) \in A, \tag{4-3}$$

where,

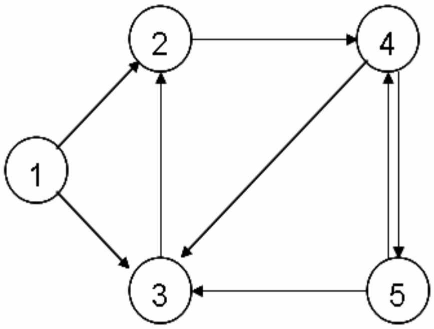
c_{ij} = The unit cost of moving product on arc (i, j)

x_{ij} = The units of flow from node i to node j

$b(i)$ = The requirement of units for nodes, where $\sum_{i=1}^{n} b(i) = 0$

u_{ij} = The upper capacity from node i to node j

There are various storage methods which can be used to capture the orientation of the network topology. One of them is the node-arc incidence matrix representation which stores the network as an $n \times m$ matrix A; this matrix contains one row for each node of the network and one column for each arc, where n and m represent the number of nodes and the number of arcs respectively (Ahuja, *et al.*, 1993:32; Bazaraa, *et al.*, 1997:425). An example of node-arc incidence matrix representation is shown in Figure II-6, and this representation is used in the formulation presented in this thesis. By using a node-arc incidence matrix representation, the constraint (4-2) can be represented as $Ax = b$.



Network Example

$$\begin{array}{c|cccccccc} & (1,2) & (1,3) & (2,4) & (3,2) & (4,3) & (4,5) & (5,3) & (5,4) \\ \hline 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 2 & -1 & 0 & 1 & -1 & 0 & 0 & 0 & 0 \\ 3 & 0 & -1 & 0 & 1 & -1 & 0 & -1 & 0 \\ 4 & 0 & 0 & -1 & 0 & 1 & 1 & 0 & -1 \\ 5 & 0 & 0 & 0 & 0 & 0 & -1 & 1 & 1 \end{array}$$

Node-arc incidence matrix of the network example

Figure II- 6: An example of node-arc incidence matrix (Ahuja, *et al.*, 1993:32)

2.5.2. Shortest Path Problem

The shortest path problem is to find a path of minimum cost from a specified source node s to another specified sink node t, assuming that each arc $(i, j) \in A$ has an associated cost c_{ij}. If the requirements of unit for a source node s, a sink node t, and all other nodes are $b(s) = 1$, $b(t) = -1$, and $b(i) = 0$ for $i \in N - \{s,t\}$, respectively, in the minimum cost flow problem, the solution to the problem will send one unit of flow from node s to node t along the shortest path (Ahuja, *et al.*, 1993:6; Bazaraa, *et al.*, 1997:572).

Let $G = (N, A)$ be a directed network defined by a set N of n nodes and a set A of m directed arcs. Each arc $(i, j) \in A$ has an associated cost $c_{i,j}$ that denotes the cost per unit flow on that arc. The network has distinct nodes s, called the source, and t, called the sink. The linear programming formulation of the shortest path problem, with the assumption that the data is integer, is as follows (Ahuja, *et al.*, 1993:94; Bazaraa, *et al.*, 1997:572; Bertsekas, *et al.*, 1998:10):

$$\text{Minimize } \sum_{(i,j)\in A} c_{i,j}x_{i,j} \tag{4-4}$$

Subject to

$$\sum_{\{j:(i,j)\in A\}} x_{i,j} = 1 \text{ for } i = s \tag{4-5}$$

$$\sum_{\{j:(i,j)\in A\}} x_{i,j} - \sum_{\{j:(j,i)\in A\}} x_{j,i} = 0 \text{ for all } i \in N - \{s,\ t\} \tag{4-6}$$

$$-\sum_{\{j:(j,i)\in A\}} x_{j,i} = -1 \text{ for } i = t \tag{4-7}$$

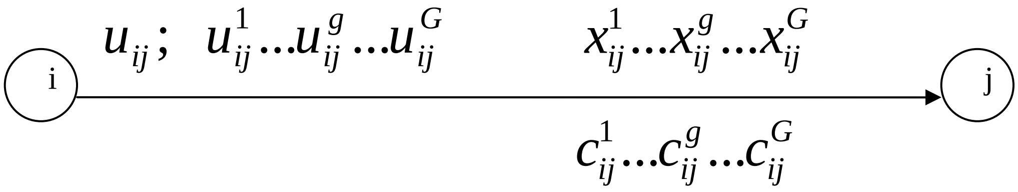
$$x_{i,j} \geq 0 \text{ for all } (i, j) \in A \tag{4-8}$$

This basic model has applications in many different problem domains, such as equipment replacement, project scheduling, cash flow management, message routing in communication systems, and traffic flow through congested cities (Ahuja, *et al.*, 1993:6).

2.5.3. Multi-Commodity Network Flow

In many application contexts, it is necessary to distinguish flows among several commodities since these commodities could share the same network. If the commodities do not interact in any way, then each single-commodity problem can be solved separately. If the commodities do share common facilities, like common arc capacities, however, it is necessary to solve the problem in concert with each other; this is known as the multi-commodity flow problem (Ahuja, *et al.*, 1993:649). The minimum cost multi-commodity network flow problem is described as the simultaneous shipping of commodities through a single network, while total flow obeys mutual and individual arc capacities at minimum cost (Goldber, *et al.*, 1997:1).

The limitations of an arc's total carrying capacity may impose a mutual flow capacity restriction on all the flows through the arc; clearly there may still be individual flow capacities for the different kinds of flow through a network (Jewell, 1966:7). Figure II-7 illustrates the idealized arc that will be considered in formulating an algorithm for multi-commodity flow problem (Jewell, 1966:9). In Figure II-7, u_{ij} represent the mutual flow capacity for arc (i, j) shared by each commodity. In order to satisfy network feasibility, it is required that the sum of flow of each commodity should be less than or equal to the capacity of the arc.



where $i, j = 1,2,..,N, \quad and \quad g = 1,2,...,G$

x_{ij}^{g} : non-negative flow of type g in (i, j)

u_{ij}^{g} : individual flow capacity of type g

u_{ij} : mutual flow capacity of arc (i, j)

c_{ij}^{g} : per-unit cost of type g flow

Figure II- 7: A Multi-Commodity Arc (Jewell, 1996: 7)

Let x_{ij}^{g} denote the flow of commodity g on arc (i, j), and let x^{g} and c^{g} denote the flow vector and per unit cost vector for commodity g where G is the number of commodities. Using this notation, the minimum cost multi-commodity network flow problem may be formulated as follows (Ahuja, *et al.*, 1993:650; Bazaraa, *et al.*, 1997:588; Bertsekas, *et al.*, 1998:17):

$$\text{Minimize } \sum_{1 \le g \le G} c^{g} x^{g} \tag{4-9}$$

Subject to

$$\sum_{\{j:(i,j)\in A\}} x_{ij}^{g} - \sum_{\{j:(j,i)\}} x_{ij}^{g} = b_{i}^{g} \text{ for all } i \in N \text{, and } g=1, 2,\ldots,G \tag{4-10}$$

$$\sum_{1 \le g \le G} x_{ij}^{g} \le u_{ij} \text{ for all } (i, j) \in A \tag{4-11}$$

$$0 \le x_{ij}^{g} \le u_{ij}^{g} \text{ for all } (i, j) \in A \text{, and } g=1, 2,\ldots,G \tag{4-12}$$

where N : Set of all nodes in a directed network

A : Set of all arcs in a directed network

b_{i}^{g} : Supply/demand of commodity g at node i

u_{ij} : Mutual capacity of arc (i, j)

u_{ij}^{g} : Capacity of arc (i, j) for commodity g

2.5.4. Assignment Problem

Assignment problems deal with the question how to assign a number of items (e.g. workers) to a number of locations (e.g. jobs). The assignment problem is a special case of the minimum cost flow problem where the network representation has a distinct form: the nodes can be partitioned into two sets N_1 and N_2 such that all arcs originate in N_1 and terminate in N_2 (Ahuja, *et al.*, 1993:7; Jensen and Barnes, 1980:4).

Let $G = (N_1 \cup N_2, A)$ is a directed bipartite network with $|N_1| = |N_2|$ and arc weights c_{ij}, where $|N_1|$ and $|N_2|$ represent the number of workers and jobs, respectively. Assume that each job must be done by exactly one person and that each person can do at most one job. The objective of the problem is to assign workers to the jobs in a way that the cost of completing all the jobs is minimized. This problem could be formulated as follows (Ahuja, *et al.*, 1993:471; Bertsekas, 1998:12):

$$\text{Minimize} \sum_{(i,j)\in A} c_{ij} x_{ij} \tag{4-13}$$

Subject to

$$\sum_{\{j:(i,j)\in A\}} x_{ij} = 1 \text{ for all } i \in N_1 \tag{4-14}$$

$$\sum_{\{j:(j,i)\in A\}} x_{ji} = 1 \text{ for all } i \in N_2 \tag{4-15}$$

$$x_{ij} \in \{0,\ 1\} \text{ for all } (i,\ j) \in A \tag{4-16}$$

2.5.5. Quadratic Assignment Problem (QAP)

The quadratic assignment problem (QAP) was first introduced by Koopmans and Beckmann as a combinatorial optimization problem, and the problem was stated as follows: Given n facilities and n locations, with a known flow between facilities and a known distance between locations, the objective is to assign facilities to locations such that a quadratic cost of the assignment is minimized (Koopmans and Beckmann, 1957).

This problem could be formulated as follows (Koopmans and Beckmann, 1957; Fedjki and Duffuaa, 2004):

$$\text{Minimize } \sum_{i}^{n} \sum_{j}^{n} c_{ij} x_{ij} + \sum_{i}^{n} \sum_{j}^{n} \sum_{k}^{n} \sum_{l}^{n} f_{ik} d_{jl} x_{ij} x_{kl} \tag{4-17}$$

Subject to

$$\sum_{i}^{n} x_{ij} = 1 \text{ for } \forall j = 1,\ldots,n \tag{4-18}$$

$$\sum_{j}^{n} x_{ij} = 1 \text{ for } \forall i = 1,\ldots,n \tag{4-19}$$

$$x_{ij} \in \{0,\ 1\} \tag{4-20}$$

where

x_{ij} =1 if facility i is located at location j, and 0 otherwise

f_{ik} : The flow from facility i to facility k

d_{jl} : The distance from location j to location l

The objective function (4-17) can be rewritten as follows (Bazaraa and Sherali, 1982; Chen, 1995; Kettani and Oral, 1993):

$\sum_{i}^{n} \sum_{j}^{n} \sum_{k}^{n} \sum_{l}^{n} c_{ijkl} x_{ij} x_{kl}$, where c_{ijkl} represent the interactive cost of simultaneously locating facility i at location j and facility k at location l.

The quadratic assignment problem covers a broad class of problems that involve the minimization of a total pair-wise interaction cost. That is, the quadratic assignment problem could be applicable in diverse areas in operations research and combinatorial data analysis. In addition to its application in facility location problems, it has a variety of applications in practical real world problems such as:

- Capital budgeting (Laughhunn, 1970)
- R&D project selection (Fox, et al., 1984)
- Facility layout design (Jacobs, 1987)
- Communication network design (Murphy and Ignizio, 1984)
- Scheduling (Geoffrion and Graves, 1976)
- Resource allocation (Ciriani, *et al*., 2004)

2.6. Summary

This chapter began with an overview of general coalition operations including humanitarian assistance and potential problems associated with them. Then, goal programming, minimum cost flow, shortest path problem, multi-commodity flow, assignment and quadratic assignment problems are introduced as modeling techniques. In Chapter III, these methods are applied to produce a methodology to make a Coalition Operation Planning Model in Humanitarian Assistance Operations.

III. Methodology

3.1. Description of Coalition Operation Planning Model

A coalition operation is generally complex due to its ad hoc characteristics as discussed in Chapter II. In particular political problems such as the inter-relationship among participants or between participants and a Host Nation, each national interest, and command and control, could significantly affect the planning of a coalition operation. Therefore, a coalition commander and staff should consider these political problems, in addition to the general problems mentioned in Chapter II, in the coalition operation planning step.

The purpose of the proposed Coalition Operation Planning Model is to help a coalition commander and his or her staff find an optimal coalition operation plan. This model is composed of three sub-models: the Coalition Mission-Unit Allocation Model, the Coalition Mission-Support Model, and the Coalition Mission-Unit Grouping Model. The general procedures of the Coalition Operation Planning Model are represented in Figure III-1. The description of each step follows:

- Step 1: Mission Analysis

In order to make a coalition operation plan, a mission analysis should be carried out in advance. Through the mission analysis, required tasks and their attributes can be determined, and available units and their attributes can be identified. The Coalition Operation Planning Model starts with the information of both the known required tasks and available units. It is recognized that conditions, resources, and requirements may change as the situation develops. However, initial planning must occur based on available information to initiate coalition operations.

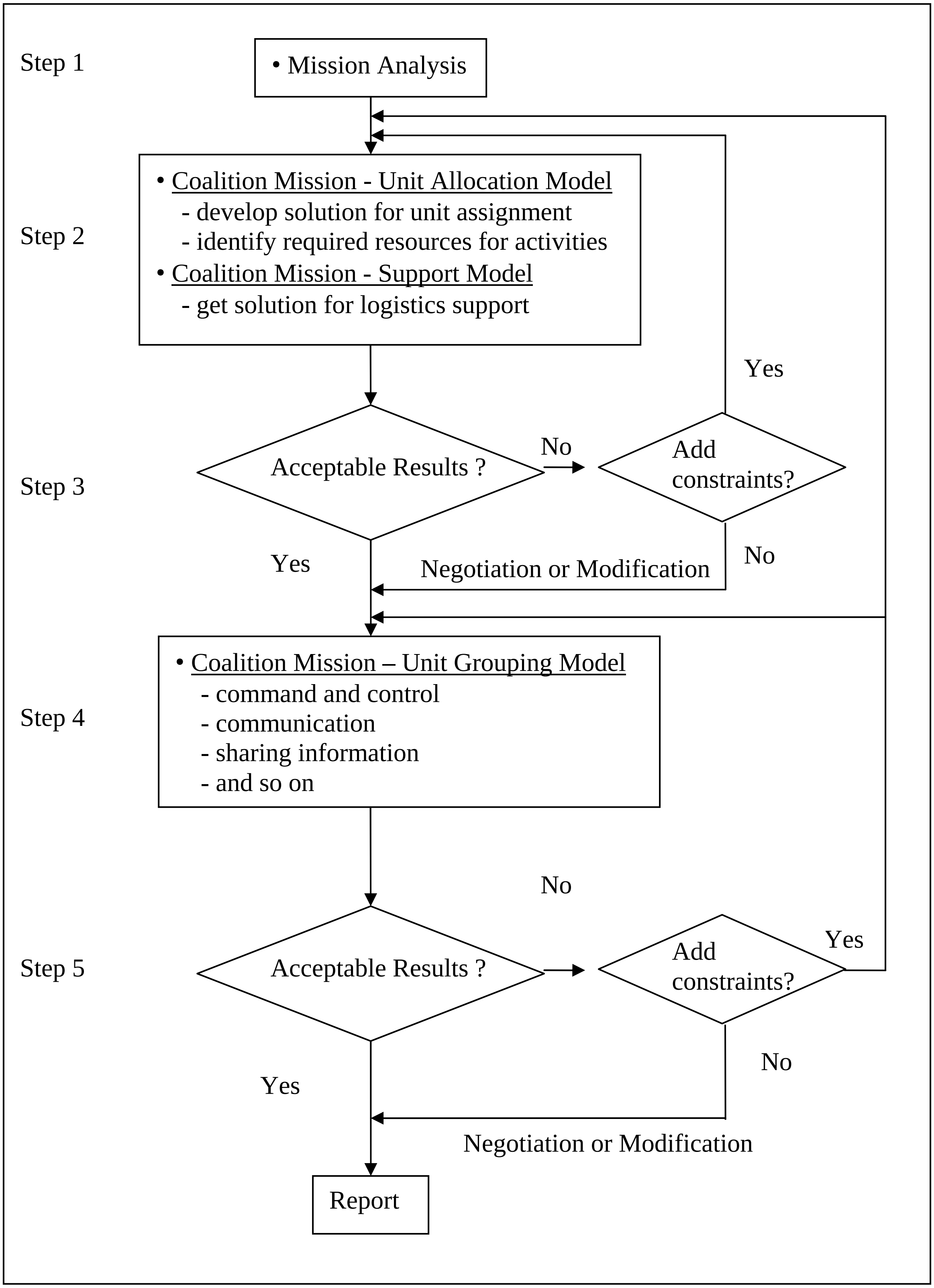


Figure III- 1: Coalition Operation Planning Model Procedure

- Step2: Coalition Mission-Unit Allocation Model / Coalition Mission-Support Model

A particular unit may be well suited for one task, but ill suited for another task since attributes of both units and tasks will vary in a coalition. Therefore, it is advisable to find an optimal units assignment to tasks in order to efficiently complete the coalition mission objectives; the Coalition Mission-Unit Allocation Model is designed to find an optimal units assignment for the known operational setting and limitations.

After a solution of unit assignment is obtained through Coalition Mission-Unit Allocation Model, the amount of each type of resource required for a particular unit's activities could be calculated by experts. Without logistics support, units could not carry out assigned tasks; the Coalition Mission-Support Model is designed to find an optimal logistics support plan.

- Step 3: Judgment or Modification of solutions from step 2

In this step, the political problems play important roles to judge whether the solutions of both unit assignment and logistics support is acceptable or not. For example, if the solution of unit assignment suggests dividing a national unit into several sub-units, then the coalition HQ or Coordination Center should review and perhaps negotiate that issue with that nation. If the specific coalition partner rejects the suggestion to divide its unit, then the analyst is required to return to step 2 adding constraints which restrict this problem, or to modify the solution. Obviously these constraints initially could be added in step 2, if each unit's divisibility is known. Besides this simple example, there could be many political problems in the solutions of both the Coalition Mission-Unit Allocation Model and the Coalition Mission-Support Model. Some of these requirements may not appear until a solution is proffered. As demonstrated in the above example, if the solutions obtained in step 2 involve unforeseen political problems, these could be mitigated by international negotiation or modification, or new solutions could be obtained by returning to step 2 with political constraints.

- Step 4: Coalition Mission-Unit Grouping Model

Several operational units may or may not operate independently. In addition, these units may not co-operate with each other due to the lack of communication equipment and linguists, incompatible system of organizations, political inter-relationship, and so on. Therefore, it may be necessary for some units assigned to a task be combined into one independent unit or augmented with different types of units or equipment. For example, if several units are assigned to a specific task, then grouping of these units may be necessary to assure a unity of effort. As another example, if a transportation unit is assigned to a location to transport resources, then this unit may not operate independently without security forces in the case of war or an emergency situation. The Coalition Mission-Unit Grouping Model is designed to group the coalition units into workable combined units.

- Step 5: Judgment or Modification of solutions from step 4

As with step 3, the solutions from step 4 might be modified or re-examined by adding some constraints in order to be acceptable.

3.2. Problem Statement of the Coalition Operation in Humanitarian Assistance

Coalition operations in Humanitarian Assistance will have numerous problems whose solutions can be supported using optimization methods. In the operation planning step after mission analysis, the coalition commander should try to find an optimal scheduling and allocation of known and available resources to carry out the mission successively. This is particularly critical since resources are generally limited. That is, he or she must plan to assign or reassign available resources to tasks determined from mission analysis. In this thesis, the Coalition Operation Planning Model in Humanitarian Assistance is developed to help the coalition HQ or Coordination Center find an effective operations plan in HA operations.

3.2.1. Situations

A humanitarian emergency has occurred causing significant damage within several countries. Since this humanitarian emergency exceeds the Host Nations' capabilities, a coalition is formed to conduct a HA operation. The entire operation is divided into three phases which are:

- Phase I: Immediate relief period (current time to day 7)
- Phase II: Rehabilitation period (day 7 to 3 months)
- Phase III: Reconstruction period (3 months onward)

It is assumed that the required tasks are determined through a mission analysis, and attributes of these tasks have been identified through rapid assessment. In addition, available resources and characteristics of these resources are recognized. The coalition commander and his staff should now try to find an optimal operation plan for allocating available resources for Humanitarian Assistance Phase-I operation. Phase-I operations are the focus of this study. The determined goals of the coalition operation are as follows:

- Goal 1: Minimizing total fatalities.
- Goal 2: Minimizing the number of suffering people; sick, homeless, starving people, and so on.

3.2.2. General Assumptions

- In a HA operation, there may be many participants from various organizations including various militaries, government organizations, NGOs, and so on. These organizations generally would like to control their units in order to achieve their own goals. However, it is assumed that coordination centers like HOC, OSOCC, and CMOC, are organized in order to efficiently control all available units.
- Further, it is assumed that, at least for the governmental and military units: there is no change of the inter-relationship between partners due to political problems after an operation plan is completed.
- The coalition commander or the coordination centers has the authority of assigning each unit to tasks and the authority to use the host nation's infrastructures.
- The coalition commander or the coordination center has the authority to combine several separate political forces into one unit which can operate independently, subject to any established political restraints.
- The cost for supporting logistics has already been established by international negotiation.

3.2.3. Attributes for required tasks and available resources in HA operation

In order to allocate each resource (Non-renewable or Renewable) to tasks (Operational areas) efficiently, it is necessary to identify attributes (characteristics) of various resources and tasks as completely as possible.

3.2.3.1. Required tasks (Operational Areas) for HA Phase-I operation

In a humanitarian emergency, there are numerous required tasks which should be carried out. The importance of these tasks is dependent on the emergency situation and operational goals (Lynch). Fiedrich *et al.* (2000) identified the required key tasks as Search and Rescue work, Stabilizing work, and immediate Rehabilitation work for Phase-I operation. In this thesis, six tasks are included; obviously other tasks can also be included depending on the emergency situation. These tasks and notations follow:

- Search and Rescue (SAR) work to rescue people in collapsed structures

$SA = \{sa_1, ..., sa_{nSA}\}$ represents the set of SAR areas

- Stabilizing work to prevent secondary disasters (e.g. dam failures, fire, etc)

$TA = \{ta_1, ..., ta_{nTA}\}$ represents the set of Stabilizing areas

- Immediate rehabilitation of the transportation lifelines to improve the accessibility of relevant area, such as hospitals, SAR areas or potential secondary disaster areas

$RA = \{ra_1, ..., ra_{nRA}\}$ represents the set of immediate Rehabilitation areas

- Medical treatment to stabilize and save injured people

$MA = \{ma_1, ..., ma_{nMA}\}$ represents the set of Medical areas

- Shelter construction work to save the life of homeless people

$SHA = \{sha_1,...,sha_{nSHA}\}$ represents the set of shelter areas which must be established

- Resource transportation work for both unit activities and relief items

$SP = \{sp_1,...,sp_{nSP}\}$ represents the set of supply points (ports of entry)

$DP = \{dp_1,...,dp_{nDP}\}$ represents the set of demand points

$TP = \{tp_1,...,tp_{nTP}\}$ represents the set of transshipment points

The entire operational area could be partitioned into several operational regions by nationality or geographical characteristics; $OA = OR_1 \cup OR_2 \cup .. \cup OR_N$, where OA represents the entire operational area, OR represents the operational region, and N represents the number of operational regions. Obviously, an operational region could require several tasks; $OR_i = \{sa_{i1}..sa_{is}, sha_{i1}..sha_{ish}, ma_{i1}..ma_{im,}...\}$. For example, if many houses in a city are destroyed due to an earthquake, then they might need SAR work, Medical treatment, Shelter construction work, and so on. Within a specific operational region, there can be several small areas which require the same work or a sub set of the regional tasks. At the level of aggregation, it is assumed that the distance between these sub-areas can be treated as negligible. Therefore, at the command level, it will be assumed that these small areas within the same operational region which need the same work can be considered as one area. Therefore, several required tasks can be combined into one task, and the number of tasks, for modeling purposes, can be reduced. This obviously creates a general requirement in deciding regions.

The specific attributes of each task could be estimated through rapid assessment (Schweier and Markus, 2004; Schweier *et al*., 2004). These attributes, which must be determined, are different for each type of task. For example, the required attribute sets for a search and rescue task might be {the number of trapped people, type of collapse, initial workload, language, and so on}, and the attribute's set of stabilizing tasks for a secondary disaster might be {the failure probability, the number of people staying in the endangered area, and so on}. These attribute sets should be considered with attribute sets of assigned resources since the goal is to allocate available resources to tasks efficiently. While clearly estimates are established in the initial assessment of the area, these attributes will be considered accurate until more accurate data is developed or obtained from the field. Sensitivity analysis should be conducted to test the robustness of these assumptions.

3.2.3.2. Potential Resources for HA Phase-I Operation

Fiedrich *et al.* (2000: 44) defined resources as machines and equipments such as crane, hydraulic excavator, dozer, roller, and so on. In a coalition operation, however, various equipments can not operate independently. Therefore, it is reasonable that units exist or are found which can operate independently. A given unit's needs are considered as renewable resources and non-renewable resources for both unit activities and relief items. Brown and Vassiliou (1993) used construction units and construction materials as resources in the ARES Model.

During HA Phase-I operation, various types of units might be required, but for demonstration purposes Search and Rescue (SAR), Construction, Medical, and Transportation units are included in this model. The notations for these units are as follows:

- $S = \{s_1, .., s_{ns}\}$: The set of all available Search and Rescue units

- $C = \{c_1,..,c_{nc}\}$: The set of all available Construction units
- $M = \{m_1,..,m_{nm}\}$: The set of all available Medical units
- $T = \{t_1,..,t_{nt}\}$: The set of all available Transportation units

As mentioned in Chapter II, the assignment of a particular unit could be restricted to a certain Host Nation due to national goals or interests in the coalition operation. In addition, some national or organizational units could be unacceptable for carrying out a certain task by a particular host nation due to political issues, religious consideration, and so on. Therefore, it is necessary to identify each type of unit within organizational units. The notation follows:

- $S_n = \{s_s,..s_{sn}\}$: The set of available Search and Rescue units in organization n
- $C_n = \{c_c,..c_{cn}\}$: The set of available Construction units in organization n
- $M_n = \{m_m,..m_{mn}\}$: The set of available Medical units in organization n
- $T_n = \{t_t,..t_{tn}\}$: The set of available Transportation units in organization n

3.3. Coalition Mission-Unit Allocation Model

After identifying required tasks and their attributes through mission analysis and rapid assessment, the coalition commander and his staff should try to determine an optimal assignment of units to tasks. The Coalition Mission-Unit Allocation Model is designed to find an optimal allocation of potential units over a time period; SAR units, Construction units, and Medical units are included for the Coalition Mission-Unit Allocation Model in this thesis.

There is a great deal of work in the literature concerning machine scheduling and project planning models (Al-Fawzan and Haouari, 2005; Pritsker et al, 1969; Lee and Kim, 1996), but moving times of the units from and to operational tasks are often neglected. This would be akin to scheduling with variable setup time. In addition, in Phase-I operations time is a critical consideration. The Shortest Path Problem is applied to find an efficient path for each unit by considering moving times.

3.3.1. Application of Shortest path problem to Unit Assignment

In HA operations, a critical factor which affects planning is response time. Therefore, the information for travel time estimates should be included in this model to find an optimal allocation of each unit. Again, this is a critical element developed from the initial assessment. Clearly, as roads and other transportation systems may have sustained damage, adjustments in travel time estimates must be made to reflect transportation systems conditions. Since each type of unit is fitted for different tasks, the same number of the directed networks as the number of types of units is required. In this model, three different networks are required since three types of units, SAR units, Construction units, and Medical units, are included in this model.

Let $G(S) = (N(S), A(S))$, $G(C) = (N(C), A(C))$, and $G(M) = (N(M), A(M))$ be a directed network for SAR units, Construction units, and Medical units, respectively. Here, each directed network is composed of potential nodes which contain information on possible tasks and time periods, and potential arcs which mean efficient assignments from and to tasks.

Figure III-2 represents an example of a directed network for SAR units. Since both SAR (Search and Rescue) unit and SA (Search and Rescue Area) have different attributes, it is necessary for each SAR unit to find an efficient path which satisfies the objectives.

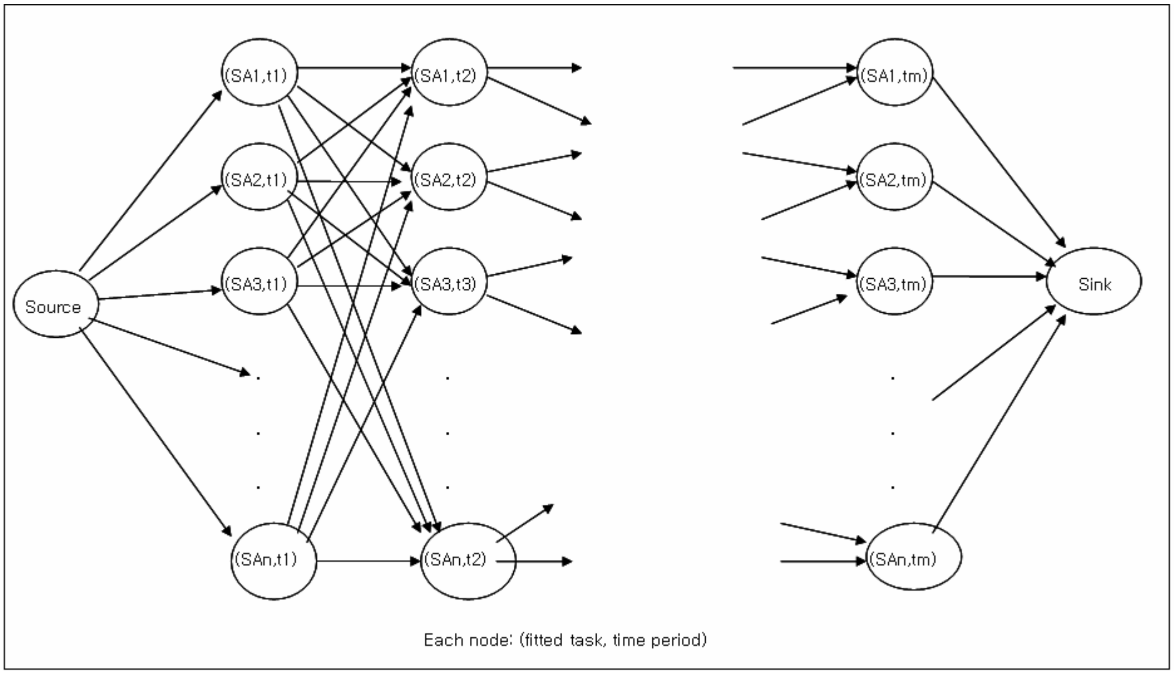


Figure III- 2: An example of a directed network for SAR unit's assignment

While the network in figure III-1 depicts every possible assignment, clearly not all of these will be efficient or feasible. The potential size of the problem can be reduced via pre-processing.

3.3.2. Size of the problem

The size of the problem could be expanded depending on the number of required tasks, available units, and time periods. However, similar tasks could be combined into one task within an operational region. In addition, the size of available units considered by the commander is different according to the command level. For example, the coalition commander might consider army or air divisions as units, but the battalion or squadron could be considered as units for a regional commander. This model could be used for each level's commander. The time period could also be aggregated depending on the operation phase. Therefore the size of problem could be reduced in this model.

3.3.3. Coalition Mission-Unit Allocation Model formulation for HA Phase-I Operation

3.3.3.1. Goals

During a HA Phase-I operation, one of the most critical goals is to minimize fatalities due to the lack of search and rescue work, shelter, medical treatment, and so on. A secondary goal considered by this model is to minimize the number of untreated patients in order to relieve suffering. Using preemptive priorities, this problem is formulated as a Goal Program.

3.3.3.2. Assigning SAR units to SA

- Definitions and Notations

S : Set of SAR Units

S^I : Set of SAR Units which are not allowed to be divided into several sub-units

$N(S)$: Set of nodes which exclude source and sink in $G(S)$

$A(S)$: Set of arcs in $G(S)$

$e^S_{i,j,k}$: Effectiveness of SAR unit i assigned to arc $(j,k) \in A(S)$

n^{SA}_k : Initial number of collapsed people in SA k

V^{SA}_k : Initial workload which has to be removed in SA k

$G^{SA}_{k(t)}$: Probability of rescued people in SA *k* at time *t* surviving

$RP^{SA}_{k(t)}$: Number of rescued people in SA *k* at time *t*

$RF^{SA}_{k(t)}$: Number of reduced fatalities in SA *k* at time *t*

- Decision variables

$XS_{i,j,k}$: The proportion of SAR unit *i* assigned to arc (j,k)

for all $i \in S$, and all $(j,k) \in A(S)$

- Assumptions and Constraints

In the ALLOCATE Model (Fiedrich *et al.*, 2000), the effectiveness for a specific SA (Search and rescue Area) is calculated depending on machines and equipment assigned to that SA. Following Fiedrich *et al'* s work, it is assumed that the effectiveness of SAR unit assigned to a SA can be estimated by considering both unit attributes and task attributes. Unit attributes might include quantity and quality of equipment, the degree of training, initial location, and so forth. Task attributes might include type of collapsed building, required language, distance between SAs, and so on. Here, travel time for both initial assignment and reassignment should be considered to estimate effectiveness for each unit. As developed in Chapter II, the number of rescued people from SAR unit *i* in SA *k* at time *t*, $RP^{SA}_{i,k(t)}$, can be calculated by (Fiedrich *et al.*, 2000):

$$RP^{SA}_{i,k(t)} = \frac{n^{SA}_k}{V^{SA}_k} \cdot \left(\sum_{\{j:(j,k(t) \in A(S)\}} e^{S}_{i,j,k(t)} \cdot XS_{i,j,k(t)} \right) \text{ for all } i \in S \text{, and } k(t) \in N(S)$$

Since some of the rescued people may have already died, multiplying $RP_{i,k(t)}^{SA}$ by the probability of surviving over time is required to estimate the reduced fatalities in SA *k* at time *t* (Fiedrich *et al.*, 2000):

$$RF_{k(t)}^{SA} = \sum_{i \in S} G_{k(t)}^{SA} \cdot RP_{i,k(t)}^{SA} \text{ for all } k(t) \in N(S)$$

3.3.3.3. Assigning Construction Units to TA

- Definitions and Notations

C : Set of Construction Units

C^I : Set of construction units which are not allowed to be divided into sub-units

$N(C)$: Set of nodes which exclude Source and Sink in $G(C)$

$N(TA)$: Set of nodes which are only associated to TA in $G(C)$

$A(C)$: Set of arcs in $G(C)$

$A(TA)$: Set of arcs which are only associated to TA in $G(C)$

$e_{i,j,k}^{TA}$: Reduced probability due to activity of unit $i \in C$ for each arc $(j,k) \in A(TA)$

α_k^{TA}: Percentage of people that will be dead due to secondary disaster in TA *k*

$n_{k(t)}^{TA}$: Number of people which stay in TA *k* at time *t*

$RF_{i,k(t)}^{TA}$: Number of reduced fatalities due to activity of construction *i* in TA *k* at time *t*

$FP_{k(t)}^{TA}$: Initial failure probability in TA *k* at time *t*

- Decision variables

$XC_{i,j,k}$: The proportion of Construction unit *i* assigned to arc (j,k)

for all $i \in C$,and all $(j,k) \in A(C)$

- Assumptions and Constraints

In the ALLOCATE Model (Fiedrich *et al.*,2000), the number of fatalities in a stabilizing area is calculated by using the decreased failure probability density function depending on assigned equipment and machines. Therefore, it is assumed that the reduced probability, $e_{i,j,k}^{TA}$, due to the activity of construction units *i*, can be estimated by experts. The number of reduced fatalities due to activity of construction unit *i* in TA *k* at time *t*, $RF_{i,k(t)}^{TA}$, is estimated by:

$$RF_{i,k(t)}^{TA} = \alpha_k^{TA} \cdot n_{k(t)}^{TA} \cdot \left(\sum_{\{j:(j,k(t) \in A(C)\}} e_{i,j,k(t)}^{TA} XC_{i,j,k(t)} \right) \text{ for all } i \in C \text{, and all } k(t) \in N(TA)$$

3.3.3.4. Assigning Construction Units to RA

- Definitions and Notations

$N(RA)$: Set of nodes which are only associated to RA in $G(C)$

$A(RA)$: Set of arcs which are only associated to RA in $G(C)$

$e_{i,j,k}^{RA}$: Effectiveness of construction unit *i* for each arc $(j,k) \in A(RA)$

$TE_{k(t)}$: Total effectiveness in the RA *k* at time *t*

RE_k : Required effectiveness for RA *k* to be accessible

- Decision variables

$y_{k(t)}^{RA}$ =1 if RA *k* is accessible at time *t*, otherwise 0 for all $k(t) \in N(RA)$

- Assumptions and Constraints

In order to make a rehabilitation area accessible, the model uses two reasonable constraints. One constraint is the demand for a minimum number of construction units. That is, at least some number of construction units should be assigned to a RA in order to make that RA accessible. Another constraint is the demand of the minimum time to make that area accessible. Therefore, it is assumed that each RA requires at least some amount of effectiveness and minimum time to be accessible. Here, linear equations are used to calculate total effectiveness in a RA which follows:

$$TE_{k(t)} = TE_{k(t-1)} + \sum_{i \in C} \sum_{\{j:(j,k(t)) \in A(C)\}} e^{RA}_{i,j,k(t)} \cdot XC_{i,j,k(t)} \text{ for all } k(t) \in N(RA)$$

In this model, binary variables, $y^{RA}_{k(t)}$, are used to represent the accessibility for each RA over a time period. As mentioned above, there could be two constraints which are as follows:

$$TE_{k(t)} \geq RE_k \cdot y_{k(t+1)} \text{ for all } k(t) \in N(RA)$$

$$y^{RA}_{k(t)} = 0 \text{ for all } k(t) \in N(RA)$$

where time *t* is less than the minimum time required to be assessable

3.3.3.5. Assigning Construction Units to SHA

- Definitions and Notations

$N(SHA)$: Set of nodes which are only associated to SHA in $G(C)$

$A(SHA)$: Set of arcs which are only associated to SHA in $G(C)$

$e_{i,j,k}^{SHA}$: Number of people who can be served with temporary shelters due to activity of construction unit *i* for each arc $(j,k) \in A(SHA)$

$G_{k(t)}^{SHA}$: Probability of causing disease for homeless people in SHA *k* at time *t*

$\alpha_{k(t)}^{SHA}$: Percentage that homeless patients will be dead in SHA *k* at time *t*

NS_{k}^{SHA}: Initial number of homeless people in SHA *k*

$F_{k(t)}^{SHA}$: Number of fatalities in SHA *k* at time *t*

$P_{k(t)}^{SHA}$: Number of patients in SHA *k* at time *t*

- Decision variables

$NS_{k(t)}^{SHA}$: Number of homeless people in SHA *k* at time t

$SS_{k(t)}^{SHA}$: Number of people who are served with temporary shelter in SHA *k* at time *t*

- Assumptions and Constraints

In humanitarian emergencies, a number of houses could be destroyed leaving many people homeless. Therefore, it is necessary to construct emergency shelters in order to save homeless people. There are eight basic types of post-disaster shelter, each with different characteristics (UNDRO, 1982: 26-34). In this model, it is assumed that the type of shelter for a damaged region is decided by considering several factors: construction time, cold weather, HN strategies, cost, and so on (UNDP, 2000: 31-54; UNDRO, 1998). In addition, it is assumed that the effectiveness of construction unit *i* for each region, $e_{i,j,k}^{SHA}$, can be estimated by experts. Here the effectiveness represents the number of people who can be served with emergency shelter.

The number of people effectively served with emergency shelter, $SS^{SHA}_{k(t)}$, is restricted due to total effectiveness and initial number of homeless people. These constraints are:

$$SS_{k(t)} \le \sum_{i \in C} \sum_{\{j:(j,k(t)) \in A(C)\}} e^{SHA}_{i,j,k(t)} \cdot XC_{i,j,k(t)} \text{ for each } k(t) \in N(SHA)$$

$$\sum_{t} SS^{SHA}_{k(t)} \le NS^{SHA}_{k} \text{ for each } k(t) \in N(SHA)$$

The number of homeless people in SHA *k* at time *t* can be calculated by using the following equation:

$$NS^{SHA}_{k(t)} = NS^{SHA}_{k} - \sum_{t' \le t} SS^{SHA}_{k(t')} \text{ for each } k(t) \in N(SHA)$$

The attributes of each region affect the importance of emergency shelter, and the weather could be one of the most significant attributes in a shelter project. Kelly (2002) states that cold weather should be systematically included as a normal part of planning and managing humanitarian response activities. Here, it is assumed that probability causing both fatalities and patients can be estimated considering regional attributes, especially cold weather, by experts. The number of patients and fatalities can be calculated by:

$$P^{SHA}_{k(t)} = G^{SHA}_{k(t)} NS^{SHA}_{k(t)} \text{ for each } k(t) \in N(SHA)$$

$$F^{SHA}_{k(t)} = \alpha^{SHA}_{k(t)} NS^{SHA}_{k(t)} \text{ for each } k(t) \in N(SHA)$$

3.3.3.6. Assigning Medical Units to MA

- Definitions and Notations

M : Set of Medical units

M^I : Set of medical units which are not allowed to be divided into sub-units

$N(M)$: Set of nodes which exclude Source and Sink in $G(M)$

$A(M)$: Set of arcs in $G(M)$

$N(S \cap M_{k(t)})$: Set of nodes in $N(S)$ associated with $k(t) \in N(M)$

$N(SHA \cap M_{k(t)})$: Set of nodes in $N(SHA)$ associated with $k(t) \in N(M)$

$e^M_{i,j,k}$: Capacity of medical unit i for each arc $(j,k) \in A(M)$

$p^{SA}_{v(t),h}$: Percentage of patient level h in SA v at time t

$p^{SHA}_{w(t),h}$: Percentage of patient level h in SHA w at time t

$P_{k(t),h}$: Number of patients for each type h in MA k at time t

$NP_{k(t),h}$: Number of common patients for type h in MA k at time t

t_h : Required time to treat patients for each type h

α^M_h : Percentage of untreated patients which will be dead for type h

$F^M_{k(t),h}$: Number of fatalities due to lack of medical treatment in MA k at time t for type h

$UP_{k(t),h}$: Number of untreated patient for type h in MA k at time t

- Decision variables

$XM_{i,j,k}$: The proportion of Medical unit i assigned to arc (j,k)

for all $i \in M$, and all $(j,k) \in A(M)$

$TP_{k(t),h}$: Number of treated patient for type h in MA k at time t

- Assumptions and Constraints

The capacity of medical unit could be restricted by the number of available doctors. In this model, the capacity of each medical unit, $e^{M}_{i,j,k}$, is calculated by multiplying working time per certain period for each doctor by the number of available doctors. Required medical care for each patient will vary depending on injury severity level. Therefore, the patients are divided into several levels using estimated percentage for each level. Here, it is assumed that each percentage, $p^{SA}_{v(t),h}$ or $p^{SHA}_{w(t),h}$, can be estimated considering type of disaster, operational time period, and so on.

The number of patients for each level can be calculated by the following equation:

$$P_{k(t),h} = \sum_{v(t)\in N(S\cap M_{k(t)})} p^{SA}_{v(t),h} \cdot RF^{SA}_{v(t)} + \sum_{w(t)\in N(SHA\cap M_{k(t)})} p^{SHA}_{w(t),h} P^{SHA}_{w(t)} + NP_{k(t),h}$$

$$\text{for each } k(t) \in N(M)$$

The number of treated patients should be restricted due to both the capacity of assigned medical units and the number of patients. These constraints are:

$$\sum_{h} t_h TP_{k(t),h} \le \sum_{i\in M} \sum_{\{j:(j,k(t))\in A(M)\}} e^{M}_{i,j,k(t)} \cdot XM_{i,j,k(t)} \text{ for each } k(t) \in N(M)$$

$$TP_{k(t),h} \le P_{k(t),h} \text{ for each } k(t) \in N(M)$$

3.3.3.7. Mathematical Formulation of the Coalition Mission-Unit Allocation Model

Given the preceding development, the Coalition Mission-Unit Allocation Model for HA Phase-I Operation can be formulated as follows:

Minimize

$$P_1[\ -w_{SA}^F(\sum_{k(t)\in N(S)} RF_{k(t)}^{SA}) \tag{3-1}$$

$$-w_{TA}^F(\sum_{i\in C}\ \sum_{k(t)\in N(TA)} RF_{i,k(t)}^{TA}) \tag{3-2}$$

$$+w_{SHA}^F(\sum_{k(t)\in N(SHA)} F_{k(t)}^{SHA}) \tag{3-3}$$

$$+w_{MA}^F(\sum_{h}\ \sum_{k(t)\in N(M)} F_{k(t),h}^{MA})\ \ ] \tag{3-4}$$

$$+P_2[\sum_{h}\ \sum_{k(t)\in N(M)} w_h^{UP} UP_{k(t),h}^{MA}] \tag{3-5}$$

Subject to

<u>SAR Units</u>

• Mass flow balance constraints (3-6)

$$\sum_{\{k:(j,k)\in A(S)\}} XS_{i,(j,k)} - \sum_{\{k:(k,j)\in A(S)\}} XS_{i,(k,j)} = 0 \text{ for all } i\in S \text{, and all } j\in N(S)$$

$$\sum_{\{j:(j,k)\in A(S)\}} XS_{i,(j,k)} = 1 \text{ for all } i\in S \text{, and } j=s$$

$$\sum_{\{j:(k,j)\in A(S)\}} XS_{i,(k,j)} = 1 \text{ for all } i\in S \text{, and } j=t$$

• Effectiveness Functions in SA

$$RP_{i,k(t)}^{SA} = \frac{n_k^{SA}}{V_k^{SA}}\cdot(\sum_{\{j:(j,k(t)\in A(S)\}} e_{i,j,k(t)}^{S}\cdot XS_{i,j,k(t)}) \text{ for all } i\in S \text{, and } k(t)\in N(S) \tag{3-7}$$

$$RF_{k(t)}^{SA} = \sum_{i\in S} G_{k(t)}^{SA}\cdot RP_{i,k(t)}^{SA} \text{ for all } k(t)\in N(S) \tag{3-8}$$

- Constraints for the Maximum number of rescued people in SA

$$\sum_{i \in S} \sum_{t} RP^{SA}_{i,k(t)} \le n^{SA}_{k} \text{ for all } k \in N(S) \tag{3-9}$$

<u>Construction Units</u>

- Mass flow balance constraints (3-10)

$$\sum_{\{k:(j,k) \in A(C)\}} XC_{i,(j,k)} - \sum_{\{k:(k,j) \in A(C)\}} XC_{i,(k,j)} = 0 \text{ for all } i \in C \text{, and all } j \in N(C)$$

$$\sum_{\{j:(j,k) \in A(C)\}} XC_{i,(j,k)} = 1 \text{ for all } i \in C \text{, and } j = s$$

$$\sum_{\{j:(k,j) \in A(C)\}} XC_{i,(k,j)} = 1 \text{ for all } i \in C \text{, and } j = t$$

- Effectiveness Functions in TA

$$RF^{TA}_{i,k(t)} = \alpha^{TA}_{k} \cdot n^{TA}_{k(t)} \cdot \Big(\sum_{\{j:(j,k(t) \in A(C)\}} e^{TA}_{i,j,k(t)} XC_{i,j,k(t)} \Big) \text{ for all } i \in C \text{, and } k(t) \in N(TA) \tag{3-11}$$

- Constraints for the Maximum reduced failure probability in TA

$$\sum_{i \in C} \sum_{\{j:(j,k(t)) \in A(C)\}} e^{TA}_{i,j,k(t)} XC^{TA}_{i,j,k(t)} \le FP^{TA}_{k(t)} \text{ for all } k(t) \in N(S) \tag{3-12}$$

- Effectiveness Functions in RA

$$TE_{k(t)} = TE_{k(t-1)} + \sum_{i \in C} \sum_{\{j:(j,k(t)) \in A(C)\}} e^{TA}_{i,j,k(t)} \cdot XC_{i,j,k(t)} \text{ for each } k(t) \in N(RA) \tag{3-13}$$

- Constraint for minimum effectiveness in RA

$$TE_{k(t)} \ge RE_{k} \cdot y_{k(t+1)} \text{ for each } k(t) \in N(RA) \tag{3-14}$$

- Constraint for minimum time in RA

$$y^{RA}_{k(t)} = 0 \text{ for each } k(t) \in N(RA)$$

where time *t* is less than minimum time required to be assessable (3-15)

$$y^{RA}_{k(t)} = \{0,\ 1\} \qquad (3\text{-}16)$$

- Constraints for the possible number of shelter which is served in SHA

$$SS_{k(t)} \le \sum_{i \in C} \sum_{\{j:(j,k(t)) \in A(C)\}} e^{SHA}_{i,j,k(t)} \cdot XC_{i,j,k(t)} \text{ for each } k(t) \in N(SHA) \qquad (3\text{-}17)$$

$$\sum_{t} SS^{SHA}_{k(t)} \le NS^{SHA}_{k} \text{ for each } k(t) \in N(SHA) \qquad (3\text{-}18)$$

- Effectiveness Function in SHA

$$NS^{SHA}_{k(t)} = NS^{SHA}_{k} - \sum_{t' \le t} SS^{SHA}_{k(t')} \text{ for each } k(t) \in N(SHA) \qquad (3\text{-}19)$$

$$P^{SHA}_{k(t)} = G^{SHA}_{k(t)} NS^{SHA}_{k(t)} \text{ for each } k(t) \in N(SHA) \qquad (3\text{-}20)$$

$$F^{SHA}_{k(t)} = \alpha^{SHA}_{k(t)} NS^{SHA}_{k(t)} \text{ for each } k(t) \in N(SHA) \qquad (3\text{-}21)$$

Medical Units

- Mass flow balance constraints (3-22)

$$\sum_{\{k:(j,k) \in A(M)\}} XM_{i,(j,k)} - \sum_{\{k:(k,j) \in A(M)\}} XM_{i,(k,j)} = 0 \text{ for all } i \in M \text{ , and all } j \in N(M)$$

$$\sum_{\{j:(j,k) \in A(M)\}} XM_{i,(j,k)} = 1 \text{ for all } i \in M \text{ , and } j = s$$

$$\sum_{\{j:(k,j) \in A(M)\}} XM_{i,(k,j)} = 1 \text{ for all } i \in M \text{ , and } j = t$$

- Effectiveness Functions in MA

$$P_{k(t),h} = \sum_{v(t) \in N(S \cap M_{k(t)})} p^{SA}_{v(t),h} \cdot RF^{SA}_{v(t)} + \sum_{w(t) \in N(SHA \cap M_{k(t)})} p^{SHA}_{w(t),h} P^{SHA}_{w(t)} + NP_{k(t),h}$$

$$\text{for each } k(t) \in N(M) \qquad (3\text{-}23)$$

$$UP_{k(t),h} = (P_{k(t),h} - TP_{k(t),h}) \text{ for each } k(t) \in N(M) \qquad (3\text{-}24)$$

$$F^{MA}_{k(t),h} = \alpha^{M}_{h}\,(P_{k(t),h} - TP_{k(t),h}) \text{ for each } k(t) \in N(M) \tag{3-25}$$

- Constraint for the possible number of treated patients in MA

$$\sum_{h} t_h TP_{k(t),h} \le \sum_{i \in M} \sum_{\{j:(j,k(t)) \in A(M)\}} e^{M}_{i,j,k(t)} \cdot XM_{i,j,k(t)} \text{ for each } k(t) \in N(M) \tag{3-26}$$

$$TP_{k(t),h} \le P_{k(t),h} \text{ for each } k(t) \in N(M) \tag{3-27}$$

Situational Constraints

- Maximum or Minimum number of assigned units (3-28)

$$\min^{SA}_{k} \le \sum_{i \in S} \sum_{\{j:(j,k) \in A(S)\}} XS_{i,j,k} \le \max^{SA}_{k} \text{ for some } k \in N(S)$$

$$\min^{TA}_{k} \le \sum_{i \in C} \sum_{\{j:(j,k) \in A(TA)\}} XC_{i,j,k} \le \max^{TA}_{k} \text{ for some } k \in N(TA)$$

$$\min^{RA}_{k} \le \sum_{i \in C} \sum_{\{j:(j,k) \in A(RA)\}} XC_{i,j,k} \le \max^{RA}_{k} \text{ for some } k \in N(RA)$$

$$\min^{SHA}_{k} \le \sum_{i \in C} \sum_{\{j:(j,k) \in A(SHA)\}} XC_{i,j,k} \le \max^{SHA}_{k} \text{ for some } k \in N(SHA)$$

$$\min^{MA}_{k} \le \sum_{i \in M} \sum_{\{j:(j,k) \in A(M)\}} XM_{i,j,k} \le \max^{MA}_{k} \text{ for some } k \in N(M)$$

- Organizational Constraints (3-29)

$$\sum_{\{k:(j,k) \in A(S-HN_Z)\}} XS_{i,j,k} = 1 \text{ for each } i \in S_n$$

$$\sum_{\{k:(j,k) \in A(C-HN_Z)\}} XC_{i,j,k} = 1 \text{ for each } i \in C_n$$

$$\sum_{\{k:(j,k) \in A(M-HN_Z)\}} XM_{i,j,k} = 1 \text{ for each } i \in M_n$$

- Accessibility Constraints (3-30)

$\sum_{\{j:(j,k(t))\in A(S)\}} XS_{i,j,k(t)} \le y_{m(t)}^{RA}$ for each $i \in S$, and $m(t) \in N(RA)$, where SA k can be accessible only through RA m

$\sum_{\{j:(j,k(t))\in A(TA\cup SHA)\}} XC_{i,j,k(t)} \le y_{m(t)}^{RA}$ for each $i \in C$, and $m(t) \in N(RA)$, where TA or SHA k can be accessible only through RA m

$\sum_{\{j:(j,k(t))\in A(M)\}} XM_{i,j,k(t)} \le y_{m(t)}^{RA}$ for each $i \in M$, and $m(t) \in N(RA)$, where MA k can be accessible only through RA m

- Indivisibility Constraints (3-31)

$XS_{i,j,k} \in \{0,\ 1\}$ for $i \in S^I$, and all $(j,k) \in A(S)$

$XC_{i,j,k} \in \{0,\ 1\}$ for $i \in C^I$, and all $(j,k) \in A(C)$

$XM_{i,j,k} \in \{0,\ 1\}$ for $i \in M^I$, and all $(j,k) \in A(M)$

Non-negativity Constraints (3-32)

All decision variables ≥ 0

In this model, both minimizing total fatalities and minimizing untreated patients are used as objectives. As mentioned in Chapter II, each objective can be converted into goals using the aspiration level for each region. Equations (3-1) and (3-2) represent the number of saved people from SAR work and Secondary disaster work, respectively. Therefore, negative coefficients are used in both equations. Equations (3-3) and (3-4) represent the number of fatalities due to the lack of shelter and medical service, respectively, and Equation (3-5) represents the number of untreated patients due to the lack of medical service.

Different directed networks for every type of unit are required to assign units to tasks over time periods. The mass flow balance constraints for every type of unit are represented in Equations (3-6), (3-10) and (3-22). In the SAR work, the number of rescued people for a whole period should be less than the initial number of collapsed people. Therefore Constraint (3-9) is added to restrict the maximum number of rescued people. The amount of reduced failure probability should be less than the initial failure probability in each stabilizing task. Therefore, Constraint (3-12) is added to restrict the maximum level of reduced failure probability.

In a coalition operation, the commander and staff might have to plan HA operations by considering political issues. That is, the minimum or maximum number of units for each region might be restricted due to political interest. Therefore, Constraint (3-28) could be added to this model depending on the operational situation. In addition, some organization *n* may restrict their units to be assigned to only a certain host nation *z*. In such a case, Constraint (3-29) can be added. Constraint (3-30) prevents available units from being assigned to a certain region if it is not accessible. Some participants will not allow their units to be divided into sub-units. Therefore, Constraint (3-31) could be added depending on political issues. Clearly a number of parameters in this model will be at best estimates. However, the purpose of this model is to aid decision makers. If time and details regarding distributions are available, a stochastic model or a simulation may be considered. Lacking such detailed data, however, the deterministic model proposed here should give the decision makers a first cut plan.

3.4. Coalition Mission-Support Model

After unit assignments are determined through the Coalition Mission-Unit Allocation Model, the amount of all types of resources, required for each unit's activities over time, can be calculated by experts. These units can not implement assigned tasks without logistics support. In addition, various items such as food, water, clothes, and so on, are required to relieve the suffering of people. The Coalition Mission-Support Model is designed to transport each resource from supply to demand points with two goals which are to minimize shortage of delivered resources and minimize total cost.

This problem is formulated using a multi-commodity network flow model. However, the capacity of each arc is not constant; that is, it is changeable depending on the number of various transportation vehicles assigned to supply points. Furthermore, each vehicle has different attributes like speed, fuel efficiency, and load capacity. In addition, moving times of transportation units from and to supply points should be considered in this model. Therefore, both assignment of transportation units to supply points and transportation of multi-commodity from supply points to demand points should be considered simultaneously in this model.

3.4.1. Assignment of transportation units to supply points

Each transportation mode, like trucks and helicopters, can not operate independently: that is, maintenance facilities, fueling, and extra crews are required for each transportation mode. In addition, assignment of available transportation units to supply points should be considered over the time periods. Like the Coalition Mission-Unit Allocation Model, the shortest path problem is applied to represent a transportation unit's assignment in this model. Figure III-3 represents a simple example of a directed network, $G(T) = (N(T), A(T))$, for a transportation unit's assignments.

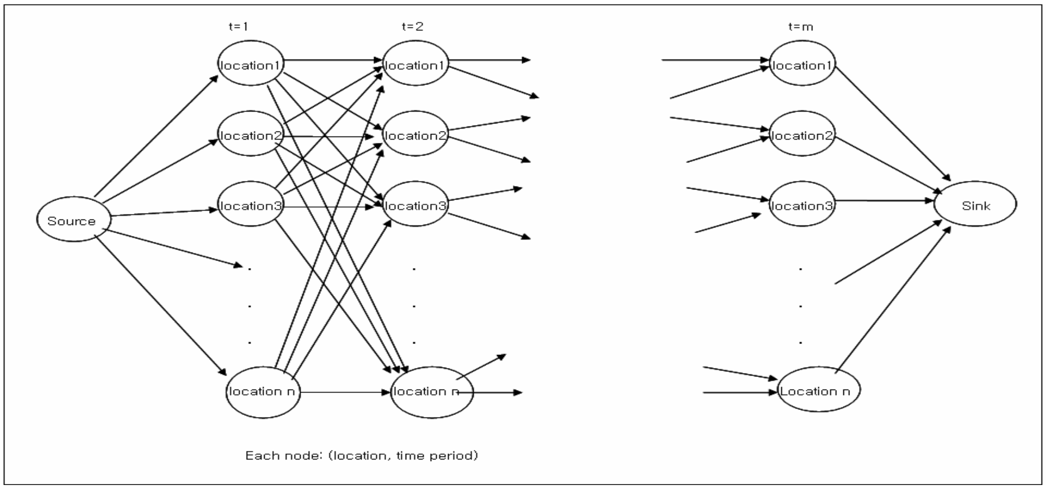


Figure III- 3: An example of a directed network for unit's assignment

Here it is assumed that possible locations of transportation units are determined considering enemy attack, geography, space for settlement, and so on. In HA operations, supply points or transshipment points might be potential locations for transportation units.

3.4.2. Capacities of resource transportations

Time is one of the most important factors which can affect a logistics support plan. There are several examples in the literature which use a time-space network for network flow models (Haghani and Oh, 1996; Yan and Tseng, 2002; Yan et al, 2005). In case of a war or an emergency situation, however, the exact delivery time might not be a realistic requirement since the uncertainty due to road conditions, the estimated demand and supply could be changed due to enemy attack, secondary disaster, wrong information through rapid assessments, and so on.

In this model, efficient routes and the number of cycles for each route (daily round trips) and mode are used to represent the capacities of each arc in a directed network for transportation of every resource. Figure III-4 represents an example of directed network, $G = (V, E)$, for resource transportation from supply points to demand points, where V is the set of nodes in G and E is the set of arcs in G. In Figure III-4, SP_n represents possible supply points, and DP_m represents potential demand points. Obviously both demand points and supply points might be changeable over time periods. If a region is not accessible due to the destruction of a road or bridge, airlift is required to transport resources. TP_i represents transshipment points to change the type of mode. Note that while helicopters can operate directly from a supply point, in this representation, it is assumed material will be trucked to a forward transshipment point. This will reduce the flight distance required for the helicopters to fly and thus increase the number of lifts. Current conditions on the ground will dictate the proper basing policy.

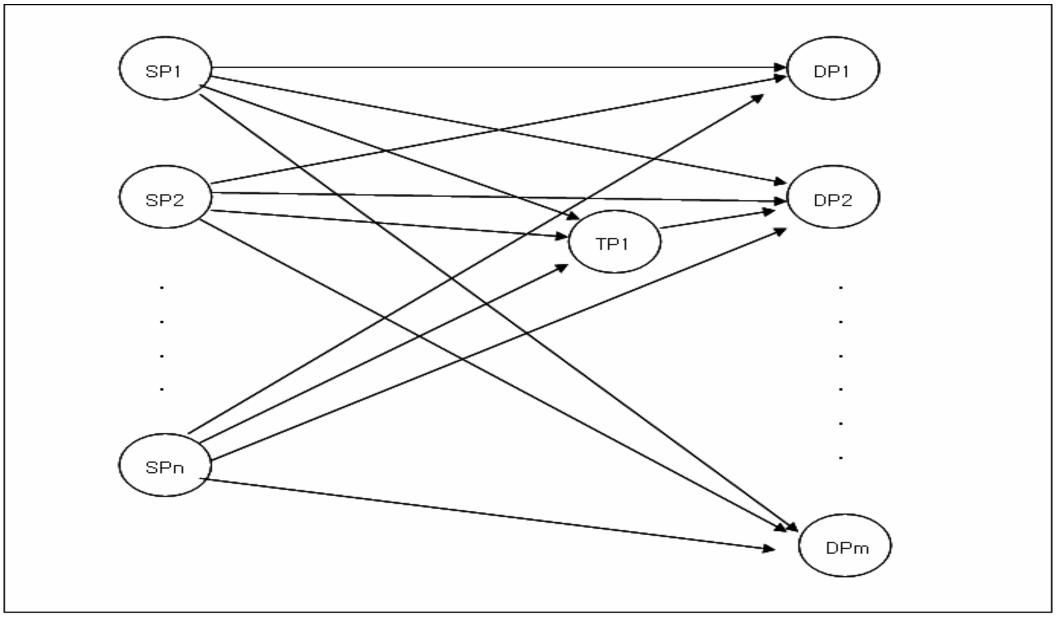


Figure III- 4: An example of a directed network for resource transportation

Numerous routes could be generated within the maximum tour time in this model. For example, the route $SP_n - DP_m - SP_n$ covers only one demand point, but the route $SP_n - DP_m - SP_{n'} - DP_{m'} - SP_n$ could cover two demand points. Here another model which finds efficient routes might be developed by applying vehicle routing approaches. The tour time for each transportation mode and route can be calculated considering road condition, repair time, loading or unloading time, and so on. Therefore, the possible number of cycles during a specific time period could be calculated for each mode, route, and time period. In Figure III-4, for example, if it takes 12 hours for a particular truck to travel the route $SP_1 - DP_1 - SP_1$, then two cycles are possible for that route during one day with the assumption that there are sufficient crews. In addition, the number of possible cycles of a truck for the route $SP_n - DP_2 - SP_n$ would be zero during certain time periods since trucks can not reach that demand point if the road is closed. After the rehabilitation work is completed in that region, however, trucks can drive to that demand point. The capacity for each arc $(i, j) \in E$ is dependent on the number of vehicles which are assigned to the routes associated with each arc $(i, j) \in E$, and the possible number of assigned modes for each route is dependent on the assigned transportation units. Therefore, the Coalition Mission-Support Model is designed to include both the unit assignment problem and the resource transportation problem.

3.4.3. Coalition Mission-Support Model formulation for HA Phase-I Operation

3.4.3.1. Goals

For the logistics support in HA Phase-I operation, the most important goal might be minimizing the shortage of delivered resource for each demand point. Here the importance of each resource would be different for each region. For example, if one region is colder than other regions, several items like the fuel for heating systems, blankets, materials for temporary shelters, and so on, are more important than in other temperate regions. A second goal used in this illustrative model is to minimize total cost. Here the cost for each delivered item includes the price of purchasing, transportation cost, and so on. Obviously there are numerous donations for each item in case of HA operation. Therefore, the price of donated items could be zero.

These two goals are captured using Goal Programming. Preemptive priorities would be used to represent the importance between two goals, and differential weights are used to represent the importance of resources for each region.

3.4.3.2. Assumptions

- The capacity of each arc $(i, j) \in E$ is restricted only due to volume of transportation modes.
- All the cost functions are linear
- All the commodity quantities at supply and demand points are estimated

3.4.3.3. Notations and Decision Variables

Definitions and Notations

T : Set of available transportation Units

$G(T) = (N(T), A(T))$: Directed network for each transportation unit's assignment

$N(T)$: Set of nodes which exclude Source and Sink in $G(T)$

$A(T)$: Set of arcs in $G(T)$

$G = (V, E)$: Directed network for transportation of resources

V : Set of nodes in G

E : Set of arcs in G

$et_{i,j,k}^{m}$: Number of available mode *m* in unit $i \in T$ for each $(j,k) \in A(T)$

R : Set of all possible routes

$Rk(t)$: Set of determined routes in location *k* at time *t*, where $(k,t) \in N(T)$

$R(i, j)$: Set of routes associated with each arc $(i, j) \in E$

A : Node-arc incidence matrix in $G = (V, E)$

$w_{dp,t}^{g}$: Penalty for the lack of delivered commodity *g* in the demand point *dp* at time *t*

B_t^g : Vector of requirements for commodity *g* at time *t*

C_t^g : Cost vector for flows of commodity *g* at time *t*

vc^g : Volume of commodity *g*

vt^m : Capacity (Volume) of transportation mode *m*

$c_{r,t}^{m}$: Number of possible cycle for mode *m* through route *r* at time *t*

Decision variables

$XT_{i,j,k}$: The proportion of transportation unit i assigned to arc (j,k)

for all $i \in T$,and all $(j,k) \in A(T)$

$y^m_{r,k(t)}$: Number of mode m assigned to route r in location k at time t

X^g_t : Vector of flows for commodity g at time t

$x^g_{(i,j),t}$: An element of X^g_t which represents the flow of commodity g through arc $(i,j) \in E$ at time t. In case of $i = d$, it represents dummy supply point

3.4.3.4. Mathematical Formulation I of the Coalition Mission-Support Model

The Coalition Mission-Support Model for HA Phase-I Operation can be formulated as follows:

$$\text{Minimize } P_1\Big(\sum_g \sum_{dp} \sum_t w^g_{dp,t} \cdot x^g_{(d,dp),t}\Big) + P_2\Big(\sum_g \sum_t C^g_t \cdot X^g_t\Big) \qquad (4\text{-}1)$$

Subject to

- Mass flow balance constraint for unit's assignment in the network $G(T)$ (4-2)

$$\sum_{\{k:(j,k)\in A(T)\}} X^T_{i,(j,k)} - \sum_{\{k:(k,j)\in A(T)\}} X^T_{i,(k,j)} = 0 \text{ for all } i \in T \text{, and all } j \in N(T)$$

$$\sum_{\{j:(j,k)\in A(T)\}} X^T_{i,(j,k)} = 1 \text{ for all } i \in T \text{, and } j = s$$

$$\sum_{\{j:(k,j)\in A(T)\}} X^T_{i,(k,j)} = 1 \text{ for all } i \in T \text{, and } j = t$$

- Capacity constraints for each arc $(i,j) \in E$

$$\sum_{r\in Rk(t)} y^m_{r,k(t)} \le \sum_{i\in T} \sum_{\{j:(j,k(t))\in A(T)\}} et^m_{i,j,k(t)} X^T_{i,j,k(t)} \text{ for all } m=1,2,..,M, \text{ and } k(t) \in N(T) \qquad (4\text{-}3)$$

$$\sum_{g} vc^{g} \cdot x^{g}_{(i,j),t} \leq \sum_{m} \sum_{r \in R(i,j)} vt^{m} \cdot c^{m}_{r,t} \cdot y^{m}_{r,t} \text{ for all } (i,j) \in E \text{, and } t=1,2,..T \qquad (4\text{-}4)$$

- Mass flow balance constraints for transportation of resources in the network G

$$AX^{g}_{t} = B^{g}_{t} \text{ for all } g=1,2,\ldots,G, \text{ and } t=1,2,\ldots T \qquad (4\text{-}5)$$

- Non-negativity constraints (4-6)

$XT_{i,j,k} \geq 0$ for all $i \in T$,and all $(j,k) \in A(T)$

$y^{m}_{r,k(t)} \geq 0$ for all $m=1,2,\ldots M$, all $r \in R$, and all $k(t) \in N(T)$

$x^{g}_{(i,j),t} \geq 0$ for all $g=1,2,..G$, all $(i,j) \in E$, and all $t=1,2,..T$

The objective function is composed of two preemptive priorities goals given in Equation (4-1). In the first goal, the decision variable, $x^{g}_{(d,dp),t}$, represents the amount of flow for commodity *g* from dummy supply point to each demand point; that is, it means the shortage of delivered commodity *g* at the demand points. Since the importance of each commodity is different depending upon the attributes of the demand point, different weights are used according to the commodity, demand point, and time period. The element of cost vector, $c^{g}_{(i,j),t}$, represents the cost per unit flow through arc $(i,j) \in E$ for commodity *g*. Obviously the cost for transportation of commodities from supply to dummy demand points should be zero.

The Constraints (4-2) represent the conservation of each unit's flow which means unit assignment to each location over time period. The possible number of modes for each route is restricted by the number of assigned units in the Constraint (4-3). In addition, the capacity of each arc $(i,j) \in E$ is restricted due to the number of modes assigned to routes associated with arc $(i,j) \in E$ in the Constraint (4-4). The Constraints

(4-5) represent the conservation of flow for each commodity and for each time. In order to balance this transportation problem, both a dummy supply point and a dummy demand point are included in the Constraints (4-5). If total supply exceeds total demand for an item, a dummy demand point plays a role to balance this problem. Even though total supply exceeds total demand, however, items could not be transported to each demand point without sufficient transportation vehicles. Therefore, a dummy supply point is also included in Constraints (4-5) as an absorbing node for any potential undeliverable item.

3.4.3.5. Mathematical Formulation II of the Coalition Mission-Support Model

In the mathematical Formulation I, the cost for the transportation of each commodity could be calculated only by considering road or airlift. However, sometimes it might be required to identify each type of mode using decision variables. That is, the decision variables, $x^g_{(i,j),t}$, can be divided to include the information of type of mode. The size of mathematical Formulation II would be expanded depending on the number of mode type, but it can represent the problem more accurately.

The different Decision Variables from mathematical Formulation I

$x^g_{m,(i,j),t}$: An element of X^g_t which represents the flow of commodity *g* through arc $(i,j) \in E$ using mode *m* at time *t*.

Here the decision variables, $x^g_{(i,j),t}$, can be calculated using following equations:

$$x^g_{(i,j),t} = \sum_m x^g_{m,(i,j),t}$$

Revised Constraint (4-4)

In order to use the decision variables, $x^{g}_{m,(i,j),t}$, the capacity of each arc $(i,j) \in E$ should be divided according to the type of modes. Therefore, Constraint (4-4) should be divided according to type of modes. The following constraints replace Constraints (4-4) for mathematical Formulation II of the Coalition Mission-Support Model.

$$\sum_{g} vc^{g} \cdot x^{g}_{m,(i,j),t} \le \sum_{r \in R(i,j)} vt^{m} \cdot c^{m}_{r,t} \cdot y^{m}_{r,t} \text{ for all } (i,j) \in E \text{, all } m=1,2,..,M, \text{ and } t=1,2,..,T$$

3.5. Coalition Mission-Unit Grouping Model

Through the previous two models, Coalition Mission-Unit Allocation Model and Coalition Mission-Support Model, tasks and locations are assigned to each unit. As mentioned in Chapter II, due to political considerations, the coalition often invites small units of foreign forces into coalition operations, even though they may offer only token forces. That is, these units might not operate independently without augmentation with other types of support units. For example, if a specific unit, assigned to a task which could involve serious enemy attacks, does not have capabilities to protect itself against an enemy, this unit could not implement an assigned task successively. This could be true of some NGO efforts. Therefore, it might be required to augment such units with security forces or other support. The Coalition Mission-Unit Grouping Model is designed to group units into one workable unit which can operate independently.

3.5.1. Goals

In a coalition operation, available units come from various nations or organizations with different capabilities, size, and political interest. That is, effectiveness of support units for each pre-assigned unit varies depending on the situation. Therefore, the first goal might be minimizing shortfalls in estimated required effectiveness for each pre-assigned unit.

In addition to effectiveness, inter-relationships between units or between units and Host Nations should be considered in this model due to the coalition's characteristics. Therefore, the second goal is minimizing a total pair-wise interaction cost which represents bad relations among national units.

3.5.2. Assumptions

- The pair-wise interaction cost among national units or between national units and Host Nations can be estimated
- Effectiveness of support units can be estimated
- Requirement of effectiveness for each pre-assigned unit is known

3.5.3. Notation and Decision Variables

Definitions and Notations

$G = (N_1 \cup N_2, A)$: A bipartite graph for assigning support units to each job

N_1 : The node set of available support units

N_2 : The node set of jobs which are required to make pre-assigned units operate independently

A : The set of edges in graph G .

$E_{i,j}$: Effectiveness vector for support unit *i* assigned to job *j*

RE_j : Required effectiveness vector for pre-assigned unit *j*

W_j : Row vector which represents importance of effectiveness in job *j*

$c^A_{i,j}$: The pair-wise interaction cost between support unit *i* and a pre-assigned unit which requires job *j*

$c^B_{i,j}$: The pair-wise interaction cost between support unit *i* and the Host Nation which is associated with job *j*

$c^C_{i,j,k,h}$: The pair-wise interaction cost between support unit *i* and support unit *k* assigned to jobs *j* and *h,* respectively

Decision variables

D^+_j: Positive deviational variable vector which represents excess of effectiveness assigned to job *j*

D^-_j: Negative deviational variable vector which represents underachievement of effectiveness assigned to job *j*

$X_{i,j}$ =1 if support unit *i* is assigned to job *j*

3.5.4. Mathematical Formulation I of the Coalition Mission-Unit Grouping Model

If there are enough available support units to augment each pre-assigned unit, then it may not be required to consider shortage of effectiveness for each unit. That is, required effectiveness for each unit could be satisfied by adding effectiveness constraints. In this case, the only consideration would be inter-relations among national units or between national units and Host Nation.

There are two possible ways to augment pre-assigned units: one is to augment each specific unit assigned to a task; another is to augment regional units. Selecting one of them would depend on the prevailing situations. Here it is assumed that the coalition commander and his or her staff decide a unit grouping method for each type of support units. There are several pair-wise interaction costs when assigning support units to each job. These are as follows:

- Total pair-wise interaction cost between support unit *i* and a pre-assigned unit which requires job *j* could be calculated by:

$$Cost_A = \sum_{(i,j)\in A} c_{i,j}^A \cdot X_{i,j}$$

When each specific pre-assigned unit is augmented with support unit *i*, the interaction cost, $c_{i,j}^A$, represents the degree of estimated poor relations between support unit *i* and a specific pre-assigned unit which require job *j*. When a regional unit is augmented with support units, however, there could be several pre-assigned units which require job *j*. With the assumption that all pre-assigned units which require job *j* interact with support unit *i*, $c_{i,j}^A$ could be calculated by:

$c_{i,j}^A = \sum_u c_{i,u}$, where $u \in \{\text{all pre-assigned units which require job j}\}$, where $c_{i,u}$ represents pair-wise interaction cost between support unit *i* and a pre-assigned unit *u*. After a regional unit is augmented with support unit *i*, the regional commander should assign or match this support unit *i* to pre-assigned units. Therefore, the worst inter-relationship between support unit *i* and pre-assigned units will be used for $c_{i,j}^A$ which can be calculated by:

$c^{A}_{i,j} = \max\{c_{i,u}\}$, where $u \in$ {all pre-assigned units which require job j}, and $c_{i,u}$ represents the pair-wise interaction cost between support unit *i* and a pre-assigned unit *u*.

- Total pair-wise interaction cost between support unit *i* and Host Nation which is associated with job *j* could be calculated by:

$$Cost_B = \sum_{(i,j)\in A} c^{B}_{i,j} \cdot X_{i,j}$$

- Total pair-wise interaction cost between support units *i* and *k* assigned to job *j* and *h* respectively could be calculated by:

$$Cost_C = \sum_{i\in N_1} \sum_{j\in N_2} \sum_{k\in N_1} \sum_{h\in N_2} c^{C}_{i,j,k,h} \cdot X_{i,j} \cdot X_{k,h}$$

Here the interaction cost matrix c^{C} is defined in the following way:

$c^{C}_{i,j,k,h} = c_{i,k}$ if job *j* and *h* are inter-related with each other or job *j* equals job *h*, otherwise 0

Therefore the mathematical formulation is:

Minimize $Total \quad \cos t = Cost_A + Cost_B + Cost_C$ (5-1)

Subject to

$$\sum_{j\in N_2} X_{i,j} = 1 \text{ for each } i \in N_1 \qquad (5\text{-}2)$$

$$\sum_{i\in N_1} E_{i,j} \cdot X_{i,j} \geq RE_j \text{ for each } j \in N_2 \qquad (5\text{-}3)$$

$$X_{i,j} \in \{0,\ 1\} \qquad (5\text{-}4)$$

Clearly, some knowledge of the units previous history is necessary. Pre-processing is necessary to determine inter-action factors.

3.5.5. Mathematical Formulation II of the Coalition Mission-Unit Grouping Model

Formulation I is devised with the assumption that there are enough support units to augment pre-assigned units to operate independently. In reality, however, available support units could generally be limited. Therefore, the required effectiveness for all jobs could not be satisfied due to the lack of available support units. That is, formulation I could be infeasible due to Constraint (5-3).

By using preemptive priorities for two goals and weights for each negative deviational variable, formulation I could be converted into goal programming as mentioned in Chapter II. The mathematical formulation II of the grouping model follows:

$$\text{Minimize } P_1\left(\sum_{j \in N_2} W_j \cdot D_j^-\right) + P_2\left(Cost_A + Cost_B + Cost_C\right) \tag{5-5}$$

Subject to

$$\sum_{j \in N_2} X_{i,j} = 1 \text{ for each } i \in N_1 \tag{5-6}$$

$$\sum_{i \in N_1} E_{i,j} \cdot X_{i,j} - D_j^+ + D_j^- = RE_j \text{ for each } j \in N_2 \tag{5-7}$$

$$X_{i,j} \in \{0,\ 1\} \text{ for all } i \in N_1, \text{ and } j \in N_2 \tag{5-8}$$

3.6. Summary

In Chapter III, the general approach for the Coalition Operation Planning Model is developed. The formulations of three sub-models, the Coalition Mission-Unit Allocation Model, the Coalition Mission-Support Model, and the Coalition Mission-Unit Grouping Model, are presented for a Humanitarian Assistance Phase-I Operation.

The third sub-model, the Coalition Mission-Unit Grouping Model, is sequenced to be implemented after the first two sub-models in the general procedures. In a coalition, however, there could be a number of small units which can not operate independently due to political interests as mentioned in Chapter II. Therefore, this third sub-model could be run directly after a mission analysis.

A variety of estimates are necessary to implement these three sub-models. The accuracy of the solutions from the models must be based on the quality of currently available information. Therefore, a rapid assessment and a mission analysis should be carried out as precisely as possible before the Coalition Operation Planning Model is implemented. Chapter IV presents the analysis and results for several scenarios.

IV. Analysis and Results

4.1. A general scenario

Sadly, there are numerous real world cases for Humanitarian Relief Operations: Pakistan Earthquake Response, Hurricane Katrina Response, India Floods Response, Response to Earthquake and Tsunami in Southeast Asia, to name a few. Due to the difficulty of obtaining specific data required by the Coalition Operation Planning Model, however, an example scenario for an earthquake disaster has been constructed to demonstrate the Coalition Operation Planning Model in this thesis. In this notional scenario, an earthquake strikes three countries; these nations do not have the capabilities to recover from the damages on their own in a reasonable time. Therefore, a coalition is formed for humanitarian assistance operation to aid these three nations.

The scenario includes 20 participants; the participants and their units are shown in Appendix B. Participants 1, 2, and 3 prefer to help only Host Nation 1, 2, and 3, respectively. That is, the units of participants 1, 2, and 3 may *only* be assigned to tasks within host nation 1, 2, and 3, respectively. Participants 6, 7, 8, 9, and 10 will not allow their units to be divided into sub-units. In addition, some units, which are of small size, are also not allowed to be divided.

The whole operational area is divided into three areas of responsibility corresponding to the three nations affected by the disaster. That is, there are three operational regions which represent the Host Nations. It is assumed an initial assessment has already been carried out. While it is recognized that this assessment has been conducted in a fluid situation and is an estimate, it represents the best data currently available and will be used for the planning process. The identified tasks are shown in Figure IV-1.

In the Coalition Operation Planning Model, unit's moving time and set up time should be considered when calculating each unit's effectiveness. Depending on the transport means and the size of the units, a unit's travel time and set up time varies for each unit. In this illustration, however, it is assumed that all units have the same capability of relocation from and to each task. The assumed example moving times between supply points and tasks, between tasks, and between supply points are shown in Appendix B.

In this scenario it is assumed that current planning is for the initial emergency response of one week for a HA Phase I operation. This one week time line is divided into three periods; a first period of 3 days, and second and third period of 2 days each. For this example, the effectiveness of each arc in directed graphs $G(S)$, $G(C)$, $G(M)$, and $G(T)$ for this example is found by multiplying the effectiveness of one day by available activity time (day).

The size of the Coalition Operation Planning Model tends to be large based on the number of available units, required tasks, commodities, indivisibility constraints involving binary variables, and so on. However, this notional scenario has been scaled back for demonstration purposes. These scenarios are solved using Xpress by Dash Optimization which is a commercial solver. The models are solved on an Intel Pentium 4 processor with 500 MB of Ram.

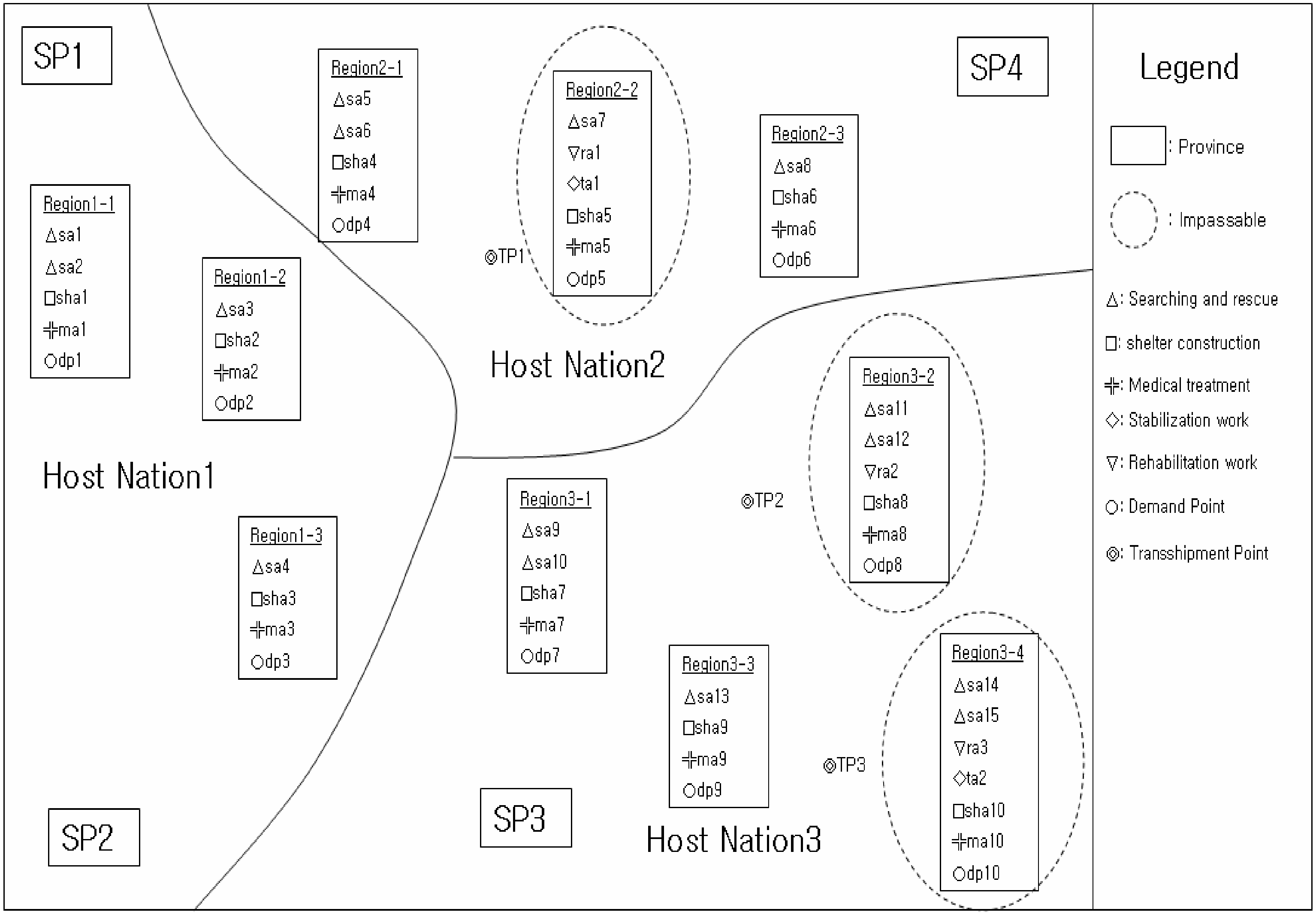


Figure IV-1: Estimated tasks from a rapid assessment

4.2. Results and Analysis for Coalition Mission-Unit Allocation Model

There are 20 search and rescue units and 15 search and rescue tasks in this scenario. The attributes of these units and tasks are shown in Table C-1 and Table C-2 in Appendix C. The effectiveness during one day is calculated depending on the types of tasks and units, unit's initial locations, and unit's size.

In this scenario, 20 construction units are available from 10 different participants, to deal with 2 stabilizing projects, 3 immediate rehabilitation efforts, and 10 shelter construction projects required for the HA Operation. It is assumed that stabilizing work, rehabilitation work, and shelter construction work require different types of construction units; type A, B, and C, respectively. The attributes of construction units and tasks are shown in Table C-3 and Table C-4. Construction types for both units and tasks could be divided more precisely in an actual operation.

For the medical unit, 20 units are available from 13 participants and there are 10 regions which require medical treatment. The attributes of medical units and tasks are shown in Table C-5 and Table C-6, respectively.

4.2.1. Results and Analysis of scenario A1

For political reasons, participants 1, 2, and 3 restrict their units to be assigned to only HN 1, 2, and 3, respectively. In addition, participants 6, 7, 8, 9, and 10 will not allow their units to be divided into several sub-units, and all small units can not be divided. With these initially known situational and political constraints, scenario A1 is solved. The complete results of this scenario are shown in Appendix D.

Before investigating the solutions of the unit allocations, it might be necessary to determine whether the objective function values are acceptable or not. This result is summarized in Table IV-1.

Table IV- 1: Summarized results of scenario A1

Tasks		HN 1	HN 2	HN 3	Total
SA	# of people in collapsed structure	2300	1550	2900	6750
	# of fatalities	1319	1041	2192	4552
	Percentage of fatalities	0.57	0.67	0.76	0.67
SHA	# of homeless people	2600	1400	2400	6400
	# of fatalities	293	189	367	849
	Percentage of fatalities	0.11	0.14	0.15	0.13
RA	Accessibility of RA 1(t=1, t=2, t=3)		(X, O, O)		
	Accessibility of RA 2(t=1, t=2, t=3)			(X, X, X)	
	Accessibility of RA 3(t=1, t=2, t=3)			(X, O, O)	
TA	# of saved people in TA1		120		120
	# of saved people in TA2			360	360
MA	# of patients	10979	9770	13988	34737
	# of untreated patients	156	1871	5635	7662
	Percentage of untreated patients	0.01	0.19	0.40	0.22
	# of fatalities	78	522	1410	2010
	Percentage of fatalities	0.01	0.05	0.10	0.06
Total fatalities		1690	1752	3969	7411

(O: opened, X: closed)

The total number of anticipated fatalities is 7,411, with a total number of untreated patients of 7,662 during week one of the HA Phase-I Operation if this initial option is implemented. In addition, 480 people could be saved if stabilizing works occur in TA 1 and TA 2. Even though these values for total number of fatalities and untreated patients are optimal for the available estimated assessment and would be regrettably acceptable to the Coalition, no unit is assigned to RA 2 which represents an immediate rehabilitation task in region 3-2. That is, region 3-2 would be isolated during the whole initial operation period. Furthermore, the number of total fatalities and the percentages of fatalities for all tasks in host nation 3 are higher than those of the other nations. While optimal for the initial assessment data and initial stated political constraints, it may or may not be acceptable to delay the response to region 3-2 or pursue a solution which results in host nation 3 facing a higher fatality rate.

4.2.2. Results and Analysis of scenario A1 vs. scenario A 2

The mathematical solution to scenario A1 might not be acceptable due for several reasons; political considerations, lack of airlift for transportation of relief items, and so on. To investigate alternatives, scenario A2 is developed by adding constraints which allow RA 2 to be opened from the second period. The full results of scenario A2 are shown in Appendix E. The objective function values are summarized in Table IV-2.

Table IV- 2: Summarized results of scenario A2

Tasks		HN 1	HN 2	HN 3	Total
SA	# of people in collapsed structure	2300	1550	2900	6750
	# of fatalities	1383	1074	2083	4540
	Percentage of fatalities	0.60	0.69	0.72	0.67
SHA	# of homeless people	2600	1400	2400	6400
	# of fatalities	437	219	339	995
	Percentage of fatalities	0.17	0.16	0.14	0.16
RA	Accessibility of RA 1(t=1, t=2, t=3)		(X, O, O)		
	Accessibility of RA 2(t=1, t=2, t=3)			(X, O, O)	
	Accessibility of RA 3(t=1, t=2, t=3)			(X, O, O)	
TA	# of saved people in TA1		120		120

	# of saved people in TA2			360	360
MA	# of patients	11219	9799	13998	35016
	# of untreated patients	251	2021	4130	6402
	Percentage of untreated patients	0.02	0.21	0.30	0.18
	# of fatalities	126	598	1224	1948
	Percentage of fatalities	0.01	0.06	0.09	0.06
Total fatalities		1946	1891	3646	7483

(O: opened, X: closed)

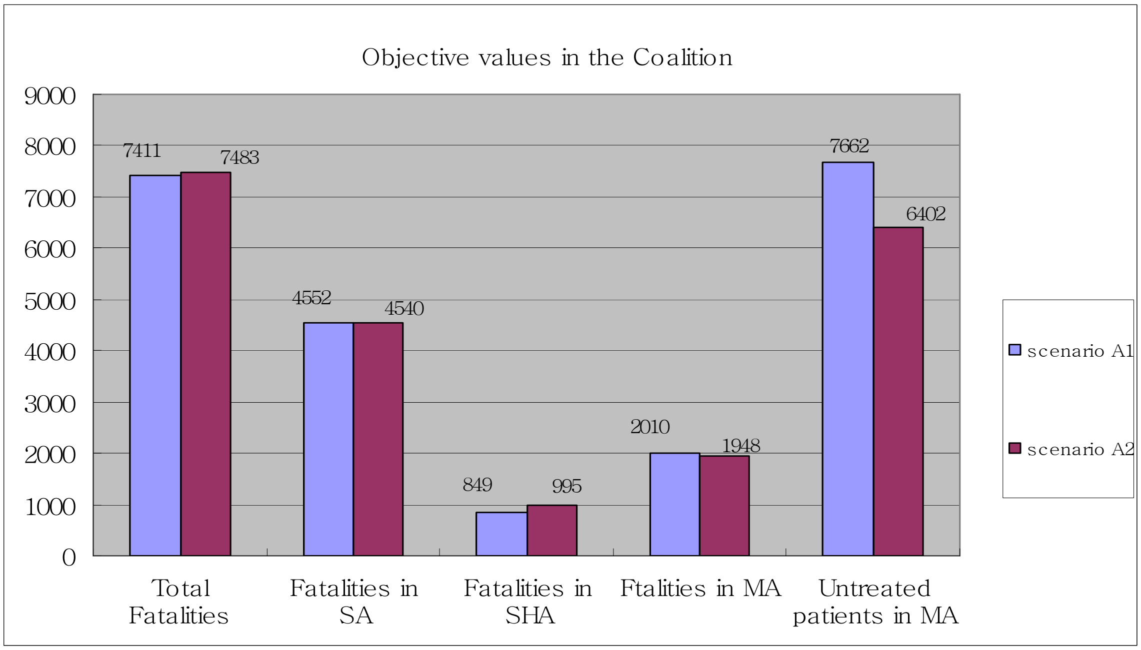


Figure IV- 2: Objective values in scenario A1 vs. A2

In the solution of scenario A2, all immediate rehabilitation areas are opened by their earliest possible date, the second period (the beginning of day 4). 480 people, which is the same number as scenario A1, are saved in the two stabilizing areas. However, the total number of fatalities is increased by 72 when compared to the solution of scenario A1. The differences between solutions of scenario A1 and scenario A2 are shown in Figure IV-2.

Compared with the results of scenario A1, the total number of fatalities in scenario A2 in both search and rescue tasks and medical treatment tasks are decreased by 12 and 62, respectively. In addition, the total number of untreated patients is decreased by 1260. However, the total number of fatalities tied to temporary shelter construction tasks is increased by 146. In scenario A1 there is no assigned unit in RA 2 as shown in Table IV-3. However, several construction units (C5, C13, C15, 10 percent of C18, and 20 percent of C20) are assigned to RA 2 in scenario A2 rather than the shelter construction tasks they carried out in scenario A1. This causes the total fatalities due to lack of temporary shelter construction work to be increased by 146 in scenario A2. Since region 3-2 is accessible from period 2 in scenario A2, search and rescue units and medical units could be assigned properly to these tasks in the region. This results in a decreased total number of fatalities in both search and rescue tasks and medical treatment tasks.

Table IV- 3: Unit assignments in the immediate rehabilitation tasks

	RA 1	RA 2	RA 3
scenario A1	•C3 •C7 (80 %) •C8 •C10 •C12		•C5 •C7(20 %) •C13 •C18(10%) •C20(20 %)
scenario A2	•C3 •C7 (80 %) •C8 •C10 •C12	•C5 •C7(20 %) •C13 •C18(10%) •C20(20 %) •C15	•C17 •C20(80%)

In Table IV-3, construction unit 5, assigned to RA3 in scenario A1, is scheduled to be assigned to RA 2 in scenario A2. This unit is initially located in RA 2 in the region 3-2 as shown in Table C-3. Therefore, assigning C5 to RA 2 is more reasonable than its assignment to RA 3. Construction 15, 17 and 80 percent of construction 20 are assigned to rehabilitation areas only in scenario A2. The different assignments of these units between scenario A1 and scenario A2 are shown in Table IV-4. In scenario A1, construction 15 is assigned to the shelter construction task in the region 1-1 (SHA1) during the first and second periods. As shown in Table C-3, construction unit 15 is suitable for both rehabilitation task and shelter construction task. Therefore, this unit is assigned to RA 2 during the first period, and reassigned to SHA 8 for the second period after the work of RA 2 is completed. As shown in Figure IV-1, both RA 2 and SHA 8 are located in region 3-2. In this scenario, it is assumed that there is no unit movement time from RA 2 and SHA 8. During the third period, construction unit 15 is reassigned to SHA 9 which is located in region 3-3 since the work of SHA 8 is projected to be completed with some of units assigned in the second period. In Table IV-4, construction 15, 17, and 20 are mostly assigned to shelter construction tasks in host nations 1 and 2 in scenario A1. In scenario A2, however, these units are scheduled to be assigned to rehabilitation tasks in host nation 3 for the first period and shelter construction tasks in host nation 3 during the second and third periods. Clearly, reallocation of resources has a cascading effect throughout the rescue areas. The restriction of these resources has clear operational and political consequences. “Fairness” and political necessity must be balanced against estimated lifes saved.

Table IV- 4: Different unit assignments in scenario A1 vs. A2

Period		1	2	3
C15	scenario A1	SHA1	SHA1	SHA9
	Scenario A2	RA2	SHA8	SHA9
C17	scenario A1	SHA6	SHA5	SHA3
	scenario A2	RA3	TA2(20%),	SHA9

			SHA10(80%)	
C20	scenario A1	RA3(20%) SHA6(60%) SHA7(20%)	TA 2(20%), SHA5(60%) SHA10(20%)	SHA9(20%) SHA3(60%) SHA9(20%)
	scenario A2	RA2(20%) RA3(80%)	SHA8(20%) SHA10(80%)	SHA9

The solution of unit allocation would be distributed among host nations or concentrated on a certain host nation. Therefore, it is necessary to examine the number of total fatalities in each host nation. Figure IV-3 and Figure IV-4 represent the total number of fatalities and untreated patients in each host nation between two scenarios.

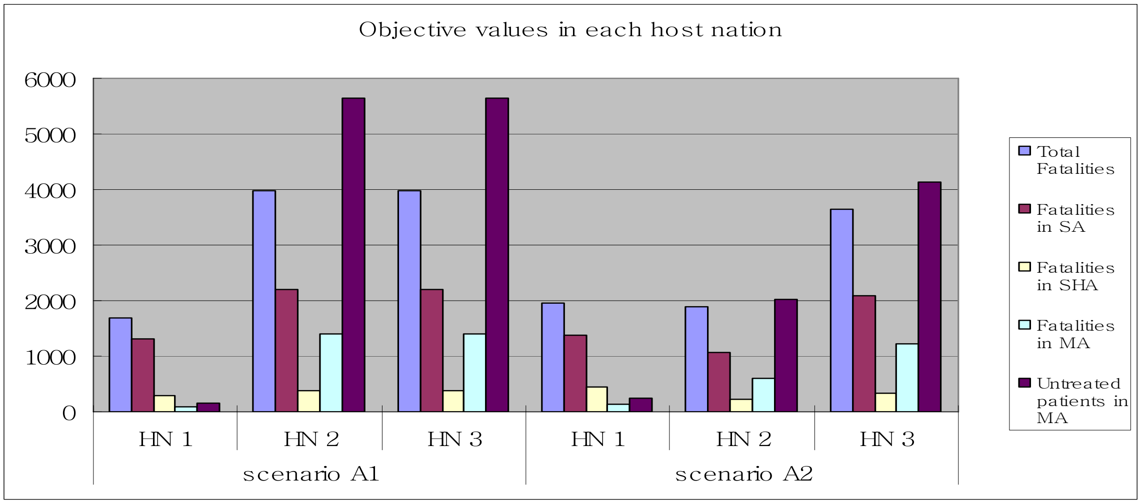


Figure IV- 3: Total number of fatalities and untreated patients in each host nation

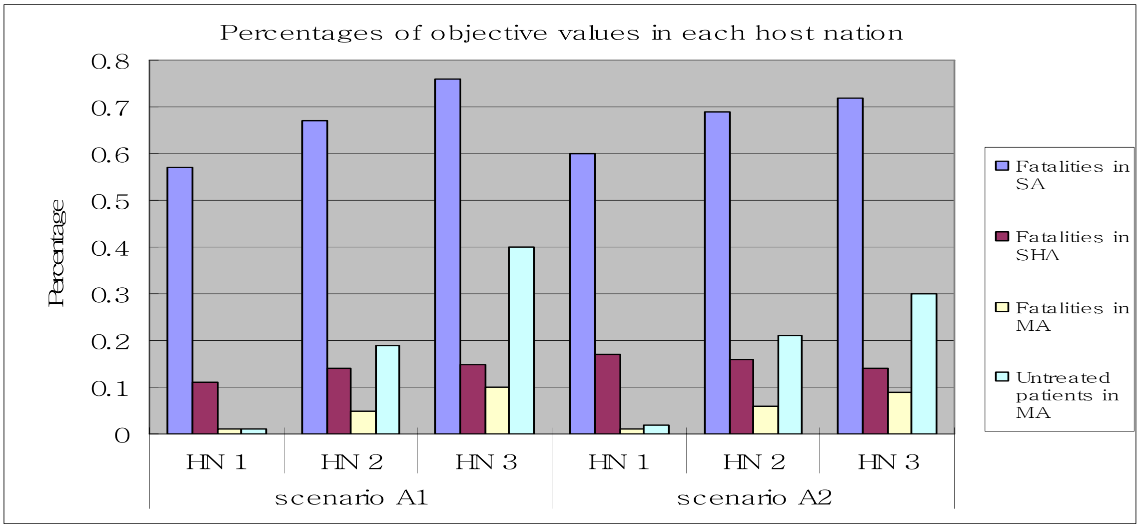


Figure IV- 4: Percentages of fatalities and untreated patients in each host nation

In both Figure IV-3 and Figure IV-4, the solution of scenario A2 while marginally higher in fatalities, is assumed to be more politically acceptable since the number of total fatalities and untreated patients in scenario A2 is more evenly distributed among host nations than in scenario A1.

In summary, scenario A1 is estimated to save 72 more people (0.96 %) than scenario A2, but region 3-2 would be isolated during the whole operational time in scenario A1. In addition, available unit's assignments in scenario A1 are more highly concentrated in host nation 1 than in scenario A2. Since some of the information developed through a rapid assessment is likely to be imprecise in an emergency situation, the increase of 72 deaths may not be a statistically meaningful difference. With the solution of scenario A1, political difficulties may occur in the coalition since region 3-2 in host nation 3 is isolated for the whole operational time. Furthermore, it is more difficult to transport relief items to this isolated region. Therefore, it is assumed in this illustration that, for operational and political reasons, the solution of scenario A2 would be more acceptable to the coalition.

4.2.3. Analysis of Unit Allocation in scenario A2

Given that scenario A2 is accepted by the coalition commander or coordination center, it is necessary to examine the solution of unit allocation shown in Appendix D. In the solution of the unit allocation question in scenario A2, it is assumed that the assignments of several units such as C7, C18, C19, and M20 are deemed unacceptable due to the complexity of control. Therefore, it might be necessary to modify some of the initial unit allocations. These unit's initial assignments and alternative assignments, ordered by the commander, are shown in Table IV-5. 80 % of construction unit 7 is assigned to RA1 (HN 1) during first period, but 50 % of this unit has to move to TA2 (HN 2) at the end of first period. Division of a unit as 90% and 10% would make the unit's control difficult, and redeployment of 10% of a unit may not affect the overall solution significantly.

Table IV- 5: Initial solution and modified solution for unit allocation

Periods		1	2	3
C7	Initial solution	RA1(80%) RA2(20%)	TA1(30%) TA2(70%)	TA1(30%) TA2(50%) SHA9(20%)
	Modified solution	RA1(30%) RA2(70%)	TA1(30%) TA2(70%)	TA1(30%) TA2(50%) SHA9(20%)
C18	Initial solution	SHA6(90%) RA2(10%)	SHA5(90%) SHA8(10%)	SHA8(90%) SHA9(10%)
	Modified solution	SHA6	SHA5	SHA8

C19	Initial solution	SHA6	SHA5	SHA3(90%) SHA8(10%)
	Modified solution	SHA6	SHA5	SHA3
M20	Initial solution	MA4(10%) MA6(80%) MA7(10%)	MA5(20%) MA6(80%)	MA5(20%) MA6(80%)
	Modified solution	MA6	MA5(20%) MA6(80%)	MA5(20%) MA6(80%)

With the modified solutions, the total effectiveness of RA 1 is decreased by 8 (11%), but the effectiveness of RA 2 is increased by 5 (8%). The doctor's available work time is decreased by 140 (hrs) and 155 (hrs) in MA4 and MA7, respectively, but increased by 280 (hrs) in MA6. With the modified unit assignments, the total number of fatalities is increased by 2 based on the estimated data, but this modified solution would make unit control easer than initial solution. Therefore, it will be assumed that the modified solution in scenario A2 would be recommended to the coalition commander.

4.3. Results and Analysis for Coalition Mission-Support Model

In the general scenario, 12 transportation units are used from 10 participants; the attributes of these units are shown in Table C-7 in Appendix C. Here all possible transportation vehicles available are identified as 6 types: 4 types of truck and 2 types of helicopter. Transportation units 4, 5, and 7 are composed of 10 or 20 helicopters. It is assumed that each sub-region operates one demand point and there are 4 supply points which represent air port, sea port, plant, or warehouse. All types of trucks can not immediately access demand points # 5, #8, and #10 which are located in the sub-region 2-2, 3-2, and 3-4, respectively, due to road destruction. Access by road is unavailable till rehabilitation works are completed. Therefore it is determined that 3 transshipment points, TP 1, TP 2, and TP 3 to facilitate airlift, are operated in these sub-regions as shown in Figure IV-1.

As mentioned in Chapter III, numerous routes for each vehicle could be found depending on efficiency. For simplicity, 55 routes which cover only one demand point are used in this scenario. They are shown in Table C-8. In the previous Coalition Mission-Unit Allocation Model, it is assumed that the coalition decides to select the unit's assignment plan which opens all rehabilitation areas from the second period. Therefore it is assumed that the coalition commander determines that transshipment points are operated only during the first period using helicopter units (T4, T5, and T7), and these helicopter units would be held in reserve to the coalition HQ from the second period forward. Through the rapid assessment, various factors, which affect the number of cycles for each vehicle and route, could be identified and estimated by experts. These factors might include the condition of roads, the number of available crews, weather, maintenance time, maximum operation time per day, and so on. The number of cycles for each vehicle and route used in this scenario is shown in Table C-9.

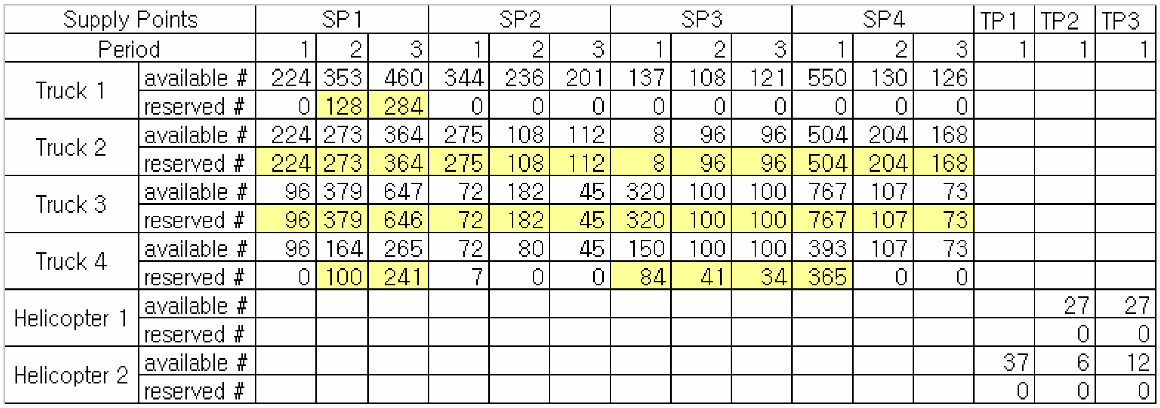
In this scenario, it is assumed that 20 commodities are required at each demand point, commodity #1, #2, and #3 are critical items for all demand points. Shortage of these items could affect the number of fatalities or patients. In addition, commodities #4 and #5 are critical items for cold regions which are regions #2-2, #3-2, and #3-4. The resource requirements over the planning time periods at both supply points and demand points are arbitrarily selected in this scenario. This data is shown in Table C-10, and these numerical numbers represent the number of containers which are required at each demand point. The type of container could vary for each commodity, but it is assumed that one identical container is used for all commodities.

As mentioned in Chapter III, the importance of resources varies depending on operational situations such as weather, the degree of damage, task priority, and so on. In order to represent the importance of each resource, weights are used for shortage of each resource in demand points over time periods. The weights used in this scenario are shown in Table C-11. The cost of resource transportation differs depending on transportation means and routes. That is, transportation costs are dependent on efficiency of vehicles which are used and the transportation distance. The transportation costs used in this study are shown in Table C-12.

4.3.1. Results and Analysis of scenarios S1, S2 and S3

Recall that participants 1, 2, and 3 want to assign their transportation units to only HN 1, 2, and 3, respectively. Several transportation units such as T1, T2, T3, T6, and T7, are not allowed to be divided into sub-units. With these initial constraints, scenario S1 is implemented, and the number of available vehicles for each supply point is summarized in Table IV-6.

Table IV- 6: The results of scenario S1



Supply Points		SP1			SP2			SP3			SP4			TP1	TP2	TP3
Period		1	2	3	1	2	3	1	2	3	1	2	3	1	1	1
Truck 1	available #	224	353	460	344	236	201	137	108	121	550	130	126			
	reserved #	0	128	284	0	0	0	0	0	0	0	0	0			
Truck 2	available #	224	273	364	275	108	112	8	96	96	504	204	168			
	reserved #	224	273	364	275	108	112	8	96	96	504	204	168			
Truck 3	available #	96	379	647	72	182	45	320	100	100	767	107	73			
	reserved #	96	379	646	72	182	45	320	100	100	767	107	73			
Truck 4	available #	96	164	265	72	80	45	150	100	100	393	107	73			
	reserved #	0	100	241	7	0	0	84	41	34	365	0	0			
Helicopter 1	available #														27	27
	reserved #														0	0
Helicopter 2	available #													37	6	12
	reserved #													0	0	0

From Table IV-6, it is found that there are sufficient trucks at every supply point under scenario S1. By adding constraints which restrict each unit's divisibility, scenario S2 and scenario S3 are implemented. Table IV-7 lists the different constraints among scenarios S1, S2, and S3. The results of these scenarios are shown in Table IV-8 and Figure IV-5.

Table IV- 7: The different constraints in scenario S1, S2, and S3

	indivisible transportation units
scenario S1	T1, T2, T3, T6, T7
scenario S2	all units except T4, T5
scenario S3	all units

Table IV- 8: The results of scenario S1, S2, and S3

	total shortage	cost (thousands)
scenario S1	7169	1067
scenario S2	7169	1086
scenario S3	9602	1006

There is no difference for the total shortages between scenario S1 and scenario S2 since the number of available trucks is enough to transport each commodity as shown in Table IV-6. However, the total cost of scenario S2 is increased by 19 (thousands) compared to scenario S1 since more inefficient vehicles are used in scenario S2 due to the indivisible constraints for every unit except T4 and T5.

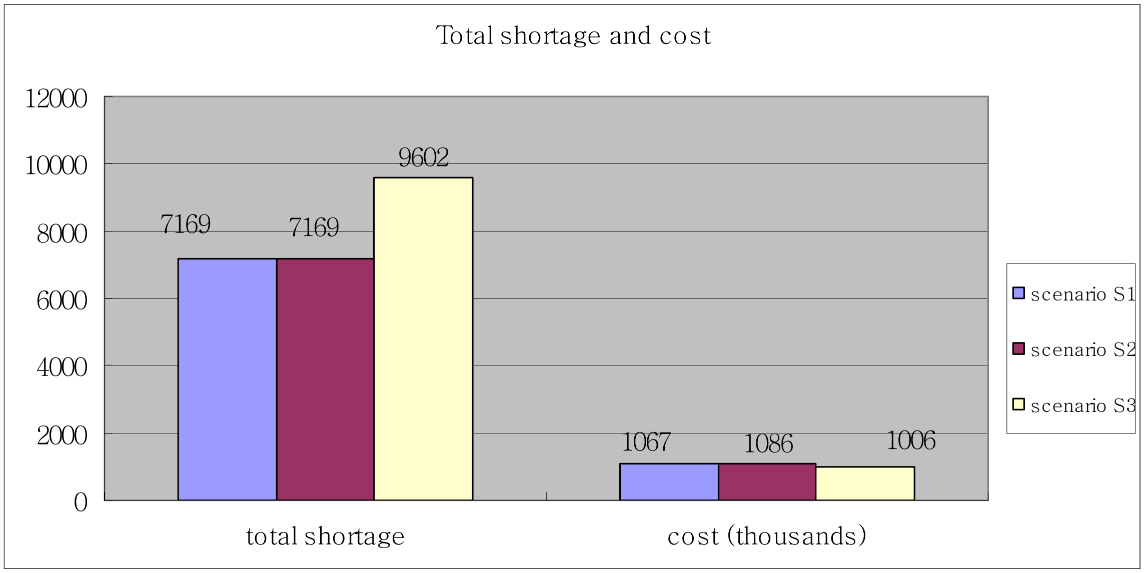


Figure IV- 5: The result of scenario S1, S2, and S3

With the indivisibility constraints for all units, the level of total shortage in scenario S3 is increased by 2,433 compared to scenario S1 and S2 since the number of helicopters is insufficient during the first period. That is, with indivisibility constraints for T4 and T5 in scenario S3, available helicopters could not be properly allocated to the transshipment points. Based on this shortfall, scenario S3's solutions would be not acceptable to the coalition commander. In scenario S2, all units except T4 and T5 are not allowed to be divided into several units. Therefore, scenario S2, while more expensive, would be operationally more acceptable than scenario S1 since scenario S2 would make unit's control easier than scenario S1. The total cost of scenario S2 is slightly higher than scenario S1.

In scenarios S1 and S2, lower limits on transported items for each demand point are not restricted. That is, some commodities could be fully transported, but some may not be delivered to certain demand points. For example, no commodity S2 is delivered to demand point 3 during the first period in scenario S2, as shown in Appendix E. Therefore, it is necessary to investigate what may happen if the lower bounds on commodities to demand points are established in scenarios S1 and S2.

4.3.2. Results and Analysis of scenario S1-2 and S2-2

The scenarios S1-2 and S2-2 are implemented by adding constraints which force at least 50 % of demand for each commodity to be transported to each demand point in scenario S1 and S2, respectively. The results of these scenarios are shown in Table IV-9, Figure IV-6, and Figure IV-7.

Table IV- 9: The results of scenario S1-2 and S2-2

	Shortage				Total cost (thousands)
	HN1	HN2	HN3	Total	
scenario S1-2	510	1594	6142	8246	1061
scenario S2-2	542	1562	6142	8246	1065

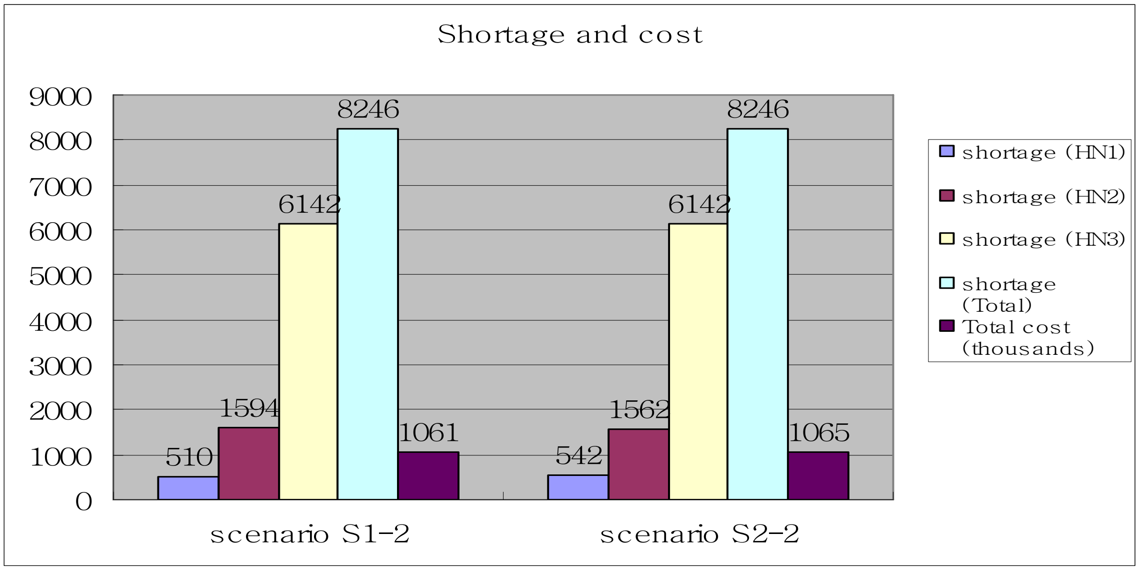


Figure IV- 6: The results of scenario S1-2 and S2-2

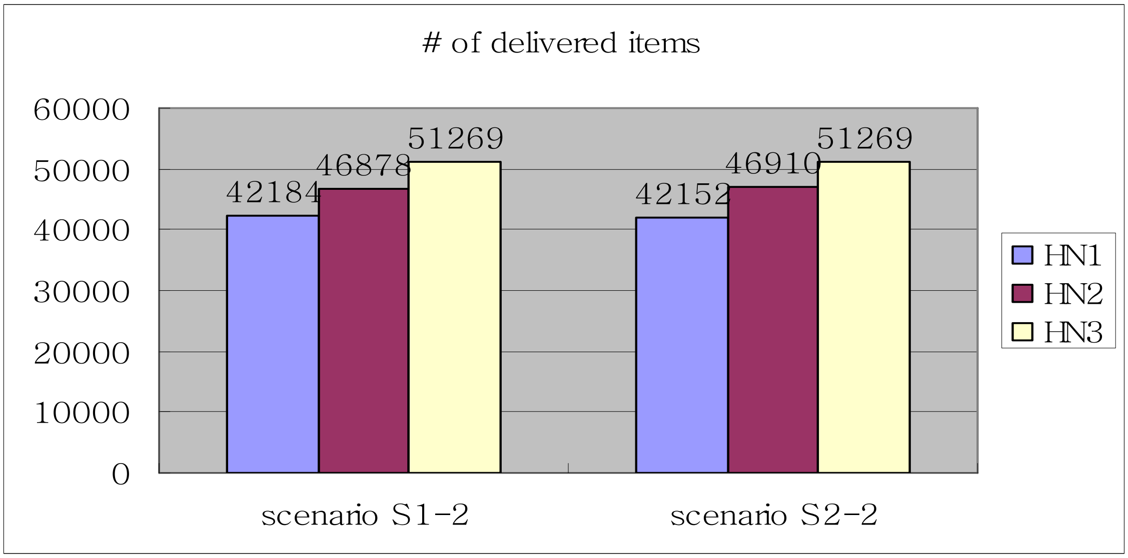


Figure IV- 7: The results of total number of delivered items among host nations

In Figure IV-6, the shortage for each host nation and total cost are slightly different, but the total shortage is approximately the same between scenarios S1-2 and S2-2. This results from sufficient number of trucks. Therefore, scenario S2-2, with greater unit control, would be more acceptable than scenario S1-2.

4.3.3. Results and Analysis of scenarios S1-3 and S2-3

The importance of each commodity varies depending on item types, weather, and so on. Therefore, an investigation to identify the effect of each commodity for each demand point was conducted. Recall that commodity S1, S2, and S3 represent critical items for all demand points such as food, water, and medical supplies. In addition, commodities #4 and #5 represent critical items such as blankets and fuel for cold regions (demand points #4, #5, #6, #8, and #10). The lack of these critical items could cause an increased number of patients and fatalities.

Scenarios S1-3 and S2-3 are implemented by adding constraints in scenario S1-2 and S2-2 which allow at least 70 % of demand for the critical items to be delivered to each demand point. The results of these scenarios are shown in Table IV-10, and Figure IV-8.

Table IV- 10: The results of scenario S1-3 and S2-3

	Shortage				Total cost (thousands)
	HN1	HN2	HN3	Total	
scenario S1-3	662	1611	6207	8480	1060
scenario S2-3	661	1587	6232	8480	1064

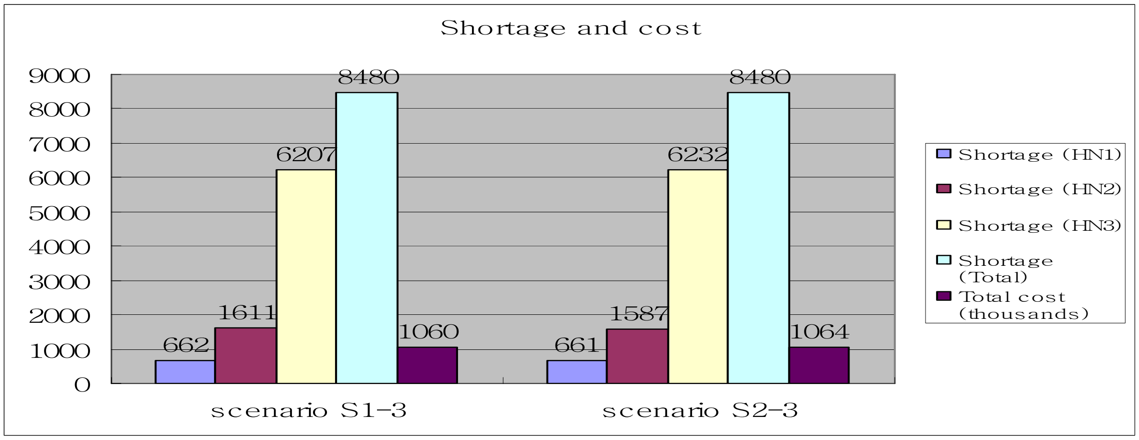


Figure IV- 8: The number of shortages and total cost in scenario S1-3 and S2-3

Total cost and the level of shortage for each host nation are slightly different between the results of scenarios S1-3 and S2-3. However, there is no difference for total shortage. Therefore, scenario S2-3's solutions would be more acceptable than scenario S1-3, again because of better unit integrity.

4.3.4. Results and Analysis of scenarios S2, S2-2, and S2-3

From the previous results and analysis, it is found that adding indivisibility constraints for every unit except T4 and T5 does not materially affect the results. Therefore, it would be desirable to select one solution among those for scenarios S2, S2-2, and S2-3 since these solutions make unit control easier. From Table IV-8, IV-9, and IV-10, the total shortages for these scenarios are summarized in Figure IV-9.

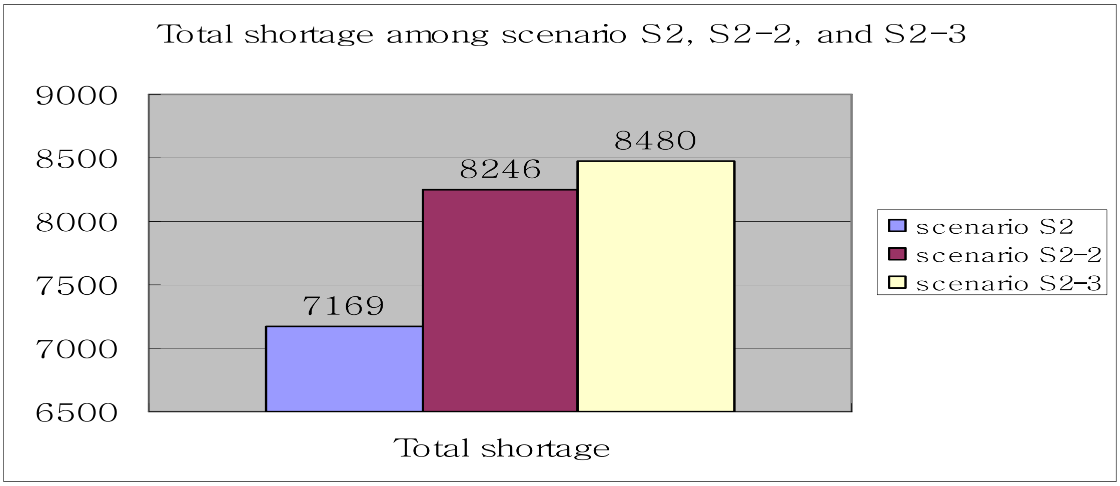


Figure IV- 9: The difference of total shortage among scenario S2, S2-2, and S2-3

In Figure IV-9, the solution of scenario S2 would be preferred if considering only the total shortage. In the solution of scenario S2, however, the shortages of various critical commodities are concentrated at certain demand points and periods. Therefore, it is necessary to check the distribution of each commodity. The results of distributions for critical commodities in scenarios S2, S2-2, and S2-3 are shown in Appendix E. As an example, the summarized results for commodity #2 are shown in Table IV-11, Figure IV-10, and Figure IV-11.

Table IV- 11: The summarized results for distribution of commodity #2

	Shortage					
Demand point	DP3	DP5	DP7	DP8	DP10	Total
scenario S2	0	25	0	375	300	700
scenario S2-2	0	150	13	387	150	700
scenario S2-3	95	110	68	337	90	700

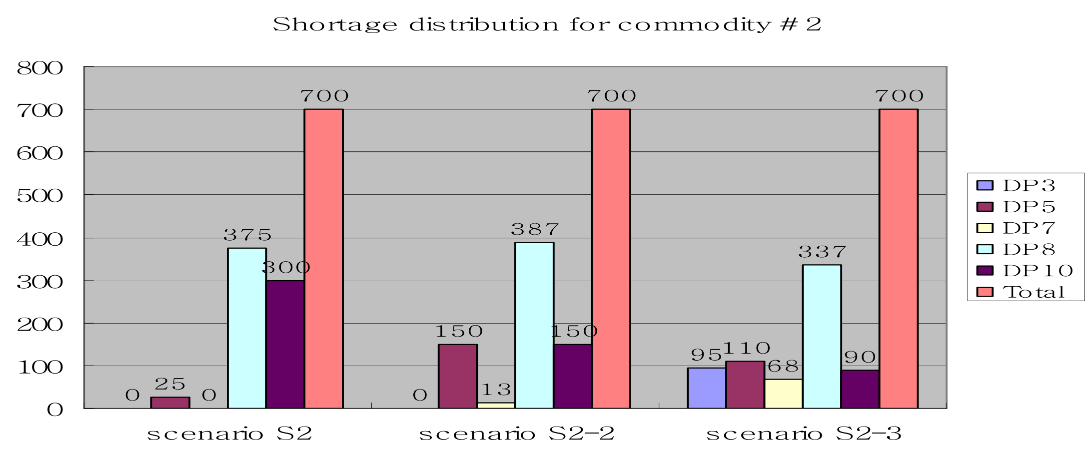


Figure IV- 10: The number of shortage for commodity #2

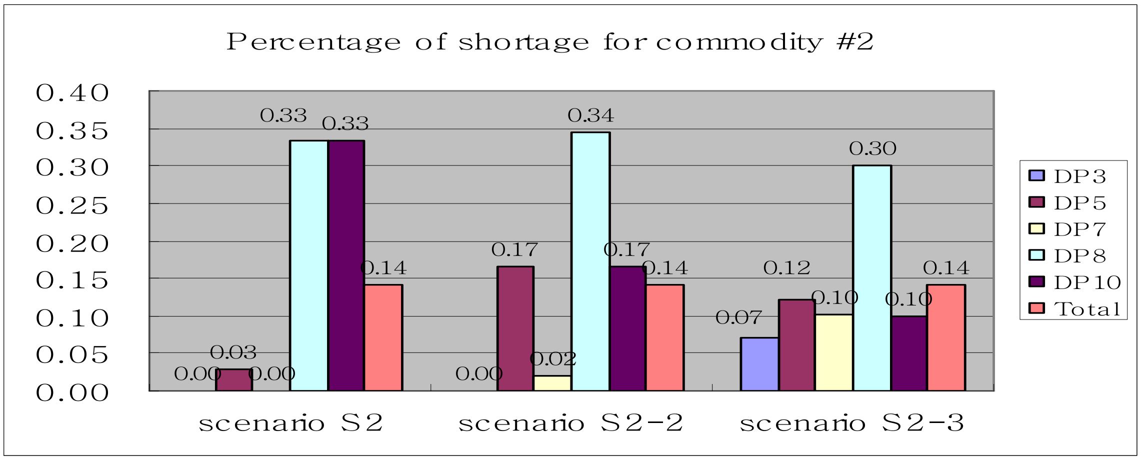


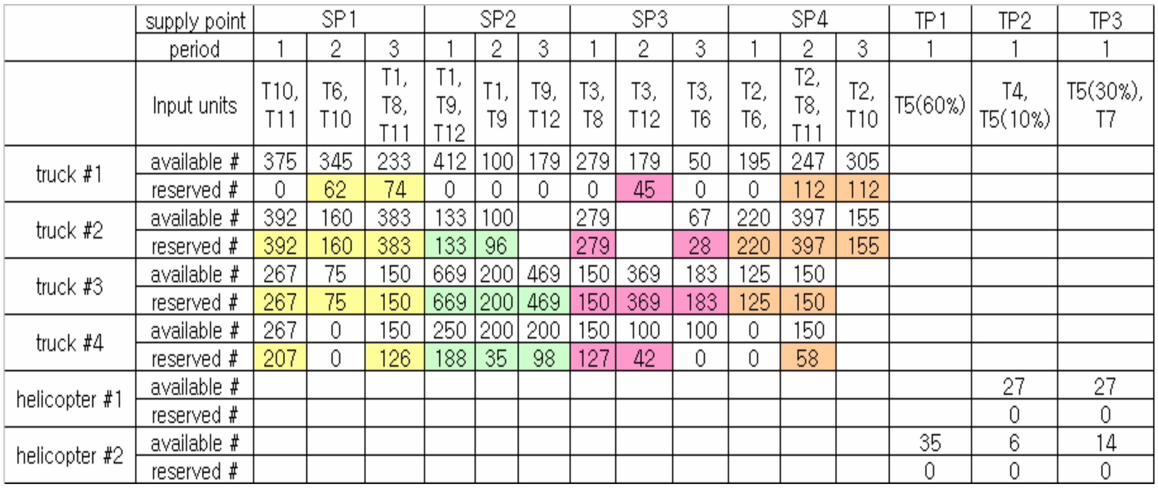
Figure IV- 11: The percentage of shortage for commodity #2

In Figure IV-10 and Figure IV-11, the total shortages for commodity #2 are the same (700) in all scenarios, but commodity #2 is well-distributed across all demand points in scenario S2-3's solution. In addition, other critical commodities are also well-distributed in scenario S2-3 as shown in Appendix E. However, the total shortage of several commodities which are not critical would be increased in scenario S2-3 compared to scenario S2 and S2-2. With the assumption that the shortages of non-critical commodities do not affect the number of fatalities and patients significantly, it is assumed that scenario S2-3's solution would be more acceptable to the coalition commander since at least 70 % of the demands for all critical items are transported to every demand points.

4.3.5. Results and Analysis of scenario S2-3

Given that scenario S2-3 is selected as the logistics support plan by the coalition commander, the results of each transportation unit's assignment are shown in Table IV-12.

Table IV- 12: Unit assignments of scenario S2-3



	supply point	SP1			SP2			SP3			SP4			TP1	TP2	TP3
	period	1	2	3	1	2	3	1	2	3	1	2	3	1	1	1
	Input units	T10, T11	T6, T10	T1, T8, T11	T1, T9, T12	T1, T9	T9, T12	T3, T8	T3, T12	T3, T6	T2, T6,	T2, T8, T11	T2, T10	T5(60%)	T4, T5(10%)	T5(30%), T7
truck #1	available #	375	345	233	412	100	179	279	179	50	195	247	305			
	reserved #	0	62	74	0	0	0	0	45	0	0	112	112			
truck #2	available #	392	160	383	133	100		279		67	220	397	155			
	reserved #	392	160	383	133	96		279		28	220	397	155			
truck #3	available #	267	75	150	669	200	469	150	369	183	125	150				
	reserved #	267	75	150	669	200	469	150	369	183	125	150				
truck #4	available #	267	0	150	250	200	200	150	100	100	0	150				
	reserved #	207	0	126	188	35	98	127	42	0	0	58				
helicopter #1	available #														27	27
	reserved #														0	0
helicopter #2	available #													35	6	14
	reserved #													0	0	0

In Table IV-12, there are some reserved trucks at every supply point, but the number of helicopters is not sufficient at all transshipment points. The shortage of each commodity at every demand point is due to the lack of supply or lack of a transportation vehicle. In this scenario, only the number of available helicopters is insufficient. Therefore, it would be necessary to identify the shortage at demand points #5, #8, and #10 which are not accessible with trucks during the first period. Table IV-13 represents the shortage of critical commodities at these demand points.

Table IV- 13: The shortage of critical commodities in DP 5, DP 8, and DP 10

Commodity	Surplus	The number of shortage during first period		
		DP5	DP8	DP10
1	2	0	42	60
2	0	90	113	90
3	0	48	60	48
4	114	0	0	54
5	5	17	112	120
Total	121	155	327	372

There is some surplus for commodities #1, #4, and #5 which are not delivered due to the lack of helicopters. With the same attributes of helicopters as shown in Table C-9, one helicopter for type 1 and 2 could transport 180 containers and 540 containers, respectively, from transshipment points to demand points during the first period. Therefore, without changing the initial logistics support plan from scenario S2-3, these surplus items could be transported to any demand point with one more of any type of helicopter. Furthermore, with the assumption that there is enough supply for these critical commodities, at least 3 more helicopters of type 2 or 5 more helicopters of type 1 would be required to meet demands at demand points #5, 8, and #10. Such analysis would support any request the coalition commander might make to participating nations for additional helicopters.

4.4. Results and Analysis for Coalition Mission-Unit Grouping Model

From the Coalition Mission-Unit Allocation Model and the Coalition Mission-Support Model, the solutions of units' allocations (Search and rescue units, Construction units, Medical units, and Transportation units) are found. However, some units can not implement assigned tasks in several regions without augmentation with support units: security units, communication units and maintenance units are included in this thesis. Therefore, it is necessary to group or augment these pre-assigned units with support units.

In this scenario, it is assumed that there are several areas which require security units from the coalition since these areas are politically unstable, and the host nations can not provide security support in these areas; these areas include supply points 1, region 1-2, and demand points and transshipment points in region 2-2, region 3-2 and region 3-4. In addition, it is assumed that the host nations can provide security for the other areas.

Without communication units, it is difficult to make a unified effort in a coalition. In addition, maintenance units are necessary for the construction units and the transportation units. In this scenario, it is assumed that the coalition commander decides to augment each regional unit with communication units and maintenance units.

With the above assumptions and the solutions of unit’s allocations from the previous two models, the coalition would be organized as shown in Figure IV-12, Figure IV-12, Figure IV-14, and Figure IV-15. In these figures, “?” represents support units which would be decided through the Coalition Mission-Unit Grouping Model, and “O” represent units which are already decided by the coalition.

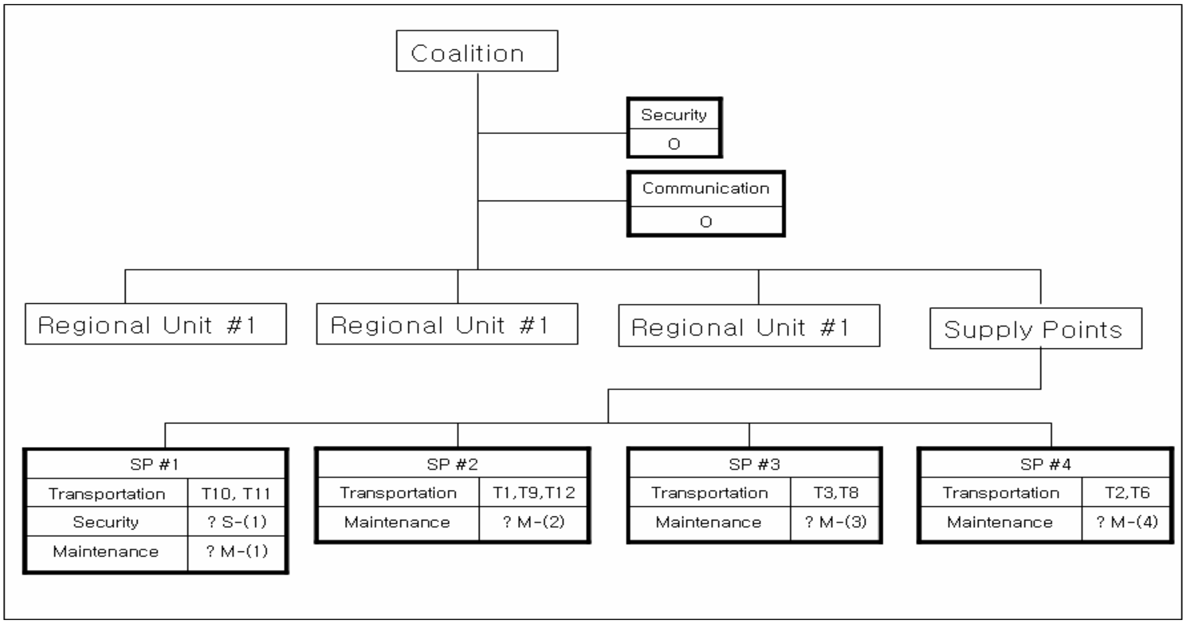


Figure IV- 12 : Structure of the Coalition

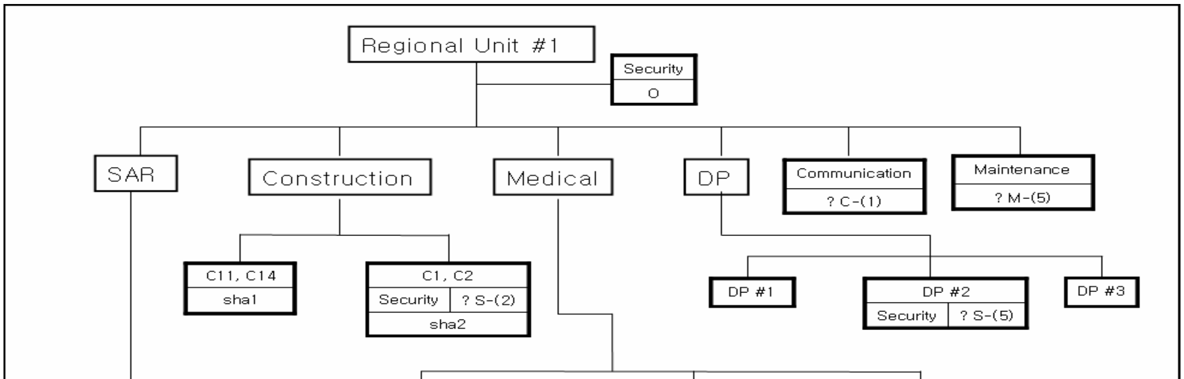


Figure IV- 13: Structure of the Regional unit #1

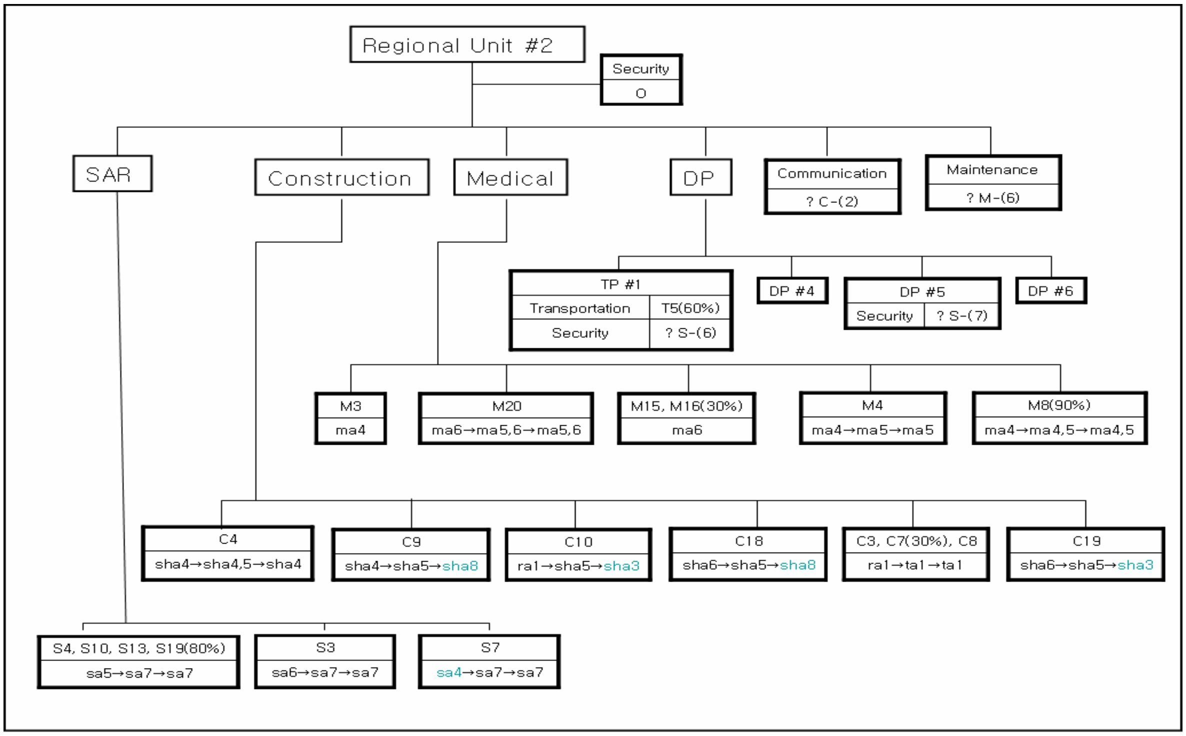


Figure IV- 14: Structure of the Regional unit #2

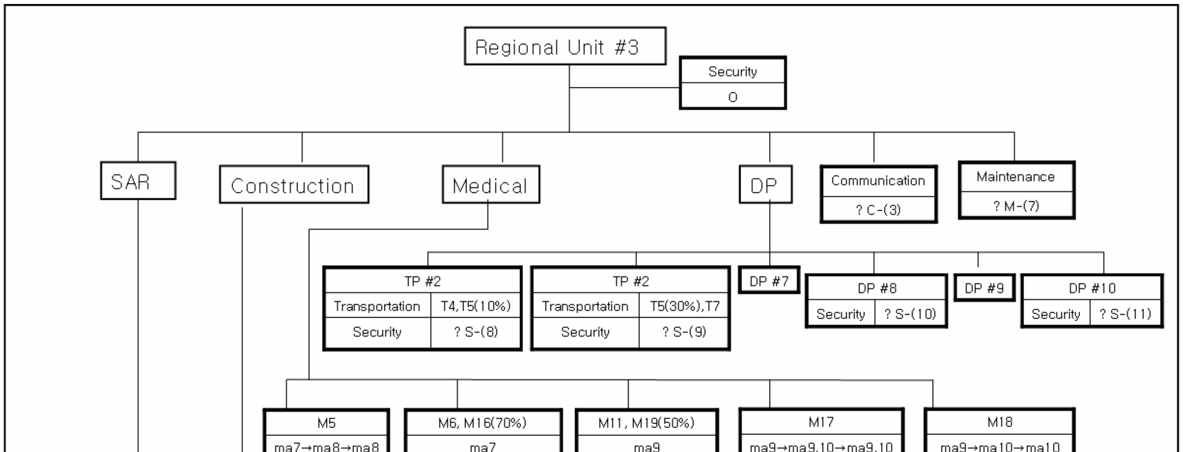


Figure IV- 15: Structure of the Regional unit #3

In Figures IV-12 through IV-15, it is assumed that some security units are already assigned to the coalition HQ and each regional unit's HQ. There are 11 areas from S-(1) to S-(11) which require security units. 15 security units are available from 6 coalition participants as shown in Table B-2. For the attributes of security unit, # of patrol cars and # equipped with night vision are used in this scenario. These attributes of security units and requirements of each area are shown in Table C-13.

The communication units are divided into 3 types (A, B, and C), depending on compatibility, in this example. It is assumed that units of type B could be compatible with other units of type A or C, but units of type A are incompatible with units of type C. In addition, it is assumed that the coalition HQ is already augmented with some communication units of type B. There are 3 areas from C-(1) to C-(3) which require communication units. 8 communication units are available from 6 participants as shown in Table B-2. In this scenario, it is assumed that the coalition commander decides the communication network as shown in Figure IV-16. (It is further assumed that individual units of all types will have their own specific individual unit equipment.)

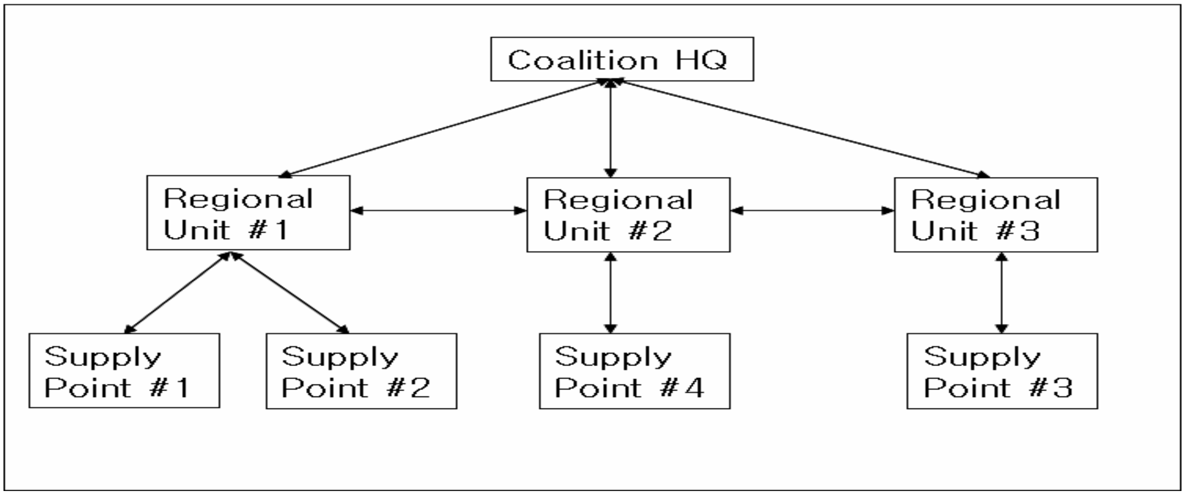


Figure IV- 16: A communication structure in the coalition

With the communication structure outlined in Figure IV-16, regional unit #1 could communicate with regional unit #3 through the coalition HQ or regional unit #2. Therefore, at least one communication unit of type B should be assigned to regional unit #2. In addition, each regional commander has the responsibility of augmenting their supply points with communication units. The attributes of communication units and the requirement of each area are shown in Table C-14.

In this scenario, 12 maintenance units are available from 8 coalition participants as shown in Table B-2, and these units are required in 7 areas from M-(1) to M-(7). It is assumed that helicopter units assigned to transshipment points are already augmented with their own maintenance units. The attributes of these units and the requirements of each area are shown in Table C-15.

The preemptive priority is used for the first goal which is minimizing the shortage of requirements in each area. Minimizing total pair-wise interaction costs is used for the second goal. Basic interaction costs between participants and between participants and host nations are randomly generated for this example as shown in Table C-16. In order to consider unit size when calculating interaction costs, the weights are used as shown in Table IV-14. For example, if a small support unit is assigned to a task which a large unit is already assigned to, and the basic interaction cost between these unit's participants is 4, then the interaction cost between these units is calculated as (weight × basic interaction cost between participants)=(3×4)=12. In practice, they will be estimated by expert staff and pre-processed for entry in the model. Questions such as previous alliance or coalition experience, existing political questions, and so forth, would be considered. While these values will clearly be estimates, they should aid the coalition commander in making initial allocation of support.

Table IV- 14: Weight for the interaction costs

Size of pre-assigned unit or support unit	Size of support unit	Weight
Small	Small	1
Small	Medium	2
Medium	Small	2
Small	Large	3
Large	Small	3
Medium	Medium	3
Medium	Large	4
Large	Medium	4
Large	Large	5

4.4.1. Results and Analysis of scenario G1

In the general scenario, participant 1, 2, and 3 restrict their units to be assigned to only HN 1, 2, and 3, respectively. In order to satisfy the structure of communication, at least one communication unit of type B must be assigned to regional unit #2. With these initial constraints, scenario G1 is implemented. The solutions of scenario G1 are shown in Table IV-15, Table IV-16, and Table IV-17.

In Table IV-15 and Table IV-16, it is found that there are reserved security units (P5 and P13) and communication units (Q1) without the shortage of requirement for all areas. However, maintenance unit is insufficient in several areas (M-1, M-5, and M-6) as shown in Table IV-17. The type of reserved communication unit, Q1, is B which is compatible with types A and C. However, participant 1 restricts that unit to be assigned to only host nation #1. Therefore, another communication unit of type B would be preferred as a reserve unit.

Table IV- 15: The results (security units) of scenario G1

Security		Shortage (Surplus)	
Security Job	Assigned units	Requirement 1	Requirement 2
S-1	P1, P4, P11		(30)
S-2	P2		
S-3	P15		
S-4	P3		
S-5	P14		
S-6	P7		
S-7	P6		
S-8	P9		
S-9	P10		
S-10	P8	(5)	(10)
S-11	P12		
Reserved	P5, P13	(15)	(30)

Interaction cost between security units and pre-assigned units	172
Interaction cost between security units and host nations	176
Interaction cost between security units	5

Table IV- 16: The results (communication units) of scenario G1

Communication		Shortage (Surplus)	
Communication Job	Assigned units	Requirement 1	Requirement 2
C-1	Q5, Q8		
C-2	Q2, Q4		
C-3	Q3, Q6, Q7		

Reserved	Q1	(10)	(10)

Interaction cost between communication units and host nations	81
Interaction cost between communication units	78

Table IV- 17: The results (maintenance units) of scenario G1

Maintenance		Shortage (Surplus)	
Maintenance Job	Assigned units	Requirement 1	Requirement 2
M-1	R5, R11	10	10
M-2	R1		
M-3	R3		
M-4	R2		
M-5	R4, R10, R12		5
M-6	R8	20	10
M-7	R6, R7, R9		
Reserved			

Interaction cost between maintenance units and pre-assigned units	64
Interaction cost between maintenance units and host nations	131
Interaction cost between maintenance units	45
Interaction cost between security units and maintenance units	42

4.4.2. Results and Analysis of scenario G2

With the constraint which allows another communication unit of type B to be reserved, scenario G2 is implemented. In this scenario, it is assumed that there is no interaction between communication units and security or maintenance units. Therefore, the solution of security units and maintenance units in scenario G2 are the same as the solutions in scenario G1. The solutions for communication units in scenario G2 are shown in Table IV-18.

In Table IV-18, there are shortages of requirements in area C-1, even though the coalition could have one reserved communication unit, Q5. The difference between solutions in scenario G1 and in scenario G2 is the location of communication units Q1 and Q 5. Therefore, it could be recommended that 50 % of Q5 is assigned to C-1, and the other 50 % of Q5 is reserved in scenario G2 with the assumption that this communication unit could be divisible.

Table IV- 18: The results (communication units) of scenario G2

Communication		Shortage (Surplus)	
Communication Job	Assigned units	Requirement 1	Requirement 2
C-1	Q1, Q8	10	10
C-2	Q2, Q5		
C-3	Q3, Q6, Q7		
Reserved	Q5	(20)	(20)
Interaction cost between communication units and host nations			84
Interaction cost between communication units			63

4.5. Summary

Through the Coalition Mission-Unit Allocation Model, three types of units, search and rescue units, construction units, and medical units, are allocated to required tasks in order to satisfy the goals of the coalition. These units can not implement their assigned tasks without logistics support. Furthermore, there would be a great number of suffering people due to the lack of various resources such as food, water, and so on in an emergency situation. Through the Coalition Mission-Support Model, an optimal logistics plan is found, and transportation units are allocated to proper locations.

As mentioned in Chapter II, a coalition might invite small units which can not operate independently due to political interests. Therefore, it is necessary to group or augment these units with other units. The solutions of unit augmentation are found through the Coalition Mission-Unit Grouping Model in this thesis. By adding these solutions in Figure IV-12, Figure IV-13, Figure IV-14, and Figure IV-15, an optimal coalition operational plan would be found for a HA.

While notional, this analysis illustrates the usefulness of the model considered. It should be noted that no matter how well an assessment is conducted, it will be at best an estimate of a fluid situation. The Coalition Operation Planning Model is simply a tool to aid the commander and his staff in developing initial plans. As has been demonstrated with the example scenarios, it is robust enough to consider the wide variety of options and restrictions that may occur in a HA operation. It does not, however, substitute for experienced judgment. It is a tool to aid decision makers, not supplant them.

The conclusions of this research and recommendations for further research are presented in the next chapter.

V. Conclusions and Recommendations

5.1. Overview

This research suggested a general procedure for the Coalition Operation Planning Model which provides an optimized operational plan for a coalition. This model is composed of three sub-models which are the Coalition Mission-Unit Allocation Model, the Coalition Mission-Support Model, and the Coalition Mission-Unit Grouping Model. In this thesis, formulations of these models are developed for a humanitarian assistance operation, and a notional scenario is employed to illustrate these models.

5.2. Research Results

This thesis focused on an initial emergency situation in a HA Operation to build the Coalition Operation Planning Model. There could be numerous tasks which are required in an initial emergency situation. Nine tasks are included in this thesis. These tasks are: 1) search and rescue, 2) stabilizing, 3) immediate rehabilitation, 4) temporary shelter construction, 5) medical treatment, 6) transportation, 7) security,

8) communication, and 9) maintenance. Since a coalition operation usually involves multiple potentially conflicting objectives, goal programming is employed to develop a methodology.

The Coalition Mission-Unit Allocation Model was developed to find an optimal assignment of units by applying the concept of the shortest path problem. In this model, search and rescue unit, construction unit, and medical unit are included to carry out the first six tasks listed above. The directed networks are constructed in order to represent a unit's assignments over time periods. That is, nodes in these networks include the information of both tasks and time periods, and arcs represent a unit's possible assignments between tasks of consecutive time periods. This model is designed to find an effective path for each unit depending on the effectiveness functions by satisfying objectives.

Even though available units are assigned to tasks through the Coalition Mission-Unit Allocation Model, it is impossible for these units to carry out assigned tasks successively without logistics support. Furthermore, numerous relief items would be required to save or relieve suffering people in a humanitarian assistance operation. The Coalition Mission-Support Model is developed to find an optimal logistics support plan by using Multi-Commodity Network Flow. In this model, transportation units are included to carry out tasks. In a directed network for the Multi-Commodity Network Flow, the capacity of each arc is not constant, but dependent upon the number of vehicles assigned to that arc. Therefore, both the transportation unit's assignment problem and the multi-commodity flow problem interact simultaneously in this model.

Through the first and second model, the solutions of unit allocations are obtained, but several units could not operate independently. That is, it is necessary to augment or group these units with other support units. The Coalition Mission-Unit Grouping Model is developed to combine these units into workable independent units by using the Quadratic Assignment Problem. The security unit, communication unit, and maintenance unit are included in this model.

The general notional scenario in an earthquake disaster is constructed to demonstrate the procedure of these three sub-models. With the assumptions that numerous estimates from rapid assessments are correct, it is shown that various political issues influence the commander’s decision.

5.3. Recommendations for Future Research

This research developed the Coalition Operation Planning Model in a HA Phase-I Operation by applying goal programming, the shortest path problem, multi-commodity network flow, and the quadratic assignment problem. There are several areas that should be developed in future research.

Clearly, this research could be applied to other problem areas such as a coalition operation in War or other types of MOOTW. In addition, this study could be extended by including HA Phase-II Operation (Rehabilitation) and Phase-III Operation (Reconstruction). The procedure and algorithm of the Coalition Operation Planning Model in a HA Phase-I Operation could be used in other problem areas. However, it would be necessary to identify different types of units and tasks and to develop various effectiveness functions.

Secondly, future research could develop the Coalition Operation Planning Model by using heuristics or the decomposition algorithm, since the size of problem could be greatly increased depending on situations such as the number of tasks, units, time periods, and a variety of constraints. By solving each model sequentially, some decomposition and approximation have already been used. Individual conditions may dictate the most viable approach. Figure V-1 and Figure V-2 represent potential block angular structures for the Coalition Mission-Unit Allocation Model and the Coalition Mission-Support Model, respectively. Due to the integer nature of this problem, the Sweeney-Murphy Decomposition algorithm (Sweeney and Murphy, 1979) would be a possible methodology for future research. Heuristics are methods that maintain a trade off between the computational time and quality of solutions. If the computational effort using an exact algorithm exceeds available time due to the problem size, heuristics could be another possible methodology. There are numerous works in the literature (Taillard, 1991; Wilhelm and Ward, 1987; Tian, *et al.*, 1995; Tate and Smith, 1995; Gambardella, *et al.*, 1999) in which heuristic methods are used for the quadratic assignment problem.

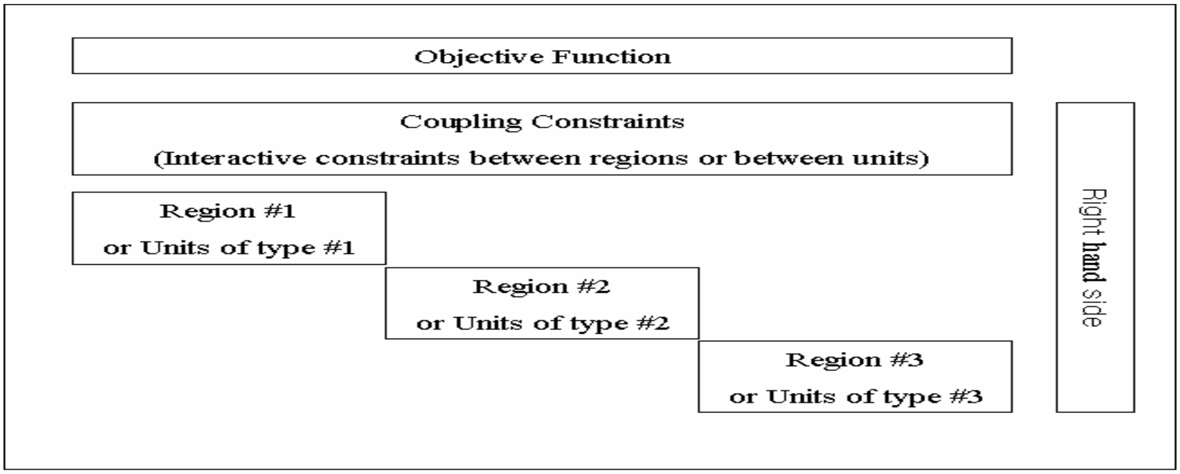


Figure V- 1: A block angular structure for the Unit Allocation Model

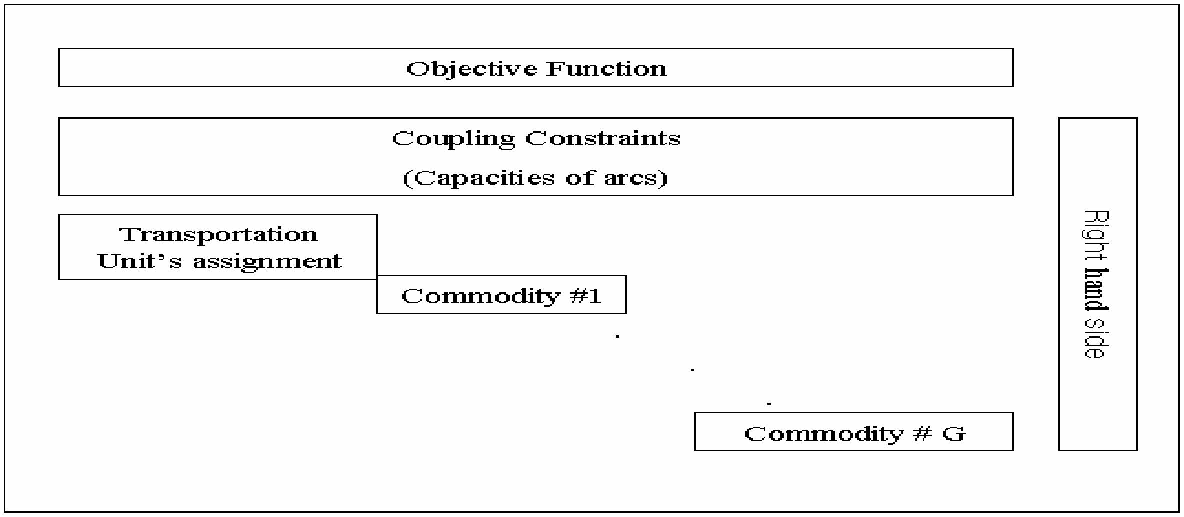


Figure V- 2: A block angular structure for the Support Model

Thirdly, a rescheduling model would be necessary for future research. In the Coalition Operation Planning Model, a number of estimates are required from a rapid assessment and a mission analysis. In an initial emergency situation, however, these assessments would likely be wrong. If a coalition operation has been started using a solution based on a wrong assessment, this solution should be adjusted with correct information.

In addition, many of the parameters in these models are estimates. It will be essential to build up a detailed data base to aid in estimating parameter values. It will also be critical to test the robustness of the models to deal with imprecise data and changing situations.

Finally, it would be useful to incorporate a graphical user interface with the Coalition Operation Planning Model, so a decision maker could easily input parameters and attain an optimal solution.

Appendix A. A Representative list of US participation in Multinational Operations

Table A- 1: A Representative list of US participation in Multinational Operation (DoD, Apr 2000:B-1)

International Relief Force in China, Boxer Rebellion (1900)	Multinational Force and Observers in the Sinai (1982)
Allied Armies in France, WWI (1918)	Maritime Interception Operations (1999 to Present)
Allied Intervention in Russia, Vicinity of Murmansk in the Far North (1918)	DESERT STORM Coalition in the Persian Gulf War (1991)
Allied Operations in WWII (1942)	Operation SOUTHERN WATCH (1992 to Present)
United Nations Truce Supervision Organization in Palestine (1948)	Operation PROVIDE COMFORT (1991-1996)
United Nations Military Observer Group in India and Pakistan (1949)	United Nations Protection Force in Former Yugoslavia (1992)
Allied Operations During the Korean War (1950)	United Nations Operation in Somalia after US Humanitarian Intervention of December 1992 (1993)
United Nations Security Force for the UN Temporary Executive Authority in West New Guinea (1962)	Multinational Force and United Nations Mission in Haiti (1994)
Inter-American Peace Force in the Dominican Republic (1965)	NATO Implementation and Stabilization Force (1995)
Multinational Force in Beirut (1982)	NATO Operation Allied Force (1999)

Appendix B. Coalition Participants and Moving times in a scenario

Table B- 1: Participants and their available units for Coalition Mission-Unit Allocation Model and Coalition Mission-Support Model

Participants	SAR Unit	Construction Unit	Medical Unit	Transportation Unit
1	• S1, • S2,	• C1, • C2	• M1, • M2	• T1
2	• S3, • S4	• C3, • C4	• M3, • M4	• T2
3	• S5, • S6,	• C5, • C6	• M5, • M6	• T3
4		• C7, • C8	• M7, • M8	
5		• C9, • C10		• T4 • T5
6		• C11, • C12		
7	• S7, • S8	• C13, • C14		
8		• C15, • C16	• M9, • M10	
9	• S9, • S10			• T6 • T7
10	• S11, • S12		• M11, • M12	
11	• S13, • S14			• T8
12	• S15		• M13	• T9
13	• S16,			• T10
14	• S17		• M14	• T11
15		• C17, • C18	• M15	
16	• S18, • S19		• M16	
17	• S20			
18		• C19, • C20	• M17, • M18	
19			• M19	
20			• M20	• T12
Total number	20	20	20	12

Table B- 2: Participants and their available units for Coalition Mission-Unit Grouping Model

Participants	Security Unit	Communication Unit	Maintenance Unit
1	• P1, • P2, • P3, • P4	• Q1	• R1
2	• P5, • P6, • P7,	• Q2	• R2
3	• P8, • P9, • P10,	• Q3	• R3
4			
5			
6			
7			
8			
9			• R4, • R5
10			
11			• R6, • R7
12		• Q4, • Q5	
13	• P11, • P12,		• R8, • R9
14			• R10, • R11
15	• P13, • P14,		
16			• R12
17			
18	• P15,		
19		• Q6,• Q7	
20		• Q8	
Total number	15	8	12

Table B- 3: Moving times between each locations (hrs)

Moving times between supply points and sub-regions (hrs)										
	R 1-1	R 1-2	R 1-3	R 2-1	R 2-2	R 2-3	R 3-1	R 3-2	R 3-3	R 3-4
SP1	5	6	8	4	7	8	8	10	10	12
SP2	8	5	3	8	8	8	5	6	5	8
SP3	8	5	5	8	8	8	5	5	3	3
SP4	10	8	8	8	8	3	5	5	5	7
Moving time between sub-regions (hrs)										
	R 1-1	R 1-2	R 1-3	R 2-1	R 2-2	R 2-3	R 3-1	R 3-2	R 3-3	R 3-4
R 1-1	0	5	8	3	5	8	5	10	8	15
R 1-2	5	0	3	3	5	8	5	8	6	10
R 1-3	8	3	0	4	5	8	3	5	4	10
R 2-1	3	3	4	0	3	5	4	8	8	10
R 2-2	5	5	5	3	0	3	3	5	8	10
R 2-3	8	8	8	5	3	0	3	5	5	8
R 3-1	5	5	3	4	3	3	0	3	3	5
R 3-2	10	8	5	8	5	5	3	0	3	5
R 3-3	8	6	4	8	8	5	3	3	0	3
R 3-4	15	10	10	10	10	8	5	5	3	0
Moving times between supply points (hrs)										
	SP1	SP2	SP3	SP4	TP1	TP2	TP3			
SP1	0	8	8	12	4	8	12			
SP2	8	0	5	12	6	8	8			
SP3	8	5	0	8	6	4	4			
SP4	12	12	8	0	5	8	10			
TP1	4	6	6	5	0	5	8			
TP2	8	8	4	8	5	0	4			
TP3	12	8	4	10	8	4	0			

Appendix C. Attributes of units and tasks in a scenario

Table C- 1: The attributes of search and rescue units

Units			Effectiveness during a day														
Label	Type/Size	Initial Location	SA1	SA2	SA3	SA4	SA5	SA6	SA7	SA8	SA9	SA10	SA11	SA12	SA13	SA14	SA15
1	A / M	Region 1-1	7	5	7	7	5	3	5	5	5	3	7	3	3	7	5
2	B / L	Region 1-2	3	5	3	5	5	3	5	5	5	3	3	3	3	3	5
3	C / L	Region 2-1	1	3	1	1	3	5	3	3	3	5	1	5	5	1	3
4	A / H	Region 2-3	9	7	9	9	7	5	7	7	7	5	9	5	5	9	7
5	A / H	Region 3-1	9	7	9	9	7	5	7	7	7	5	9	5	5	9	7
6	A / M	Region 3-3	7	5	7	7	5	3	5	5	5	3	7	3	3	7	5
7	B / L	SP2	3	5	3	5	5	3	5	5	5	3	3	3	3	3	5
8	C / M	SP2	3	5	3	3	5	7	5	5	5	7	3	7	7	3	5
9	A / L	SP2	5	3	5	5	3	1	3	3	3	1	5	1	1	5	3
10	B / H	SP2	7	9	7	7	9	7	9	9	9	7	7	7	7	7	9
11	A / H	SP2	9	7	9	9	7	5	7	7	7	5	9	5	5	9	7
12	B / H	SP2	7	9	7	7	9	7	9	9	9	7	7	7	7	7	9
13	B/ H	Region 1-3	7	9	7	7	9	7	9	9	9	7	7	7	7	7	9
14	C / L	Region 1-3	1	3	1	1	3	5	3	3	3	5	1	5	5	1	3
15	A / L	Region 3-1	5	3	5	5	3	1	3	3	3	1	5	1	1	5	3
16	B / M	Region 1-2	5	7	5	5	7	5	7	7	7	5	5	5	5	5	7
17	C / M	Region 1-1	3	5	3	3	5	7	5	5	5	7	3	7	7	3	5
18	A / L	SP4	5	3	5	5	3	1	3	3	3	1	5	1	1	5	3
19	B / H	SP4	7	9	7	7	9	7	9	9	9	7	7	7	7	7	9
20	A / M	SP4	7	5	7	7	5	3	5	5	5	3	7	3	3	7	5

Table C- 2: The attributes of search and rescue tasks

Task label	Type	n_k^{SA}	V_k^{SA}	$G_{k(t)}^{SA}$			$(p^{SA}_{k(1),h}, p^{SA}_{k(2),h}, p^{SA}_{k(3),h})$			
				t=1	t=2	t=3	h=1	h=2	h=3	h=4
1	A	500	100	0.8	0.5	0.4	(0.5,0.6,0.7)	(0.3,0.3,0.3)	(0.1,0.1,0)	(0.1,0,0)
2	B	300	100	0.85	0.6	0.3	(0.3,0.4,0.5)	(0.5,0.5,0.5)	(0.1,0.1,0)	(0.1,0,0)
3	A	700	150	0.9	0.7	0.5	(0.2,0.4,0.5)	(0.4,0.4,0.4)	(0.2,0.1,0.1)	(0.2,0.1,0)
4	A	800	180	0.8	0.5	0.4	(0.4,0.5,0.6)	(0.2,0.3,0.3)	(0.2,0.1,0.1)	(0.2,0.1,0)
5	B	400	90	0.7	0.4	0.2	(0.5,0.6,0.7)	(0.2,0.3,0.3)	(0.2,0.1,0)	(0.1,0,0)
6	C	350	100	0.6	0.4	0.2	(0.5,0.6,0.7)	(0.3,0.3,0.3)	(0.2,0.1,0)	(0,0,0)
7	B	500	150	0.7	0.5	0.3	(0.6,0.7,0.8)	(0.3,0.2,0.2)	(0.1,0.1,0)	(0,0,0)
8	B	300	100	0.8	0.5	0.4	(0.5,0.6,0.7)	(0.3,0.2,0.3)	(0.1,0.2,0)	(0.1,0,0)
9	B	200	150	0.7	0.5	0.35	(0.6,0.7,0.8)	(0.3,0.2,0.2)	(0.1,0.1,0)	(0,0,0)
10	C	600	100	0.7	0.5	0.3	(0.4,0.5,0.6)	(0.2,0.3,0.4)	(0.2,0.2,0)	(0.2,0,0)
11	A	200	50	0.7	0.5	0.3	(0.5,0.6,0.7)	(0.3,0.3,0.3)	(0.1,0.1,0)	(0.1,0,0)
12	B	900	180	0.7	0.5	0.3	(0.3,0.4,0.5)	(0.5,0.5,0.5)	(0.1,0.1,0)	(0.1,0,0)
13	C	200	50	0.8	0.6	0.4	(0.2,0.4,0.5)	(0.4,0.4,0.4)	(0.2,0.1,0.1)	(0.2,0.1,0)
14	A	300	70	0.65	0.4	0.2	(0.4,0.5,0.6)	(0.2,0.3,0.3)	(0.2,0.1,0.1)	(0.2,0.1,0)
15	B	500	100	0.8	0.6	0.3	(0.5,0.6,0.7)	(0.2,0.3,0.3)	(0.2,0.1,0)	(0.1,0,0)

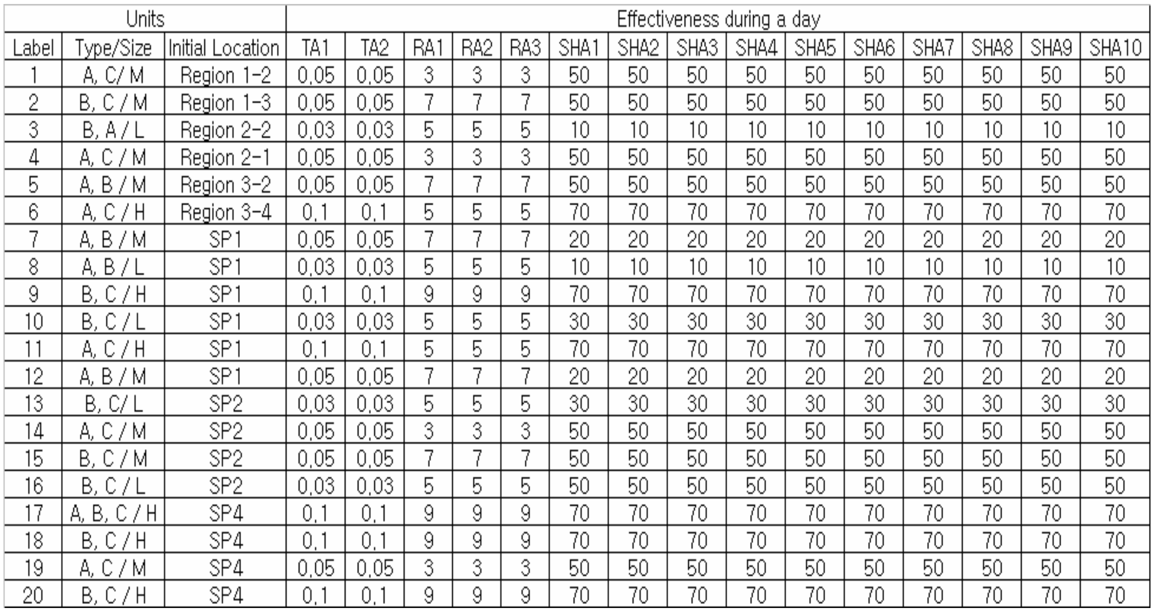
n_k^{SA} : Initial number of collapsed people in SA *k*

V_k^{SA} : Initial workload which has to be removed in SA *k*

$G_{k(t)}^{SA}$: Probability of surviving from rescued people in SA *k* at time *t*

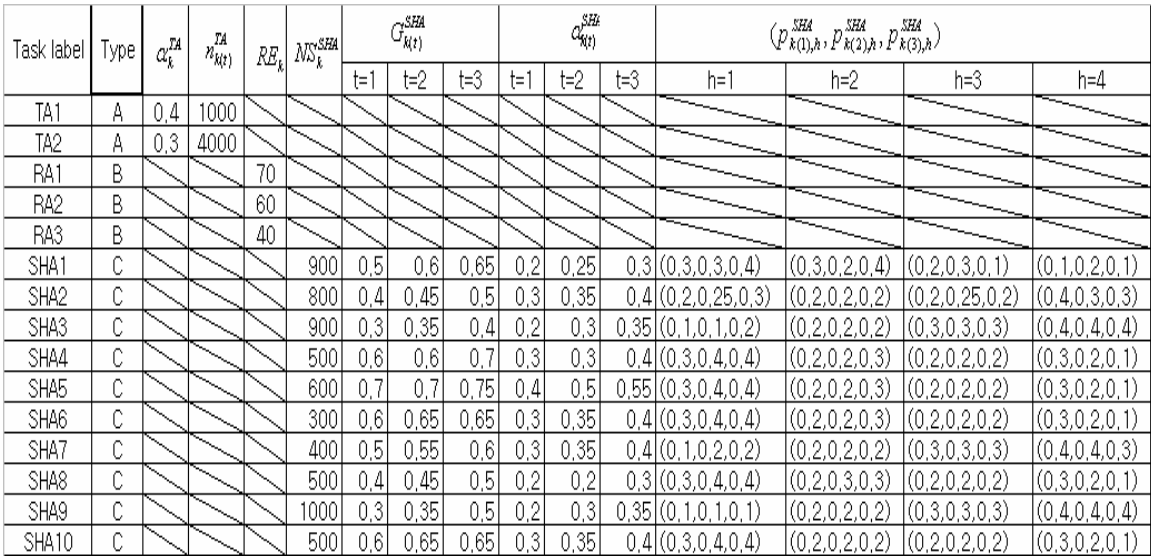
$p_{k(t),h}^{SA}$: Percentage of patient level *h* in SA *k* at time *t*

Table C- 3: The attributes of construction units



Units			Effectiveness during a day														
Label	Type/Size	Initial Location	TA1	TA2	RA1	RA2	RA3	SHA1	SHA2	SHA3	SHA4	SHA5	SHA6	SHA7	SHA8	SHA9	SHA10
1	A, C/ M	Region 1-2	0,05	0,05	3	3	3	50	50	50	50	50	50	50	50	50	50
2	B, C / M	Region 1-3	0,05	0,05	7	7	7	50	50	50	50	50	50	50	50	50	50
3	B, A / L	Region 2-2	0,03	0,03	5	5	5	10	10	10	10	10	10	10	10	10	10
4	A, C / M	Region 2-1	0,05	0,05	3	3	3	50	50	50	50	50	50	50	50	50	50
5	A, B / M	Region 3-2	0,05	0,05	7	7	7	50	50	50	50	50	50	50	50	50	50
6	A, C / H	Region 3-4	0,1	0,1	5	5	5	70	70	70	70	70	70	70	70	70	70
7	A, B / M	SP1	0,05	0,05	7	7	7	20	20	20	20	20	20	20	20	20	20
8	A, B / L	SP1	0,03	0,03	5	5	5	10	10	10	10	10	10	10	10	10	10
9	B, C / H	SP1	0,1	0,1	9	9	9	70	70	70	70	70	70	70	70	70	70
10	B, C / L	SP1	0,03	0,03	5	5	5	30	30	30	30	30	30	30	30	30	30
11	A, C / H	SP1	0,1	0,1	5	5	5	70	70	70	70	70	70	70	70	70	70
12	A, B / M	SP1	0,05	0,05	7	7	7	20	20	20	20	20	20	20	20	20	20
13	B, C/ L	SP2	0,03	0,03	5	5	5	30	30	30	30	30	30	30	30	30	30
14	A, C / M	SP2	0,05	0,05	3	3	3	50	50	50	50	50	50	50	50	50	50
15	B, C / M	SP2	0,05	0,05	7	7	7	50	50	50	50	50	50	50	50	50	50
16	B, C / L	SP2	0,03	0,03	5	5	5	50	50	50	50	50	50	50	50	50	50
17	A, B, C / H	SP4	0,1	0,1	9	9	9	70	70	70	70	70	70	70	70	70	70
18	B, C / H	SP4	0,1	0,1	9	9	9	70	70	70	70	70	70	70	70	70	70
19	A, C / M	SP4	0,05	0,05	3	3	3	50	50	50	50	50	50	50	50	50	50
20	B, C / H	SP4	0,1	0,1	9	9	9	70	70	70	70	70	70	70	70	70	70

Table C- 4: The attributes of construction tasks



Task label	Type	α_k^{TA}	$n_{k(t)}^{TA}$	RE_k	NS_k^{SHA}	$G_{k(t)}^{SHA}$			$\alpha_{k(t)}^{SH}$			$(p_{k(1),h}^{SHA}, p_{k(2),h}^{SHA}, p_{k(3),h}^{SHA})$			
						t=1	t=2	t=3	t=1	t=2	t=3	h=1	h=2	h=3	h=4
TA1	A	0,4	1000												
TA2	A	0,3	4000												
RA1	B			70											
RA2	B			60											
RA3	B			40											
SHA1	C				900	0,5	0,6	0,65	0,2	0,25	0,3	(0,3,0,3,0,4)	(0,3,0,2,0,4)	(0,2,0,3,0,1)	(0,1,0,2,0,1)
SHA2	C				800	0,4	0,45	0,5	0,3	0,35	0,4	(0,2,0,25,0,3)	(0,2,0,2,0,2)	(0,2,0,25,0,2)	(0,4,0,3,0,3)
SHA3	C				900	0,3	0,35	0,4	0,2	0,3	0,35	(0,1,0,1,0,2)	(0,2,0,2,0,2)	(0,3,0,3,0,3)	(0,4,0,4,0,4)
SHA4	C				500	0,6	0,6	0,7	0,3	0,3	0,4	(0,3,0,4,0,4)	(0,2,0,2,0,3)	(0,2,0,2,0,2)	(0,3,0,2,0,1)
SHA5	C				600	0,7	0,7	0,75	0,4	0,5	0,55	(0,3,0,4,0,4)	(0,2,0,2,0,3)	(0,2,0,2,0,2)	(0,3,0,2,0,1)
SHA6	C				300	0,6	0,65	0,65	0,3	0,35	0,4	(0,3,0,4,0,4)	(0,2,0,2,0,3)	(0,2,0,2,0,2)	(0,3,0,2,0,1)
SHA7	C				400	0,5	0,55	0,6	0,3	0,35	0,4	(0,1,0,2,0,2)	(0,2,0,2,0,2)	(0,3,0,3,0,3)	(0,4,0,4,0,3)
SHA8	C				500	0,4	0,45	0,5	0,2	0,2	0,3	(0,3,0,4,0,4)	(0,2,0,3,0,3)	(0,2,0,2,0,2)	(0,3,0,2,0,1)
SHA9	C				1000	0,3	0,35	0,5	0,2	0,3	0,35	(0,1,0,1,0,1)	(0,2,0,2,0,2)	(0,3,0,3,0,3)	(0,4,0,4,0,4)
SHA10	C				500	0,6	0,65	0,65	0,3	0,35	0,4	(0,3,0,4,0,4)	(0,2,0,2,0,2)	(0,2,0,2,0,2)	(0,3,0,2,0,1)

α_k^{TA} : Percentage that people will be dead due to secondary disaster in TA *k*

$n_{k(t)}^{TA}$: Number of people which stay in TA *k* at time *t*

RE_k : Required effectiveness for TA *k* to be accessible

NS_k^{SHA} : Initial number of homeless people in SHA *k*

$G_{k(t)}^{SHA}$: Probability of causing disease for homeless people in SHA *k* at time *t*

$\alpha_{k(t)}^{SHA}$: Percentage that homeless patients will be dead in SHA *k* at time *t*

$p_{k(t),h}^{SHA}$: Percentage of patient level *h* in SHA *k* at time *t*

Table C- 5: The attributes of medical units

Units			Effectiveness during a day									
Label	Size	Initial Location	MA1	MA2	MA3	MA4	MA5	MA6	MA7	MA8	MA9	MA10
1	H	Region 1-1	900	900	900	900	900	900	900	900	900	900
2	M	Region 1-2	600	600	600	600	600	600	600	600	600	600
3	H	Region 2-1	900	900	900	900	900	900	900	900	900	900
4	L	Region 2-3	300	300	300	300	300	300	300	300	300	300
5	H	Region 3-1	900	900	900	900	900	900	900	900	900	900
6	M	Region 3-3	600	600	600	600	600	600	600	600	600	600
7	L	SP1	300	300	300	300	300	300	300	300	300	300
8	H	SP1	900	900	900	900	900	900	900	900	900	900
9	H	SP2	900	900	900	900	900	900	900	900	900	900
10	L	SP2	300	300	300	300	300	300	300	300	300	300
11	M	SP2	600	600	600	600	600	600	600	600	600	600
12	H	SP2	900	900	900	900	900	900	900	900	900	900
13	H	Region 1-3	900	900	900	900	900	900	900	900	900	900
14	M	Region 1-3	600	600	600	600	600	600	600	600	600	600
15	M	SP4	600	600	600	600	600	600	600	600	600	600
16	H	SP4	900	900	900	900	900	900	900	900	900	900
17	H	SP4	900	900	900	900	900	900	900	900	900	900
18	L	SP4	300	300	300	300	300	300	300	300	300	300
19	H	SP3	900	900	900	900	900	900	900	900	900	900
20	M	SP3	600	600	600	600	600	600	600	600	600	600

Table C- 6: The attributes of medical treatment tasks

		MA1				MA2				MA3				MA4				MA5			
$NP_{k(t),h}$		h=1	h=2	h=3	h=4	h=1	h=2	h=3	h=4	h=1	h=2	h=3	h=4	h=1	h=2	h=3	h=4	h=1	h=2	h=3	h=4
	t=1	100	200	300	400	100	200	300	400	100	200	300	400	100	200	300	400	100	200	300	400
	t=2	80	200	350	400	80	200	350	400	80	200	350	400	80	200	350	400	80	200	350	400
	t=3	70	150	400	400	70	150	400	400	70	150	400	400	70	150	400	400	70	150	400	400
		MA6				MA7				MA8				MA9				MA10			
$NP_{k(t),h}$		h=1	h=2	h=3	h=4	h=1	h=2	h=3	h=4	h=1	h=2	h=3	h=4	h=1	h=2	h=3	h=4	h=1	h=2	h=3	h=4
	t=1	100	200	300	400	100	200	300	400	100	200	300	400	100	200	300	400	100	200	300	400
	t=2	80	200	350	400	80	200	350	400	80	200	350	400	80	200	350	400	80	200	350	400
	t=3	70	150	400	400	70	150	400	400	70	150	400	400	70	150	400	400	70	150	400	400
		h=1	h=2	h=3	h=4																
t_h		10	6	3	1																
α_h^M		0.5	0.3	0.2	0.2																

$NP_{k(t),h}$: Number of natural patients for type *h* in MA *k* at time *t*

t_h : Required time to treat patients for each type *h*

α_h^M : Percentage which untreated patients will be dead for type *h*

Table C- 7: The number of vehicles in each transportation unit

Unit label	Initial Location	Mode #1 (Truck 1)	Mode #2 (Truck 2)	Mode #3 (Truck 3)	Mode #4 (Truck 4)	Mode #5 (Hel #1)	Mode #6 (Hel #2)
T1	SP1	50	50				
T2	SP4	40	40				
T3	SP3			50	50		
T4	SP1					10	
T5	SP1						20
T6	SP2	30	40	50			
T7	SP2					10	
T8	SP2	100	100				
T9	SP4			100	100		
T10	SP4	150	50				
T11	SP3		100	100	100		
T12	SP3	100		150			

Table C- 8: Selected routes

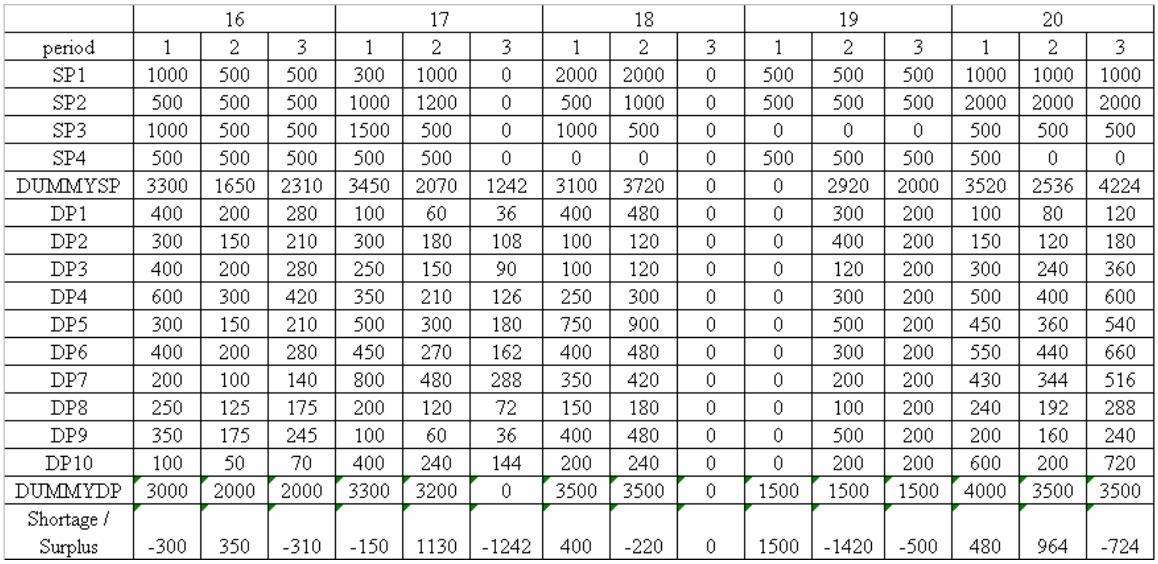
Route	Tour		
	1	2	3
1	SP1	DP1	SP1
2	SP1	DP2	SP1
3	SP1	DP3	SP1
4	SP1	DP4	SP1
5	SP1	DP5	SP1
6	SP1	DP6	SP1
7	SP1	DP7	SP1
8	SP1	DP8	SP1
9	SP1	DP9	SP1
10	SP1	DP10	SP1
11	SP1	TP1	SP1
12	SP1	TP2	SP1
13	SP1	TP3	SP1
14	SP2	DP1	SP2
15	SP2	DP2	SP2
16	SP2	DP3	SP2
17	SP2	DP4	SP2
18	SP2	DP5	SP2
19	SP2	DP6	SP2
20	SP2	DP7	SP2
21	SP2	DP8	SP2
22	SP2	DP9	SP2
23	SP2	DP10	SP2
24	SP2	TP1	SP2
25	SP2	TP2	SP2
26	SP2	TP3	SP2
27	SP3	DP1	SP3
28	SP3	DP2	SP3
29	SP3	DP3	SP3
30	SP3	DP4	SP3
31	SP3	DP5	SP3
32	SP3	DP6	SP3
33	SP3	DP7	SP3
34	SP3	DP8	SP3
35	SP3	DP9	SP3
36	SP3	DP10	SP3
37	SP3	TP1	SP3
38	SP3	TP2	SP3
39	SP3	TP3	SP3
40	SP4	DP1	SP4
41	SP4	DP2	SP4
42	SP4	DP3	SP4
43	SP4	DP4	SP4
44	SP4	DP5	SP4
45	SP4	DP6	SP4
46	SP4	DP7	SP4
47	SP4	DP8	SP4
48	SP4	DP9	SP4
49	SP4	DP10	SP4
50	SP4	TP1	SP4
51	SP4	TP2	SP4
52	SP4	TP3	SP4
53	TP1	DP5	TP1
54	TP2	DP8	TP2
55	TP3	DP10	TP3

Table C- 9: Number of cycle for each route and vehicle

route #	route1			route2			route3			route4			route5			route6			route7		
Periods	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Vehicle 1	2.4	2.4	2.4	1.7	1.7	1.7	1.5	1.5	1.5	2	2	2	0	2	2	1.5	1.5	1.5	1.5	1.5	1.5
Vehicle 2	2.8	2.8	2.8	1.9	1.9	1.9	1.6	1.6	1.6	2.3	2.3	2.3	0	2.3	2.3	1.6	1.6	1.6	1.6	1.6	1.6
Vehicle 3	2.6	2.6	2.6	1.8	1.8	1.8	1.6	1.6	1.6	2.1	2.1	2.1	0	2.1	2.1	1.6	1.6	1.6	1.6	1.6	1.6
Vehicle 4	2.2	2.2	2.2	1.6	1.6	1.6	1.4	1.4	1.4	1.8	1.8	1.8	0	1.8	1.8	1.4	1.4	1.4	1.4	1.4	1.4
Vehicle 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vehicle 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
route #	route8			route9			route10			route11			route12			route13			route14		
Periods	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Vehicle 1	0	1.3	1.3	1.3	1.3	1.3	0	1	1	2	2	2	1.3	1.3	1.3	1	1	1	1.7	1.7	1.7
Vehicle 2	0	1.4	1.4	1.4	1.4	1.4	0	1.1	1.1	2.3	2.3	2.3	1.4	1.4	1.4	1.1	1.1	1.1	1.9	1.9	1.9
Vehicle 3	0	1.4	1.4	1.4	1.4	1.4	0	1	1	2.1	2.1	2.1	1.4	1.4	1.4	1	1	1	1.8	1.8	1.8
Vehicle 4	0	1.3	1.3	1.3	1.3	1.3	0	1	1	1.8	1.8	1.8	1.3	1.3	1.3	1	1	1	1.6	1.6	1.6
Vehicle 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vehicle 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
route #	route15			route16			route17			route18			route19			route20			route21		
Periods	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Vehicle 1	2	2	2	3	3	3	2	2	2	0	1.5	1.5	1.3	1.3	1.3	2.4	2.4	2.4	0	1.7	1.7
Vehicle 2	2.3	2.3	2.3	3.6	3.6	3.6	2.3	2.3	2.3	0	1.6	1.6	1.4	1.4	1.4	2.8	2.8	2.8	0	1.9	1.9
Vehicle 3	2.1	2.1	2.1	3.2	3.2	3.2	2.1	2.1	2.1	0	1.6	1.6	1.4	1.4	1.4	2.6	2.6	2.6	0	1.8	1.8
Vehicle 4	1.8	1.8	1.8	2.7	2.7	2.7	1.8	1.8	1.8	0	1.4	1.4	1.3	1.3	1.3	2.2	2.2	2.2	0	1.6	1.6
Vehicle 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vehicle 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
route #	route22			route23			route24			route25			route26			route27			route28		
Periods	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Vehicle 1	2.4	2.4	2.4	0	1.5	1.5	1.5	1.5	1.5	1.7	1.7	1.7	1.5	1.5	1.5	1.5	1.5	1.5	2.4	2.4	2.4
Vehicle 2	2.8	2.8	2.8	0	1.6	1.6	1.6	1.6	1.6	1.9	1.9	1.9	1.6	1.6	1.6	1.6	1.6	1.6	2.8	2.8	2.8
Vehicle 3	2.6	2.6	2.6	0	1.6	1.6	1.6	1.6	1.6	1.8	1.8	1.8	1.6	1.6	1.6	1.6	1.6	1.6	2.6	2.6	2.6
Vehicle 4	2.2	2.2	2.2	0	1.4	1.4	1.4	1.4	1.4	1.6	1.6	1.6	1.4	1.4	1.4	1.4	1.4	1.4	2.2	2.2	2.2
Vehicle 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vehicle 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
route #	route29			route30			route31			route32			route33			route34			route35		
Periods	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Vehicle 1	3	3	3	2	2	2	0	2	2	2	2	2	4	4	4	0	2.4	2.4	3	3	3
Vehicle 2	3.6	3.6	3.6	2.3	2.3	2.3	0	2.3	2.3	2.3	2.3	2.3	5.2	5.2	5.2	0	2.8	2.8	3.6	3.6	3.6
Vehicle 3	3.2	3.2	3.2	2.1	2.1	2.1	0	2.1	2.1	2.1	2.1	2.1	4.4	4.4	4.4	0	2.6	2.6	3.2	3.2	3.2
Vehicle 4	2.7	2.7	2.7	1.8	1.8	1.8	0	1.8	1.8	1.8	1.8	1.8	3.4	3.4	3.4	0	2.2	2.2	2.7	2.7	2.7
Vehicle 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vehicle 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
route #	route36			route37			route38			route39			route40			route41			route42		
Periods	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Vehicle 1	0	2.4	2.4	2	2	2	2.4	2.4	2.4	2.4	2.4	2.4	1	1	1	1.5	1.5	1.5	1.5	1.5	1.5
Vehicle 2	0	2.8	2.8	2.3	2.3	2.3	2.8	2.8	2.8	2.8	2.8	2.8	1.1	1.1	1.1	1.6	1.6	1.6	1.6	1.6	1.6
Vehicle 3	0	2.6	2.6	2.1	2.1	2.1	2.6	2.6	2.6	2.6	2.6	2.6	1	1	1	1.6	1.6	1.6	1.6	1.6	1.6
Vehicle 4	0	2.2	2.2	1.8	1.8	1.8	2.2	2.2	2.2	2.2	2.2	2.2	1	1	1	1.4	1.4	1.4	1.4	1.4	1.4
Vehicle 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vehicle 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
route #	route43			route44			route45			route46			route47			route48			route49		
Periods	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Vehicle 1	1.5	1.5	1.5	0	2	2	3	3	3	1.5	1.5	1.5	0	1.7	1.7	1.5	1.5	1.5	0	1.3	1.3
Vehicle 2	1.6	1.6	1.6	0	2.3	2.3	3.6	3.6	3.6	1.6	1.6	1.6	0	1.9	1.9	1.6	1.6	1.6	0	1.4	1.4
Vehicle 3	1.6	1.6	1.6	0	2.1	2.1	3.2	3.2	3.2	1.6	1.6	1.6	0	1.8	1.8	1.6	1.6	1.6	0	1.4	1.4
Vehicle 4	1.4	1.4	1.4	0	1.8	1.8	2.7	2.7	2.7	1.4	1.4	1.4	0	1.6	1.6	1.4	1.4	1.4	0	1.3	1.3
Vehicle 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vehicle 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
route #	route50			route51			route52			route53			route54			route55					
Periods	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3			
Vehicle 1	2	2	2	1.7	1.7	1.7	1.3	1.3	1.3	0	0	0	0	0	0	0	0	0			
Vehicle 2	2.3	2.3	2.3	1.9	1.9	1.9	1.4	1.4	1.4	0	0	0	0	0	0	0	0	0			
Vehicle 3	2.1	2.1	2.1	1.8	1.8	1.8	1.4	1.4	1.4	0	0	0	0	0	0	0	0	0			
Vehicle 4	1.8	1.8	1.8	1.6	1.6	1.6	1.3	1.3	1.3	0	0	0	0	0	0	0	0	0			
Vehicle 5	0	0	0	0	0	0	0	0	0	12	12	12	12	12	12	12	12	12			
Vehicle 6	0	0	0	0	0	0	0	0	0	12	12	12	12	12	12	12	12	12			

Table C- 10: Resource requirement for both supply points and demand points

	1			2			3			4			5		
period	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
SP1	700	800	400	1000	1100	1100	300	300	300	500	500	500	1000	500	1000
SP2	600	500	800	0	0	0	500	500	500	500	500	500	500	500	500
SP3	300	500	500	1000	1000	1000	400	400	400	500	500	500	1000	500	500
SP4	500	500	400	1000	1000	1000	500	500	500	500	500	500	500	500	500
DUMMYSP	2200	2200	2200	3300	3300	3300	1760	1760	1760	1980	1980	1980	2755	2495	2495
DP1	200	200	200	300	300	300	160	160	160	180	180	180	240	240	240
DP2	100	100	100	150	150	150	80	80	80	90	90	90	100	100	100
DP3	300	300	300	450	450	450	240	240	240	270	270	270	300	300	300
DP4	400	400	400	600	600	600	320	320	320	360	360	360	480	200	200
DP5	200	200	200	300	300	300	160	160	160	180	180	180	280	280	280
DP6	100	100	100	150	150	150	80	80	80	90	90	90	100	100	100
DP7	150	150	150	225	225	225	120	120	120	135	135	135	180	200	200
DP8	250	250	250	375	375	375	200	200	200	225	225	225	375	375	375
DP9	300	300	300	450	450	450	240	240	240	270	270	270	300	300	300
DP10	200	200	200	300	300	300	160	160	160	180	180	180	400	400	400
DUMMYDP	2100	2300	2100	3000	3100	3100	1700	1700	1700	2000	2000	2000	3000	2000	2500
Shortage / Surplus	-100	100	-100	-300	-200	-200	-60	-60	-60	20	20	20	245	-495	5
	6			7			8			9			10		
period	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
SP1	1000	500	0	1000	1000	1000	2000	2000	2000	0	0	0	1000	1000	500
SP2	0	0	500	1000	500	1000	3000	2000	2000	1000	1000	1000	500	500	500
SP3	500	500	500	1500	1500	1500	500	1000	1000	1000	1000	1000	1000	500	500
SP4	500	500	500	1000	1000	1000	500	500	500	500	0	0	500	500	500
DUMMYSP	2000	2000	2000	4300	4300	4300	5160	5160	5160	2800	2240	1680	3360	2688	1680
DP1	100	100	100	500	500	500	600	600	600	400	320	240	480	384	240
DP2	200	200	200	600	600	600	720	720	720	200	160	120	240	192	120
DP3	300	300	300	700	700	700	840	840	840	500	400	300	600	480	300
DP4	100	100	100	400	400	400	480	480	480	200	160	120	240	192	120
DP5	100	100	100	500	500	500	600	600	600	300	240	180	360	288	180
DP6	200	200	200	300	300	300	360	360	360	100	80	60	120	96	60
DP7	500	500	500	200	200	200	240	240	240	300	240	180	360	288	180
DP8	100	100	100	400	400	400	480	480	480	200	160	120	240	192	120
DP9	300	300	300	200	200	200	240	240	240	400	320	240	480	384	240
DP10	100	100	100	500	500	500	600	600	600	200	160	120	240	192	120
DUMMYDP	2000	1500	1500	4500	4000	4500	6000	5500	5500	2500	2000	2000	3000	2500	2000
Shortage / Surplus	0	-500	-500	200	-300	200	840	340	340	-300	-240	320	-360	-188	320
	11			12			13			14			15		
period	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
SP1	500	500	500	0	0	0	0	0	0	1000	0	0	700	500	500
SP2	500	500	500	500	1000	1000	0	0	0	500	500	500	1000	1000	1000
SP3	100	0	0	500	500	1000	1200	0	0	500	500	500	1000	1000	500
SP4	500	500	500	500	500	500	500	0	0	500	500	500	1000	1000	500
DUMMYSP	1500	1500	1500	1800	2160	2592	1900	0	0	2470	1500	1000	4300	3440	2580
DP1	100	100	100	50	60	72	0	0	0	0	0	0	400	320	240
DP2	50	50	50	100	120	144	0	0	0	0	0	0	500	400	300
DP3	150	150	150	200	240	288	0	0	0	0	0	0	600	480	360
DP4	200	200	200	400	480	576	0	0	0	0	0	0	700	560	420
DP5	50	50	50	350	420	504	700	0	0	910	500	300	300	240	180
DP6	250	250	250	200	240	288	0	0	0	0	0	0	400	320	240
DP7	100	100	100	100	120	144	0	0	0	0	0	0	200	160	120
DP8	100	100	100	50	60	72	0	0	0	0	0	0	400	320	240
DP9	300	300	300	200	240	288	0	0	0	0	0	0	450	360	270
DP10	200	200	200	150	180	216	1200	0	0	1560	1000	700	350	280	210
DUMMYDP	1600	1500	1500	1500	2000	2500	1700	0	0	2500	1500	1500	3700	3500	2500
Shortage / Surplus	100	0	0	-300	-160	-92	-200	0	0	30	0	500	-600	60	-80



	16			17			18			19			20		
period	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
SP1	1000	500	500	300	1000	0	2000	2000	0	500	500	500	1000	1000	1000
SP2	500	500	500	1000	1200	0	500	1000	0	500	500	500	2000	2000	2000
SP3	1000	500	500	1500	500	0	1000	500	0	0	0	0	500	500	500
SP4	500	500	500	500	500	0	0	0	0	500	500	500	500	0	0
DUMMYSP	3300	1650	2310	3450	2070	1242	3100	3720	0	0	2920	2000	3520	2536	4224
DP1	400	200	280	100	60	36	400	480	0	0	300	200	100	80	120
DP2	300	150	210	300	180	108	100	120	0	0	400	200	150	120	180
DP3	400	200	280	250	150	90	100	120	0	0	120	200	300	240	360
DP4	600	300	420	350	210	126	250	300	0	0	300	200	500	400	600
DP5	300	150	210	500	300	180	750	900	0	0	500	200	450	360	540
DP6	400	200	280	450	270	162	400	480	0	0	300	200	550	440	660
DP7	200	100	140	800	480	288	350	420	0	0	200	200	430	344	516
DP8	250	125	175	200	120	72	150	180	0	0	100	200	240	192	288
DP9	350	175	245	100	60	36	400	480	0	0	500	200	200	160	240
DP10	100	50	70	400	240	144	200	240	0	0	200	200	600	200	720
DUMMYDP	3000	2000	2000	3300	3200	0	3500	3500	0	1500	1500	1500	4000	3500	3500
Shortage / Surplus	-300	350	-310	-150	1130	-1242	400	-220	0	1500	-1420	-500	480	964	-724

Table C- 11: Weights for shortage of resources

Demand point	Demand point 1			Demand point 2			Demand point 3			Demand point 4			Demand point 5		
Period	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Commodity 1	309	202	104	300	202	103	303	204	107	301	209	108	504	201	101
Commodity 2	308	204	107	302	202	105	300	200	106	303	208	105	500	209	101
Commodity 3	301	208	100	300	206	109	306	207	109	309	208	109	507	203	106
Commodity 4	305	201	100	305	206	102	302	207	107	305	202	105	500	208	108
Commodity 5	309	204	104	300	205	108	308	202	108	302	203	103	505	204	102
Commodity 6	302	206	104	301	207	108	301	209	106	300	204	106	501	205	109
Commodity 7	304	201	109	303	201	108	305	201	104	302	202	106	502	209	106
Commodity 8	300	206	105	303	208	100	305	200	102	303	209	103	502	206	104
Commodity 9	304	209	109	300	208	105	304	204	109	306	207	100	500	205	109
Commodity 10	304	200	104	306	205	107	309	209	104	306	200	109	505	207	101
Commodity 11	301	206	103	307	202	102	308	205	105	306	209	106	509	201	105
Commodity 12	301	206	100	305	202	106	300	203	103	305	206	106	500	203	100
Commodity 13	303	202	100	301	201	102	300	204	107	303	204	104	506	207	100
Commodity 14	307	200	105	308	201	104	307	201	109	307	206	109	503	205	104
Commodity 15	303	203	107	305	201	107	306	208	100	301	202	101	507	208	107
Commodity 16	307	204	100	306	200	103	304	206	100	300	208	100	507	209	106
Commodity 17	300	205	106	303	206	106	307	207	107	303	201	109	505	201	107
Commodity 18	308	206	102	304	208	106	303	204	103	307	205	102	501	203	102
Commodity 19	309	205	103	300	202	108	309	206	103	309	204	101	501	206	109
Commodity 20	302	204	105	309	207	103	305	203	106	301	200	103	503	201	108
Demand point	Demand point 6			Demand point 7			Demand point 8			Demand point 9			Demand point 10		
Period	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Commodity 1	301	202	109	309	209	105	505	207	109	306	204	108	505	201	105
Commodity 2	303	202	102	303	205	100	501	200	100	308	202	107	502	202	108
Commodity 3	306	208	100	302	205	103	504	200	107	307	202	105	505	201	105
Commodity 4	309	207	104	301	202	100	506	202	105	307	203	107	501	206	104
Commodity 5	309	203	105	300	208	102	506	209	106	305	201	107	504	208	102
Commodity 6	308	200	103	307	208	109	501	206	100	309	206	109	505	204	107
Commodity 7	301	206	101	301	206	108	507	209	104	309	207	103	509	209	109
Commodity 8	306	203	105	301	205	103	504	206	103	309	206	103	501	205	108
Commodity 9	309	203	104	302	208	101	507	201	100	302	203	103	508	205	100
Commodity 10	306	202	102	304	205	108	508	200	108	305	209	105	501	208	103
Commodity 11	301	201	106	303	209	101	503	207	102	306	208	108	503	201	107
Commodity 12	307	206	100	300	209	109	507	205	102	306	201	109	507	204	105
Commodity 13	306	201	101	307	203	102	500	204	105	304	209	101	502	204	107
Commodity 14	304	206	107	303	205	105	502	204	108	309	201	109	502	205	100
Commodity 15	307	200	102	301	201	108	503	201	106	300	201	107	508	208	101
Commodity 16	302	200	108	301	201	104	504	208	103	305	207	100	504	202	108
Commodity 17	305	203	105	300	203	102	500	204	108	307	205	109	504	202	107
Commodity 18	304	205	106	301	205	101	500	207	105	308	204	107	503	209	105
Commodity 19	305	202	106	308	206	109	500	209	105	302	207	105	500	207	105
Commodity 20	300	205	100	306	200	109	502	205	102	300	202	100	509	206	106

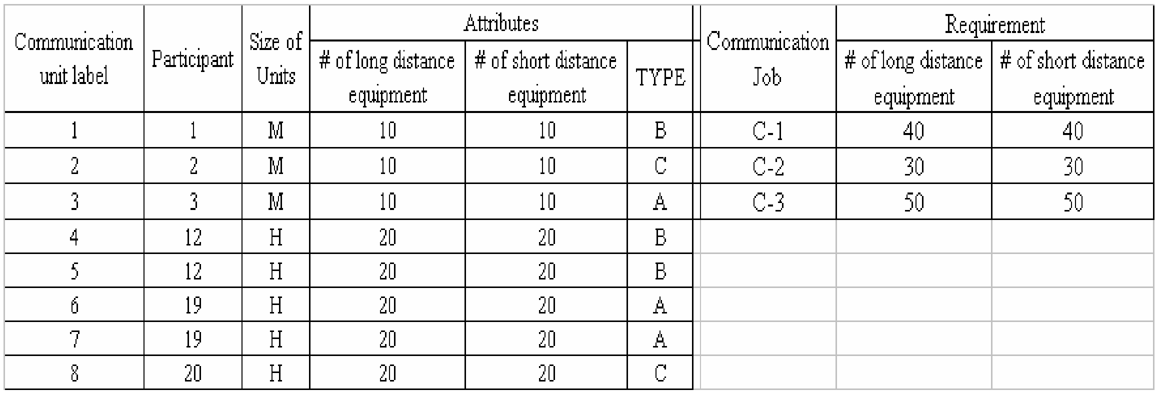
Table C- 12: Transportation cost for each vehicle and location

Mode	Location	DP1	DP2	DP3	DP4	DP5	DP6	DP7	DP8	DP9	DP10	TP1	TP2	TP3
Vehicle 1	SP1	4	4	6	4	6	7	5	8	8	10	6	8	10
	SP2	4	4	3	5	6	7	5	7	8	8	6	7	8
	SP3	6	5	3	5	5	7	3	5	3	6	5	5	6
	SP4	7	7	6	5	4	3	5	6	6	7	4	6	7
Vehicle 2	SP1	5	5	8	5	8	9	7	11	12	15	8	11	15
	SP2	5	5	4	7	8	9	7	9	11	12	8	9	12
	SP3	8	7	4	7	7	9	4	7	4	8	7	7	8
	SP4	9	9	8	7	5	4	7	8	8	9	5	8	9
Vehicle 3	SP1	6	6	9	6	9	10	7	11	13	15	9	11	15
	SP2	6	6	5	7	9	10	7	10	11	13	9	10	13
	SP3	9	7	5	7	7	10	5	7	5	9	7	7	9
	SP4	10	10	9	7	6	5	7	9	9	10	6	9	10
Vehicle 4	SP1	5	5	6	5	6	7	5	8	9	10	6	8	10
	SP2	5	5	4	5	6	7	5	7	8	9	6	7	9
	SP3	6	5	4	5	5	7	4	5	4	6	5	5	6
	SP4	7	7	6	5	5	4	5	6	6	7	5	6	7
Mode	**Location**	**DP5**	**DP8**	**DP10**										
Vehicle 5	TP1	50												
	TP2		50											
	TP3			50										
Vehicle 6	TP1	30												
	TP2		30											
	TP3			30										

Table C- 13: The attributes of security units and requirement of each area

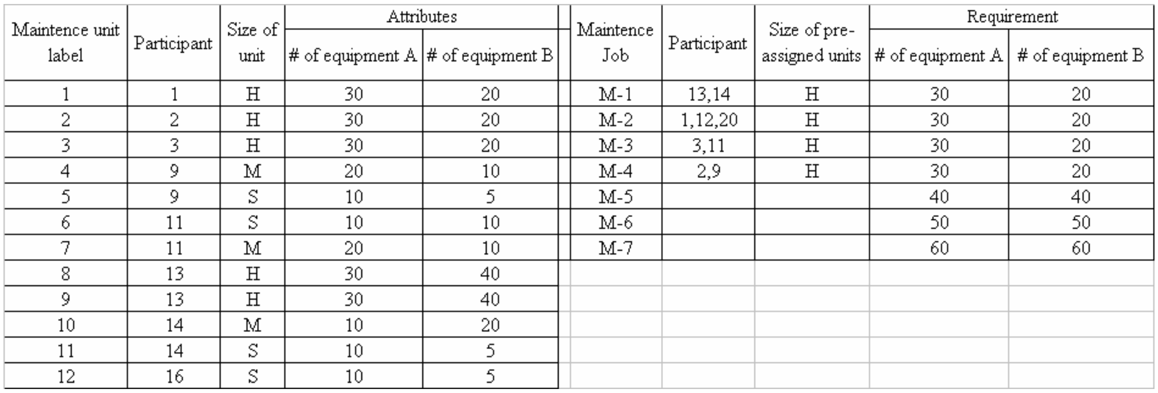
Scurity unit label	Participant	Size of security units	Attributes		Scurity Job	Size of pre-assigned units	Requirement	
			# of patrol car	# of equipment for night vision			# of patrol car	# of equipment for night vision
1	1	H	15	30	S-1	H	30	30
2	1	H	15	30	S-2	H	15	30
3	1	M	15	30	S-3	H	15	30
4	1	M	10	20	S-4	H	15	30
5	2	S	5	10	S-5		10	20
6	2	S	5	10	S-6	M	10	20
7	2	M	10	20	S-7		5	10
8	3	M	10	20	S-8	M	10	20
9	3	M	10	20	S-9	M	10	20
10	3	M	10	20	S-10		5	10
11	13	S	5	10	S-11		5	10
12	13	S	5	10				
13	15	M	10	20				
14	15	M	10	20				
15	18	H	15	30				

Table C- 14: The attributes of communication units and requirement of each area



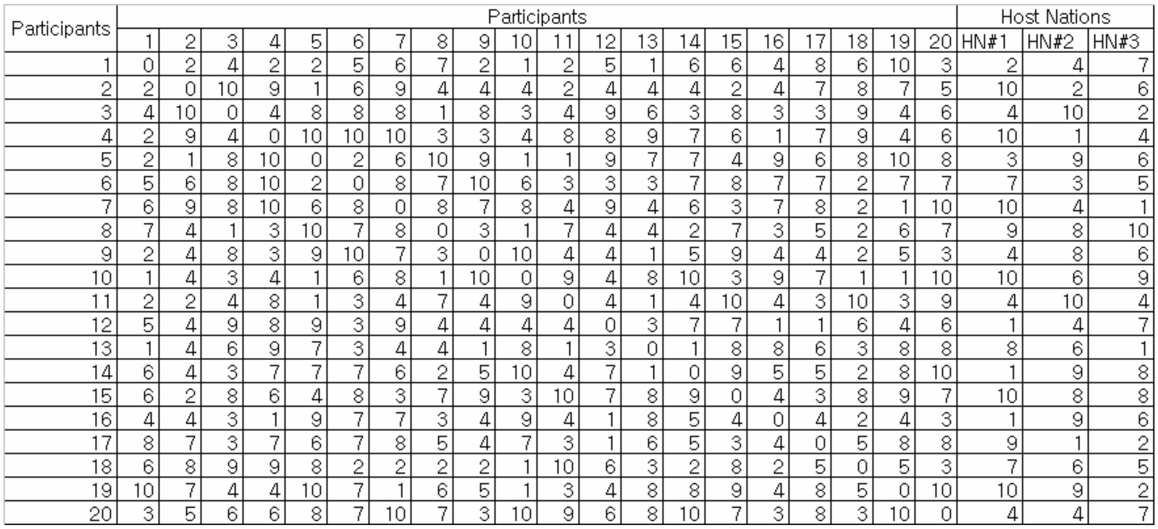
Communication unit label	Participant	Size of Units	Attributes			Communication Job	Requirement	
			# of long distance equipment	# of short distance equipment	TYPE		# of long distance equipment	# of short distance equipment
1	1	M	10	10	B	C-1	40	40
2	2	M	10	10	C	C-2	30	30
3	3	M	10	10	A	C-3	50	50
4	12	H	20	20	B			
5	12	H	20	20	B			
6	19	H	20	20	A			
7	19	H	20	20	A			
8	20	H	20	20	C			

Table C- 15: The attributes of maintenance units and requirement of each area



Maintence unit label	Participant	Size of unit	Attributes		Maintence Job	Participant	Size of pre-assigned units	Requirement	
			# of equipment A	# of equipment B				# of equipment A	# of equipment B
1	1	H	30	20	M-1	13,14	H	30	20
2	2	H	30	20	M-2	1,12,20	H	30	20
3	3	H	30	20	M-3	3,11	H	30	20
4	9	M	20	10	M-4	2,9	H	30	20
5	9	S	10	5	M-5			40	40
6	11	S	10	10	M-6			50	50
7	11	M	20	10	M-7			60	60
8	13	H	30	40					
9	13	H	30	40					
10	14	M	10	20					
11	14	S	10	5					
12	16	S	10	5					

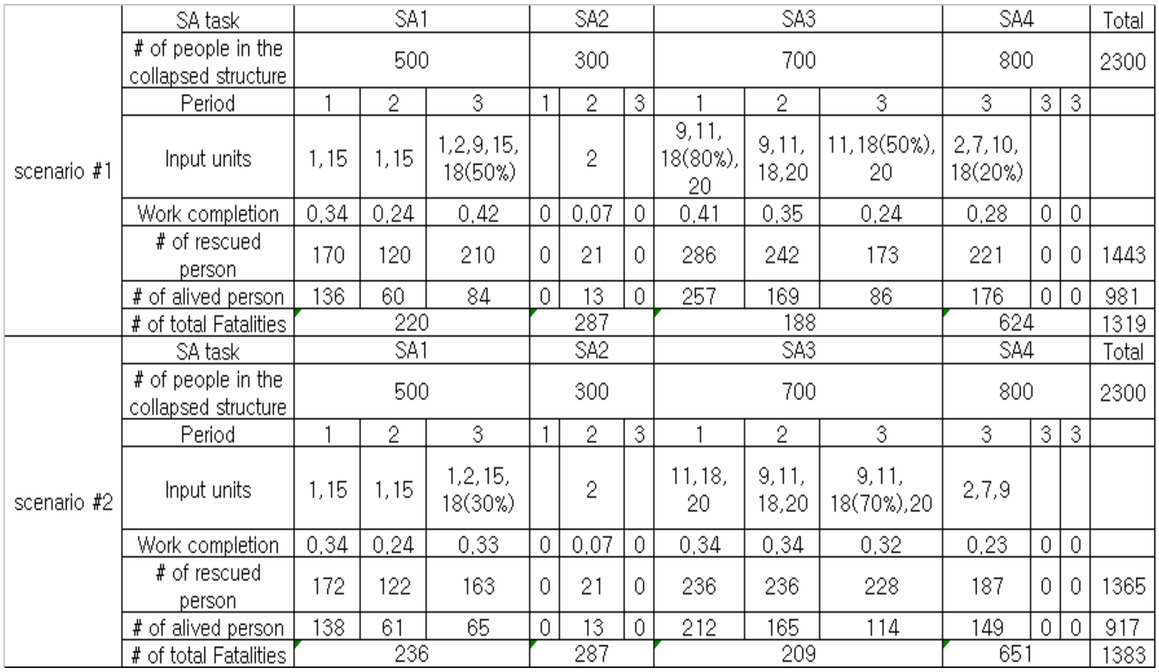
Table C- 16: The basic interaction costs



Participants	Participants																				Host Nations		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	HN#1	HN#2	HN#3
1	0	2	4	2	2	5	6	7	2	1	2	5	1	6	6	4	8	6	10	3	2	4	7
2	2	0	10	9	1	6	9	4	4	4	2	4	4	4	2	4	7	8	7	5	10	2	6
3	4	10	0	4	8	8	8	1	8	3	4	9	6	3	8	3	3	9	4	6	4	10	2
4	2	9	4	0	10	10	10	3	3	4	8	8	9	7	6	1	7	9	4	6	10	1	4
5	2	1	8	10	0	2	6	10	9	1	1	9	7	7	4	9	6	8	10	8	3	9	6
6	5	6	8	10	2	0	8	7	10	6	3	3	3	7	8	7	7	2	7	7	7	3	5
7	6	9	8	10	6	8	0	8	7	8	4	9	4	6	3	7	8	2	1	10	10	4	1
8	7	4	1	3	10	7	8	0	3	1	7	4	4	2	7	3	5	2	6	7	9	8	10
9	2	4	8	3	9	10	7	3	0	10	4	4	1	5	9	4	4	2	5	3	4	8	6
10	1	4	3	4	1	6	8	1	10	0	9	4	8	10	3	9	7	1	1	10	10	6	9
11	2	2	4	8	1	3	4	7	4	9	0	4	1	4	10	4	3	10	3	9	4	10	4
12	5	4	9	8	9	3	9	4	4	4	4	0	3	7	7	1	1	6	4	6	1	4	7
13	1	4	6	9	7	3	4	4	1	8	1	3	0	1	8	8	6	3	8	8	8	6	1
14	6	4	3	7	7	7	6	2	5	10	4	7	1	0	9	5	5	2	8	10	1	9	8
15	6	2	8	6	4	8	3	7	9	3	10	7	8	9	0	4	3	8	9	7	10	8	8
16	4	4	3	1	9	7	7	3	4	9	4	1	8	5	4	0	4	2	4	3	1	9	6
17	8	7	3	7	6	7	8	5	4	7	3	1	6	5	3	4	0	5	8	8	9	1	2
18	6	8	9	9	8	2	2	2	2	1	10	6	3	2	8	2	5	0	5	3	7	6	5
19	10	7	4	4	10	7	1	6	5	1	3	4	8	8	9	4	8	5	0	10	10	9	2
20	3	5	6	6	8	7	10	7	3	10	9	6	8	10	7	3	8	3	10	0	4	4	7

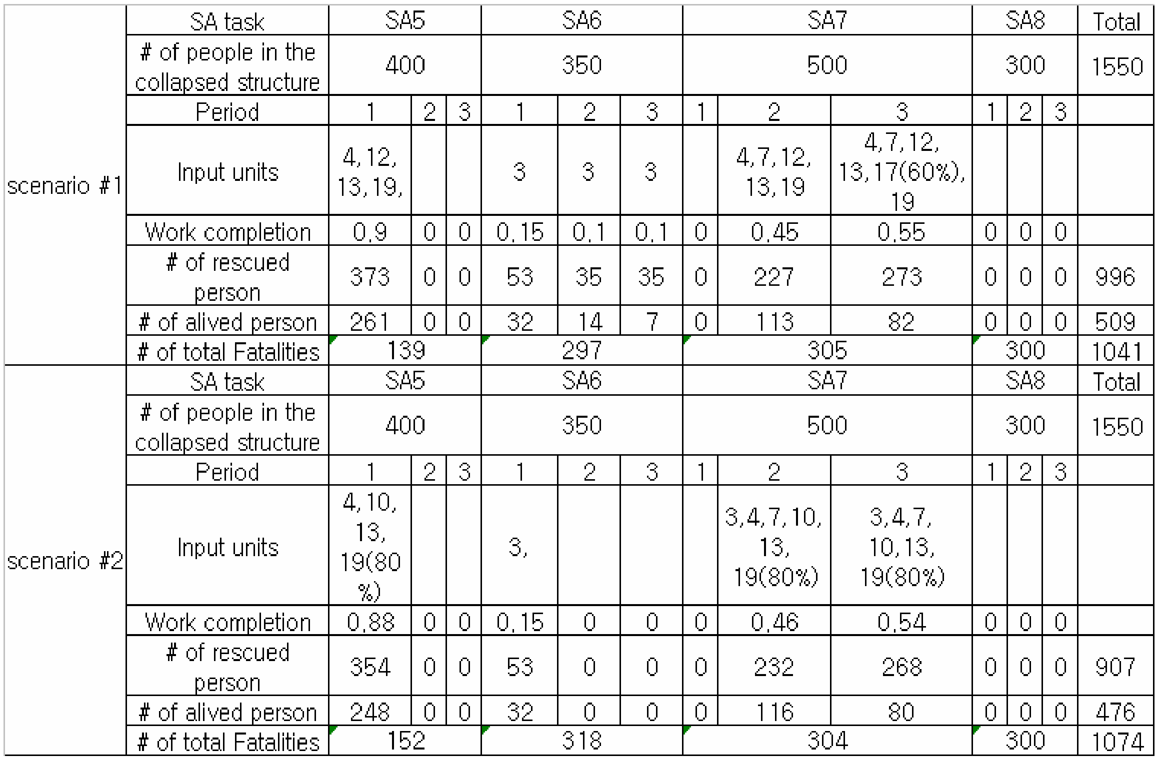
Appendix D. The results of Coalition Mission-Unit Allocation Model

Table D- 1: The results of search and rescue tasks in the host nation 1



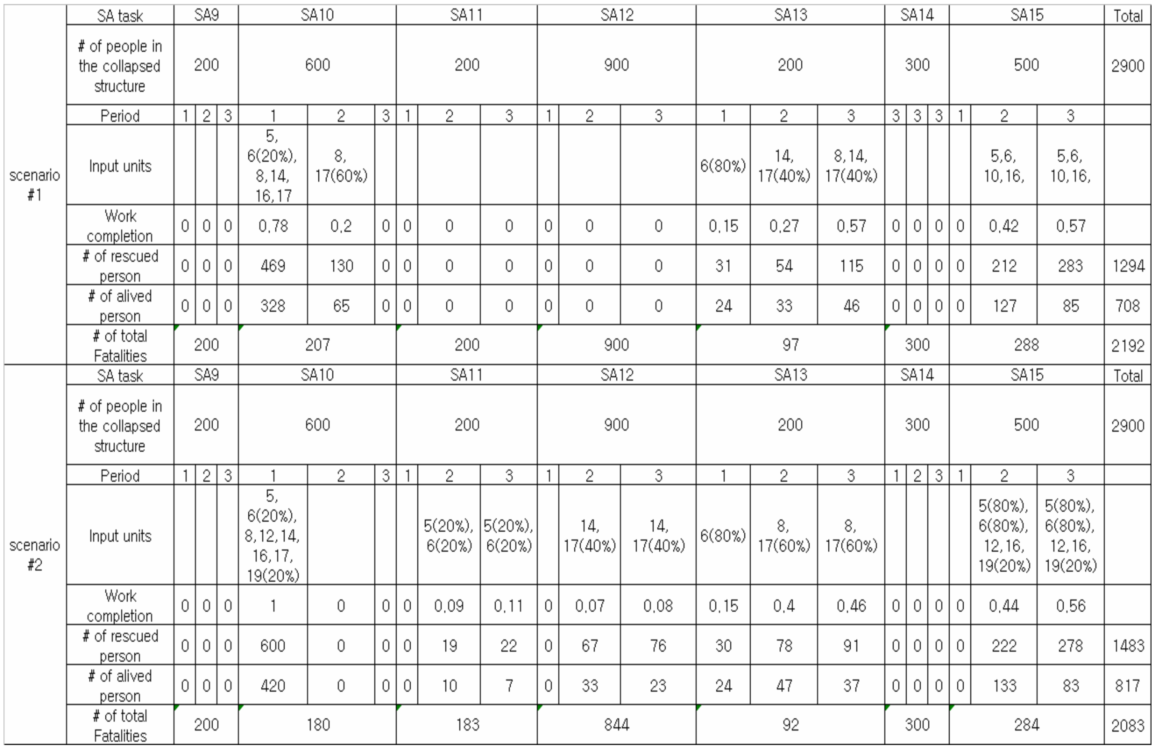
	SA task	SA1			SA2			SA3			SA4			Total
scenario #1	# of people in the collapsed structure	500			300			700			800			2300
	Period	1	2	3	1	2	3	1	2	3	3	3	3	
	Input units	1,15	1,15	1,2,9,15, 18(50%)		2		9,11, 18(80%), 20	9,11, 18,20	11,18(50%), 20	2,7,10, 18(20%)			
	Work completion	0,34	0,24	0,42	0	0,07	0	0,41	0,35	0,24	0,28	0	0	
	# of rescued person	170	120	210	0	21	0	286	242	173	221	0	0	1443
	# of alived person	136	60	84	0	13	0	257	169	86	176	0	0	981
	# of total Fatalities	220			287			188			624			1319
scenario #2	SA task	SA1			SA2			SA3			SA4			Total
	# of people in the collapsed structure	500			300			700			800			2300
	Period	1	2	3	1	2	3	1	2	3	3	3	3	
	Input units	1,15	1,15	1,2,15, 18(30%)		2		11,18, 20	9,11, 18,20	9,11, 18(70%),20	2,7,9			
	Work completion	0,34	0,24	0,33	0	0,07	0	0,34	0,34	0,32	0,23	0	0	
	# of rescued person	172	122	163	0	21	0	236	236	228	187	0	0	1365
	# of alived person	138	61	65	0	13	0	212	165	114	149	0	0	917
	# of total Fatalities	236			287			209			651			1383

Table D- 2: The results of search and rescue tasks in the host nation 2



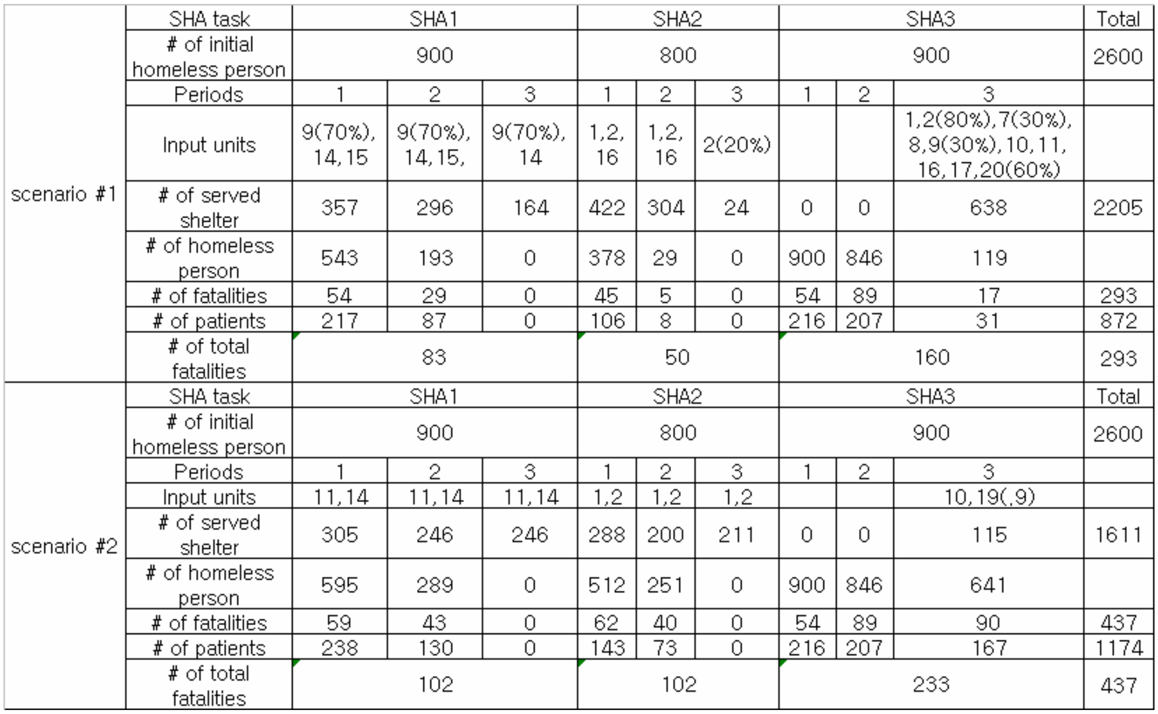
	SA task	SA5			SA6			SA7			SA8			Total
scenario #1	# of people in the collapsed structure	400			350			500			300			1550
	Period	1	2	3	1	2	3	1	2	3	1	2	3	
	Input units	4,12, 13,19,			3	3	3		4,7,12, 13,19	4,7,12, 13,17(60%), 19				
	Work completion	0,9	0	0	0,15	0,1	0,1	0	0,45	0,55	0	0	0	
	# of rescued person	373	0	0	53	35	35	0	227	273	0	0	0	996
	# of alived person	261	0	0	32	14	7	0	113	82	0	0	0	509
	# of total Fatalities	139			297			305			300			1041
scenario #2	SA task	SA5			SA6			SA7			SA8			Total
	# of people in the collapsed structure	400			350			500			300			1550
	Period	1	2	3	1	2	3	1	2	3	1	2	3	
	Input units	4,10, 13, 19(80%)			3,				3,4,7,10, 13, 19(80%)	3,4,7, 10,13, 19(80%)				
	Work completion	0,88	0	0	0,15	0	0	0	0,46	0,54	0	0	0	
	# of rescued person	354	0	0	53	0	0	0	232	268	0	0	0	907
	# of alived person	248	0	0	32	0	0	0	116	80	0	0	0	476
	# of total Fatalities	152			318			304			300			1074

Table D- 3: The results of search and rescue tasks in the host nation 3



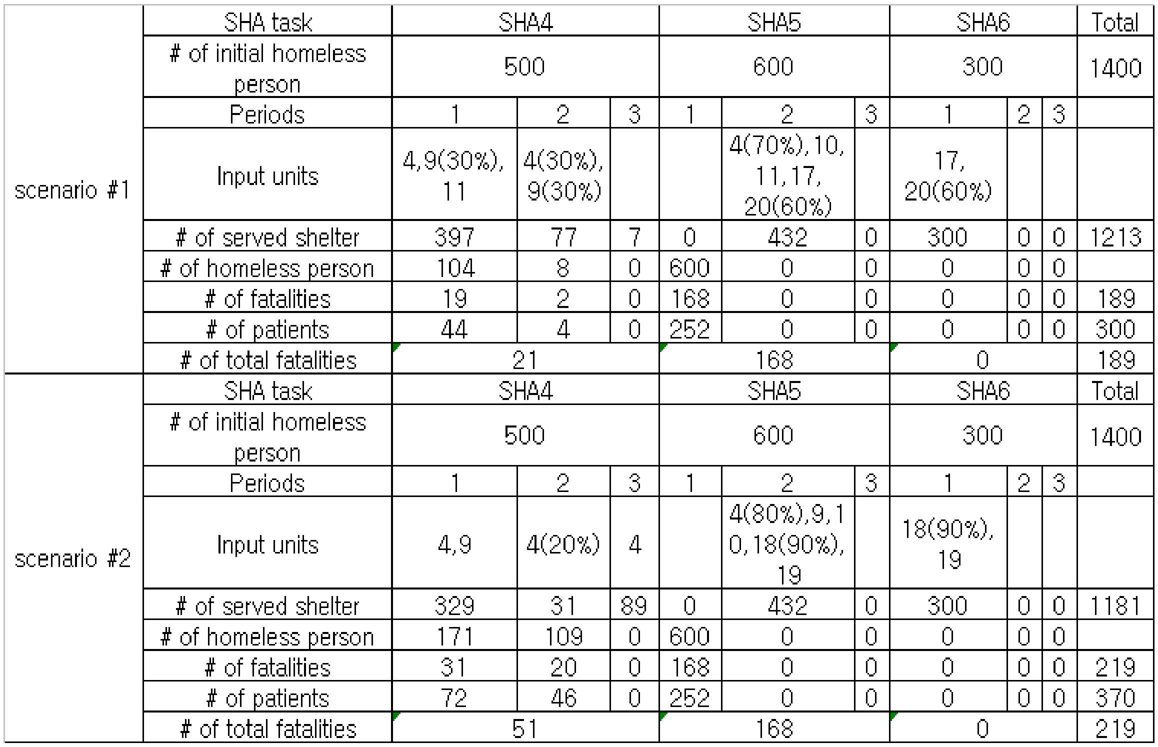
	SA task	SA9			SA10			SA11			SA12			SA13			SA14			SA15			Total
scenario #1	# of people in the collapsed structure	200			600			200			900			200			300			500			2900
	Period	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	3	3	3	1	2	3	
	Input units				5, 6(20%), 8,14, 16,17	8, 17(60%)								6(80%)	14, 17(40%)	8,14, 17(40%)					5,6, 10,16,	5,6, 10,16,	
	Work completion	0	0	0	0,78	0,2	0	0	0	0	0	0	0	0,15	0,27	0,57	0	0	0	0	0,42	0,57	
	# of rescued person	0	0	0	469	130	0	0	0	0	0	0	0	31	54	115	0	0	0	0	212	283	1294
	# of alived person	0	0	0	328	65	0	0	0	0	0	0	0	24	33	46	0	0	0	0	127	85	708
	# of total Fatalities	200			207			200			900			97			300			288			2192
scenario #2	SA task	SA9			SA10			SA11			SA12			SA13			SA14			SA15			Total
	# of people in the collapsed structure	200			600			200			900			200			300			500			2900
	Period	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
	Input units				5, 6(20%), 8,12,14, 16,17, 19(20%)				5(20%), 6(20%)	5(20%), 6(20%)		14, 17(40%)	14, 17(40%)	6(80%)	8, 17(60%)	8, 17(60%)					5(80%), 6(80%), 12,16, 19(20%)	5(80%), 6(80%), 12,16, 19(20%)	
	Work completion	0	0	0	1	0	0	0	0,09	0,11	0	0,07	0,08	0,15	0,4	0,46	0	0	0	0	0,44	0,56	
	# of rescued person	0	0	0	600	0	0	0	19	22	0	67	76	30	78	91	0	0	0	0	222	278	1483
	# of alived person	0	0	0	420	0	0	0	10	7	0	33	23	24	47	37	0	0	0	0	133	83	817
	# of total Fatalities	200			180			183			844			92			300			284			2083

Table D- 4: The results of temporary shelter construction tasks in the host nation 1



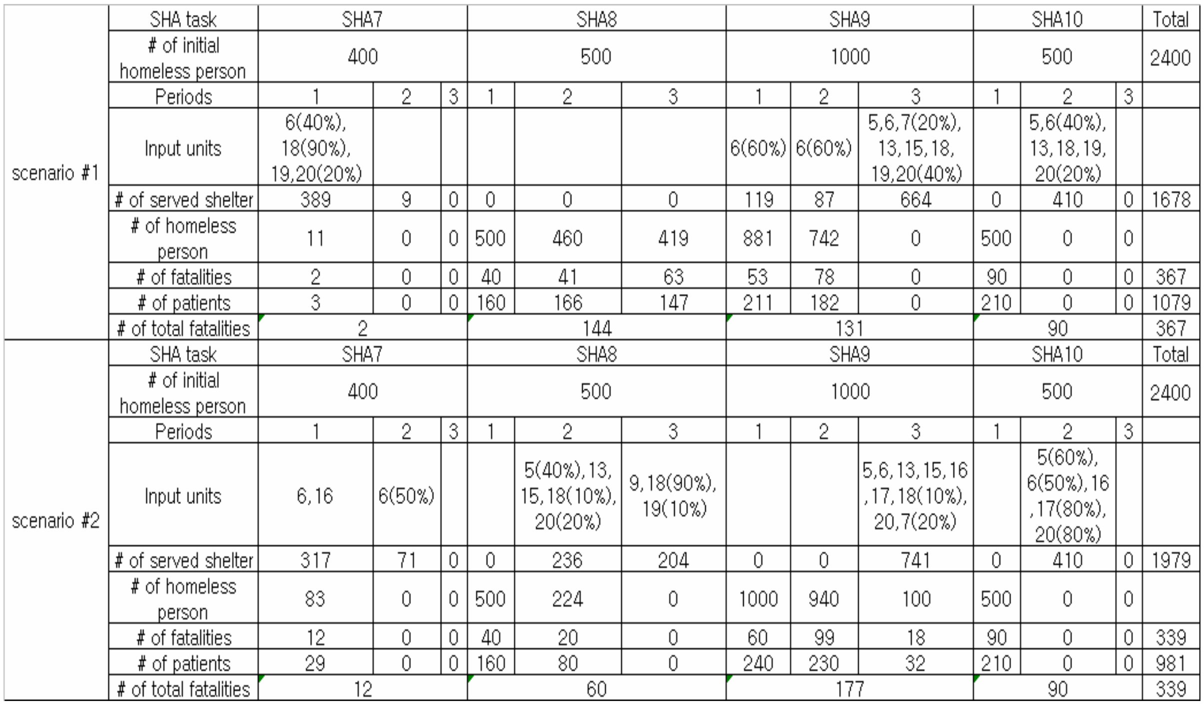
	SHA task	SHA1			SHA2			SHA3			Total
scenario #1	# of initial homeless person	900			800			900			2600
	Periods	1	2	3	1	2	3	1	2	3	
	Input units	9(70%), 14,15	9(70%), 14,15,	9(70%), 14	1,2, 16	1,2, 16	2(20%)			1,2(80%),7(30%), 8,9(30%),10,11, 16,17,20(60%)	
	# of served shelter	357	296	164	422	304	24	0	0	638	2205
	# of homeless person	543	193	0	378	29	0	900	846	119	
	# of fatalities	54	29	0	45	5	0	54	89	17	293
	# of patients	217	87	0	106	8	0	216	207	31	872
	# of total fatalities	83			50			160			293
scenario #2	SHA task	SHA1			SHA2			SHA3			Total
	# of initial homeless person	900			800			900			2600
	Periods	1	2	3	1	2	3	1	2	3	
	Input units	11,14	11,14	11,14	1,2	1,2	1,2			10,19(,9)	
	# of served shelter	305	246	246	288	200	211	0	0	115	1611
	# of homeless person	595	289	0	512	251	0	900	846	641	
	# of fatalities	59	43	0	62	40	0	54	89	90	437
	# of patients	238	130	0	143	73	0	216	207	167	1174
	# of total fatalities	102			102			233			437

Table D- 5: The results of temporary shelter construction tasks in the host nation 2



scenario #1	SHA task	SHA4			SHA5			SHA6			Total
	# of initial homeless person	500			600			300			1400
	Periods	1	2	3	1	2	3	1	2	3	
	Input units	4,9(30%), 11	4(30%), 9(30%)			4(70%),10, 11,17, 20(60%)		17, 20(60%)			
	# of served shelter	397	77	7	0	432	0	300	0	0	1213
	# of homeless person	104	8	0	600	0	0	0	0	0	
	# of fatalities	19	2	0	168	0	0	0	0	0	189
	# of patients	44	4	0	252	0	0	0	0	0	300
	# of total fatalities	21			168			0			189
scenario #2	SHA task	SHA4			SHA5			SHA6			Total
	# of initial homeless person	500			600			300			1400
	Periods	1	2	3	1	2	3	1	2	3	
	Input units	4,9	4(20%)	4		4(80%),9,1 0,18(90%), 19		18(90%), 19			
	# of served shelter	329	31	89	0	432	0	300	0	0	1181
	# of homeless person	171	109	0	600	0	0	0	0	0	
	# of fatalities	31	20	0	168	0	0	0	0	0	219
	# of patients	72	46	0	252	0	0	0	0	0	370
	# of total fatalities	51			168			0			219

Table D- 6: The results of temporary shelter construction tasks in the host nation 3



scenario #1	SHA task	SHA7			SHA8			SHA9			SHA10			Total
	# of initial homeless person	400			500			1000			500			2400
	Periods	1	2	3	1	2	3	1	2	3	1	2	3	
	Input units	6(40%), 18(90%), 19,20(20%)						6(60%)	6(60%)	5,6,7(20%), 13,15,18, 19,20(40%)		5,6(40%), 13,18,19, 20(20%)		
	# of served shelter	389	9	0	0	0	0	119	87	664	0	410	0	1678
	# of homeless person	11	0	0	500	460	419	881	742	0	500	0	0	
	# of fatalities	2	0	0	40	41	63	53	78	0	90	0	0	367
	# of patients	3	0	0	160	166	147	211	182	0	210	0	0	1079
	# of total fatalities	2			144			131			90			367
scenario #2	SHA task	SHA7			SHA8			SHA9			SHA10			Total
	# of initial homeless person	400			500			1000			500			2400
	Periods	1	2	3	1	2	3	1	2	3	1	2	3	
	Input units	6,16	6(50%)			5(40%),13, 15,18(10%), 20(20%)	9,18(90%), 19(10%)			5,6,13,15,16 ,17,18(10%), 20,7(20%)		5(60%), 6(50%),16 ,17(80%), 20(80%)		
	# of served shelter	317	71	0	0	236	204	0	0	741	0	410	0	1979
	# of homeless person	83	0	0	500	224	0	1000	940	100	500	0	0	
	# of fatalities	12	0	0	40	20	0	60	99	18	90	0	0	339
	# of patients	29	0	0	160	80	0	240	230	32	210	0	0	981
	# of total fatalities	12			60			177			90			339

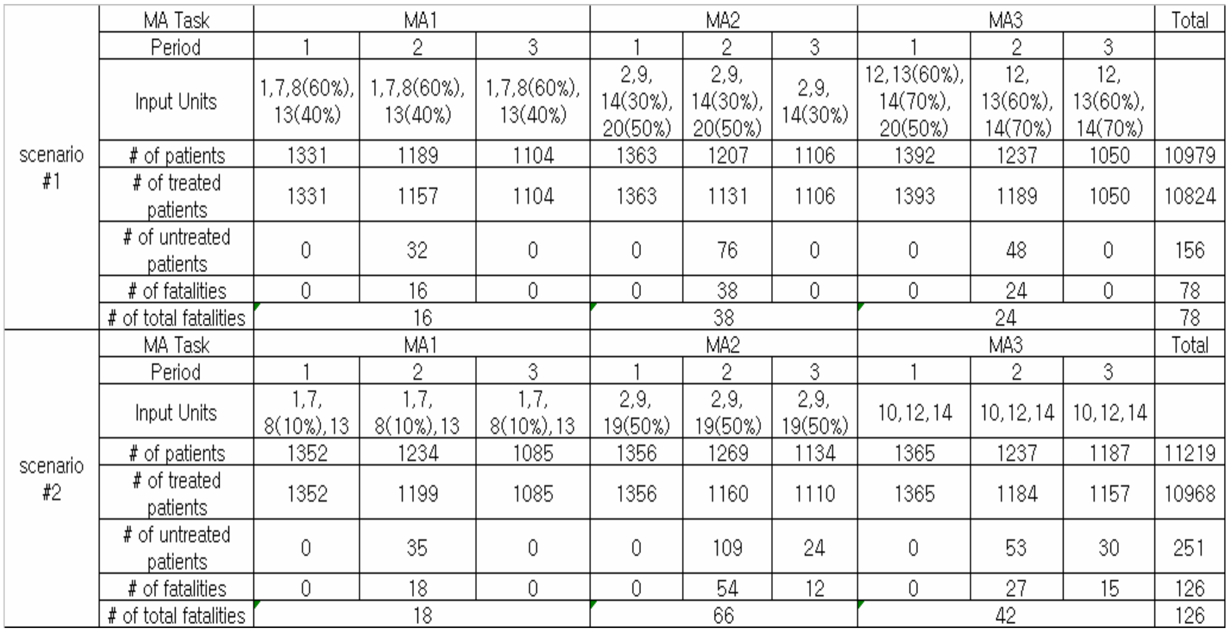
Table D- 7: The results of stabilizing tasks in the host nation 2 and 3

	Host nation	Host nation 2			Host nation 3		
scenario #1	TA task	TA 1			TA 2		
	α_k^{TA}	0.4			0.3		
	$n_{k(t)}^{TA}$	1000			4000		
	Periods	1	2	3	1	2	3
	Input units		3,7(30%),8	3,4		20(20%),7(70%),12	7(50%),12
	Failure Prob.	0.3	0.15	0.15	0.3	0.15	0.15
	Reduced Prob.	0	0.15	0.15	0	0.15	0.15
	Reduced Fatalities	0	60	60	0	180	180
scenario #2	TA task	TA 1			TA 2		
	α_k^{TA}	0.4			0.3		
	$n_{k(t)}^{TA}$	1000			4000		
	Periods	1	2	3	1	2	3
	Input Units		3,8,7(30%)	3,8,7(30%)		12,17(20%),7(70%)	12,7(50%)
	Failure Prob.	0.3	0.15	0.15	0.3	0.15	0.15
	Reduced Prob.	0	0.15	0.15	0	0.15	0.15
	Reduced Fatalities	0	60	60	0	180	180

Table D- 8: The results of immediate rehabilitation tasks in the host nation 2 and 3

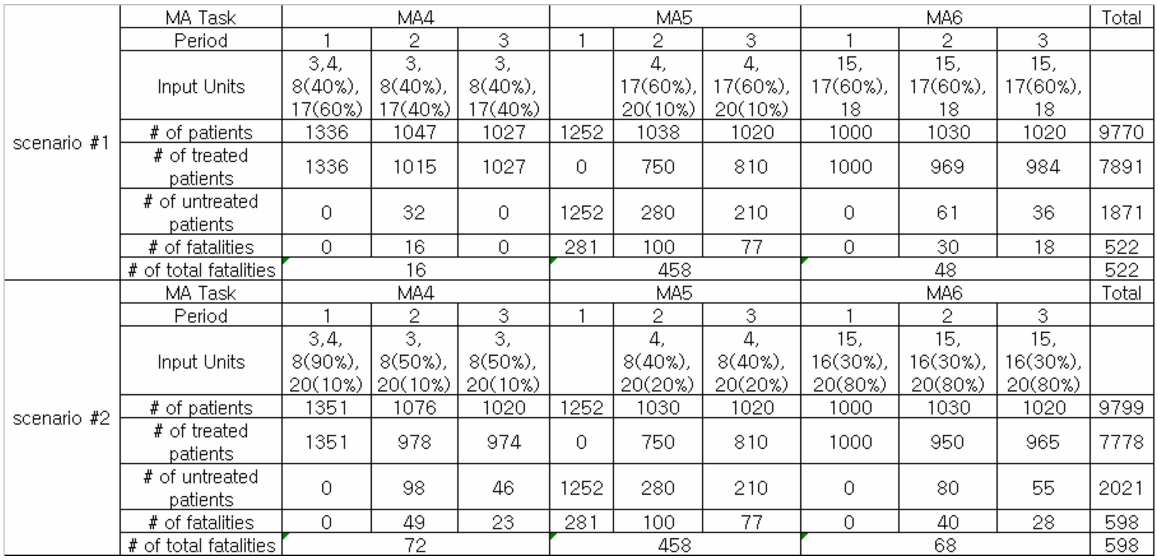
	Host Nation	Host nation 2			Host nation 3					
scenario #1	RA Task	RA1			RA2			RA3		
	Required Effectiveness	70			60			40		
	Periods	1	2	3	1	2	3	1	2	3
	Input units	3,7(80%), 8,10,12,						5,7(20%), 13,18(10%), 20(20%)		
	Total Effectiveness	70	70	70	0	0	0	40	40	40
	Accessibility	NO	YES	YES	NO	NO	NO	NO	YES	YES
scenario #2	RA Task	RA1			RA2			RA3		
	Required Effectiveness	70			60			40		
	Periods	1	2	3	1	2	3	1	2	3
	Input units	3,8,10, 12,7(80%)			5,7(20%), 13,15,18(10%), 20(20%)			17,20(80%)		
	Total Effectiveness	70	70	70	60	60	60	40	40	40
	Accessibility	NO	YES	YES	NO	YES	YES	NO	YES	YES

Table D- 9: The results of medical treatment tasks in the host nation 1



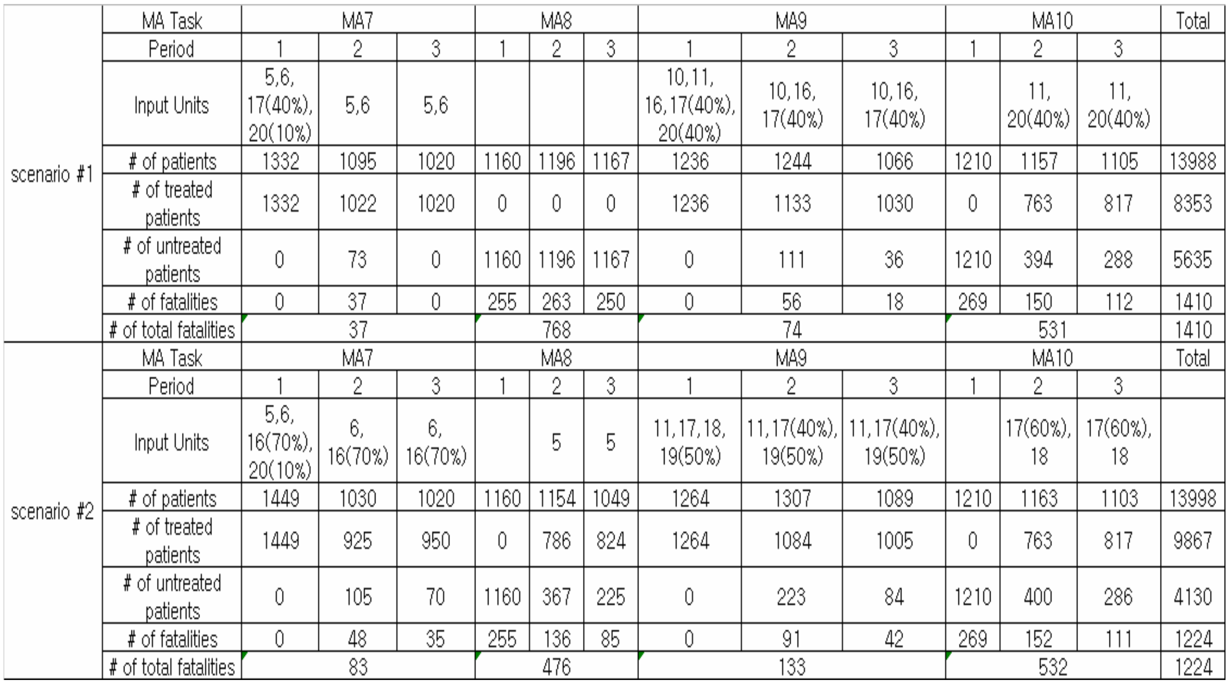
	MA Task	MA1			MA2			MA3			Total
scenario #1	Period	1	2	3	1	2	3	1	2	3	
	Input Units	1,7,8(60%), 13(40%)	1,7,8(60%), 13(40%)	1,7,8(60%), 13(40%)	2,9, 14(30%), 20(50%)	2,9, 14(30%), 20(50%)	2,9, 14(30%)	12,13(60%), 14(70%), 20(50%)	12, 13(60%), 14(70%)	12, 13(60%), 14(70%)	
	# of patients	1331	1189	1104	1363	1207	1106	1392	1237	1050	10979
	# of treated patients	1331	1157	1104	1363	1131	1106	1393	1189	1050	10824
	# of untreated patients	0	32	0	0	76	0	0	48	0	156
	# of fatalities	0	16	0	0	38	0	0	24	0	78
	# of total fatalities	16			38			24			78
scenario #2	MA Task	MA1			MA2			MA3			Total
	Period	1	2	3	1	2	3	1	2	3	
	Input Units	1,7, 8(10%),13	1,7, 8(10%),13	1,7, 8(10%),13	2,9, 19(50%)	2,9, 19(50%)	2,9, 19(50%)	10,12,14	10,12,14	10,12,14	
	# of patients	1352	1234	1085	1356	1269	1134	1365	1237	1187	11219
	# of treated patients	1352	1199	1085	1356	1160	1110	1365	1184	1157	10968
	# of untreated patients	0	35	0	0	109	24	0	53	30	251
	# of fatalities	0	18	0	0	54	12	0	27	15	126
	# of total fatalities	18			66			42			126

Table D- 10: The results of medical treatment tasks in the host nation 2



	MA Task	MA4			MA5			MA6			Total
scenario #1	Period	1	2	3	1	2	3	1	2	3	
	Input Units	3,4, 8(40%), 17(60%)	3, 8(40%), 17(40%)	3, 8(40%), 17(40%)		4, 17(60%), 20(10%)	4, 17(60%), 20(10%)	15, 17(60%), 18	15, 17(60%), 18	15, 17(60%), 18	
	# of patients	1336	1047	1027	1252	1038	1020	1000	1030	1020	9770
	# of treated patients	1336	1015	1027	0	750	810	1000	969	984	7891
	# of untreated patients	0	32	0	1252	280	210	0	61	36	1871
	# of fatalities	0	16	0	281	100	77	0	30	18	522
	# of total fatalities	16			458			48			522
scenario #2	MA Task	MA4			MA5			MA6			Total
	Period	1	2	3	1	2	3	1	2	3	
	Input Units	3,4, 8(90%), 20(10%)	3, 8(50%), 20(10%)	3, 8(50%), 20(10%)		4, 8(40%), 20(20%)	4, 8(40%), 20(20%)	15, 16(30%), 20(80%)	15, 16(30%), 20(80%)	15, 16(30%), 20(80%)	
	# of patients	1351	1076	1020	1252	1030	1020	1000	1030	1020	9799
	# of treated patients	1351	978	974	0	750	810	1000	950	965	7778
	# of untreated patients	0	98	46	1252	280	210	0	80	55	2021
	# of fatalities	0	49	23	281	100	77	0	40	28	598
	# of total fatalities	72			458			68			598

Table D- 11: The results of medical treatment tasks in the host nation 3



scenario #1	MA Task	MA7			MA8			MA9			MA10			Total
	Period	1	2	3	1	2	3	1	2	3	1	2	3	
	Input Units	5,6, 17(40%), 20(10%)	5,6	5,6				10,11, 16,17(40%), 20(40%)	10,16, 17(40%)	10,16, 17(40%)		11, 20(40%)	11, 20(40%)	
	# of patients	1332	1095	1020	1160	1196	1167	1236	1244	1066	1210	1157	1105	13988
	# of treated patients	1332	1022	1020	0	0	0	1236	1133	1030	0	763	817	8353
	# of untreated patients	0	73	0	1160	1196	1167	0	111	36	1210	394	288	5635
	# of fatalities	0	37	0	255	263	250	0	56	18	269	150	112	1410
	# of total fatalities	37			768			74			531			1410
scenario #2	MA Task	MA7			MA8			MA9			MA10			Total
	Period	1	2	3	1	2	3	1	2	3	1	2	3	
	Input Units	5,6, 16(70%), 20(10%)	6, 16(70%)	6, 16(70%)		5	5	11,17,18, 19(50%)	11,17(40%), 19(50%)	11,17(40%), 19(50%)		17(60%), 18	17(60%), 18	
	# of patients	1449	1030	1020	1160	1154	1049	1264	1307	1089	1210	1163	1103	13998
	# of treated patients	1449	925	950	0	786	824	1264	1084	1005	0	763	817	9867
	# of untreated patients	0	105	70	1160	367	225	0	223	84	1210	400	286	4130
	# of fatalities	0	48	35	255	136	85	0	91	42	269	152	111	1224
	# of total fatalities	83			476			133			532			1224

Appendix E. The results of Coalition Mission-Support Model

Table E- 1: The results of scenario S2 for commodity #1

Period	Supply Point	Input		DP1	DP2	DP3	DP4	DP5	DP6	DP7	DP8	DP9	DP10	TP1	TP2	TP3	total	Inventory
1	SP1	700		150			400			150							700	0
	SP2	600		50	100	300									50	100	600	0
	SP3	300										300					300	0
	SP4	500							100					200	200		500	0
	TP1	200						200									200	0
	TP2	250									250						250	0
	TP3	100											100				100	0
	Demand			200	100	300	400	200	100	150	250	300	200					
	Supply			200	100	300	400	200	100	150	250	300	100					
2	SP1	800	800	200	100		400			100							800	0
	SP2	500	500			300				50	150						500	0
	SP3	500	500								100	300					400	100
	SP4	500	500					200	100				200				500	0
	Demand		0	200	100	300	400	200	100	150	250	300	200					
	Supply		0	200	100	300	400	200	100	150	250	300	200					
3	SP1	400	400				400										400	0
	SP2	800	800	200	100	300				150	50						800	0
	SP3	500	600								200	300	100				600	0
	SP4	400	400					200	100				100				400	0
	Demand			200	100	300	400	200	100	150	250	300	200					
	Supply			200	100	300	400	200	100	150	250	300	200					
Total shortage				0	0	0	0	0	0	0	0	0	100					

Table E- 2: The results of scenario S2-2 for commodity #1

Period	Supply Point	Input		DP1	DP2	DP3	DP4	DP5	DP6	DP7	DP8	DP9	DP10	TP1	TP2	TP3	total	Inventory
1	SP1	700		150			400			150							700	0
	SP2	600		50	100	300									50	100	600	0
	SP3	300										300					300	0
	SP4	500							100					200	200		500	0
	TP1	200						200									200	0
	TP2	250									250						250	0
	TP3	100											100				100	0
	Demand			200	100	300	400	200	100	150	250	300	200					
	Supply			200	100	300	400	200	100	150	250	300	100					
2	SP1	800	800	200			400	50		150							800	0
	SP2	500	500		100	300		100									500	0
	SP3	500	500									300	200				500	0
	SP4	500	500					50	100		250						400	100
	Demand		0	200	100	300	400	200	100	150	250	300	200					
	Supply		0	200	100	300	400	200	100	150	250	300	200					
3	SP1	400	400				400										400	0
	SP2	800	800	200	100	300				150	50						800	0
	SP3	500	500									300	200				500	0
	SP4	400	500					200	100		200						500	0
	Demand			200	100	300	400	200	100	150	250	300	200					
	Supply			200	100	300	400	200	100	150	250	300	200					
Total shortage				0	0	0	0	0	0	0	0	0	100					

Table E- 3: The results of scenario S2-3 for commodity #1

Period	Supply Point	Input		DP1	DP2	DP3	DP4	DP5	DP6	DP7	DP8	DP9	DP10	TP1	TP2	TP3	total	Inventory
1	SP1	700		148			400			150							698	2
	SP2	600		52	100	300									148		600	0
	SP3	300										300					300	0
	SP4	500							100					200	60	140	500	0
	TP1	200						200									200	0
	TP2	208									208						208	0
	TP3	140											140				140	0
	Demand			200	100	300	400	200	100	150	250	300	200					
	Supply			200	100	300	400	200	100	150	208	300	140					
2	SP1	800	802	200	100		400										700	102
	SP2	500	500			300					200						500	0
	SP3	500	500							150		300	50				500	0
	SP4	500	500					200	100		50		150				500	0
	Demand		0	200	100	300	400	200	100	150	250	300	200					
	Supply		0	200	100	300	400	200	100	150	250	300	200					
3	SP1	400	502				400			102							502	0
	SP2	800	800	200	100	300				48	150						798	2
	SP3	500	500									300	200				500	0
	SP4	400	400					200	100		100						400	0
	Demand			200	100	300	400	200	100	150	250	300	200					
	Supply			200	100	300	400	200	100	150	250	300	200					
Total shortage				0	0	0	0	0	0	0	42	0	60					

Table E- 4: The results of scenario S2 for commodity #2

Period	Supply Point	Input		DP1	DP2	DP3	DP4	DP5	DP6	DP7	DP8	DP9	DP10	TP1	TP2	TP3	total	Inventory
1	SP1	1000		300	150		550										1000	0
	SP2	0															0	0
	SP3	1000				450				100		450					1000	0
	SP4	1000					50		150	125				275			600	400
	TP1	275						275									275	0
	TP2	0															0	0
	TP3	0															0	0
	Demand			300	150	450	600	300	150	225	375	450	300					
	Supply			300	150	450	600	275	150	225	0	450	0					
2	SP1	1100	1100	300	150		600			50							1100	0
	SP2	0	0														0	0
	SP3	1000	1000			350						450					800	200
	SP4	1000	1400			100		300	150	175	375		300				1400	0
	Demand		0	300	150	450	600	300	150	225	375	450	300					
	Supply		0	300	150	450	600	300	150	225	375	450	300					
3	SP1	1100	1100	300	150		600			50							1100	0
	SP2	0	0														0	0
	SP3	1000	1200			450				175	125	450					1200	0
	SP4	1000	1000					300	150		250		300				1000	0
	Demand			300	150	450	600	300	150	225	375	450	300					
	Supply			300	150	450	600	300	150	225	375	450	300					
Total shortage				0	0	0	0	25	0	0	375	0	300					

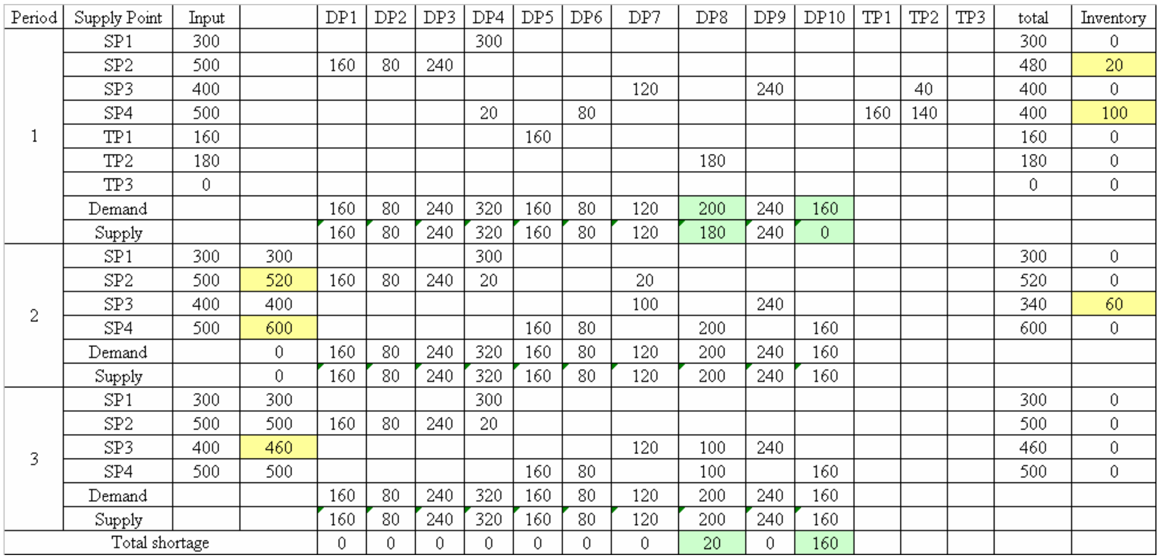
Table E- 5: The results of scenario S2-2 for commodity #2

Period	Supply Point	Input		DP1	DP2	DP3	DP4	DP5	DP6	DP7	DP8	DP9	DP10	TP1	TP2	TP3	total	Inventory
1	SP1	1000		300	150		550										1000	0
	SP2	0															0	0
	SP3	1000				450				100		450					1000	0
	SP4	1000					50		150	125				150	187.5	150	812.5	187.5
	TP1	150						150									150	0
	TP2	187.5									187.5						187.5	0
	TP3	150											150				150	0
	Demand			300	150	450	600	300	150	225	375	450	300					
	Supply			300	150	450	600	150	150	225	187.5	450	150					
2	SP1	1100	1100	300	150		600			50							1100	0
	SP2	0	0														0	0
	SP3	1000	1000			450				100		450					1000	0
	SP4	1000	1187.5					300	150	75	362.5		300				1188	0
	Demand		0	300	150	450	600	300	150	225	375	450	300					
	Supply		0	300	150	450	600	300	150	225	362.5	450	300					
3	SP1	1100	1100	300	150		600			50							1100	0
	SP2	0	0														0	0
	SP3	1000	1000			450				100		450					1000	0
	SP4	1000	1000					300	150	62.5	187.5		300				1000	0
	Demand			300	150	450	600	300	150	225	375	450	300					
	Supply			300	150	450	600	300	150	212.5	187.5	450	300					
Total shortage				0	0	0	0	150	0	12.5	387.5	0	150					

Table E- 6: The results of scenario S2-3 for commodity #2

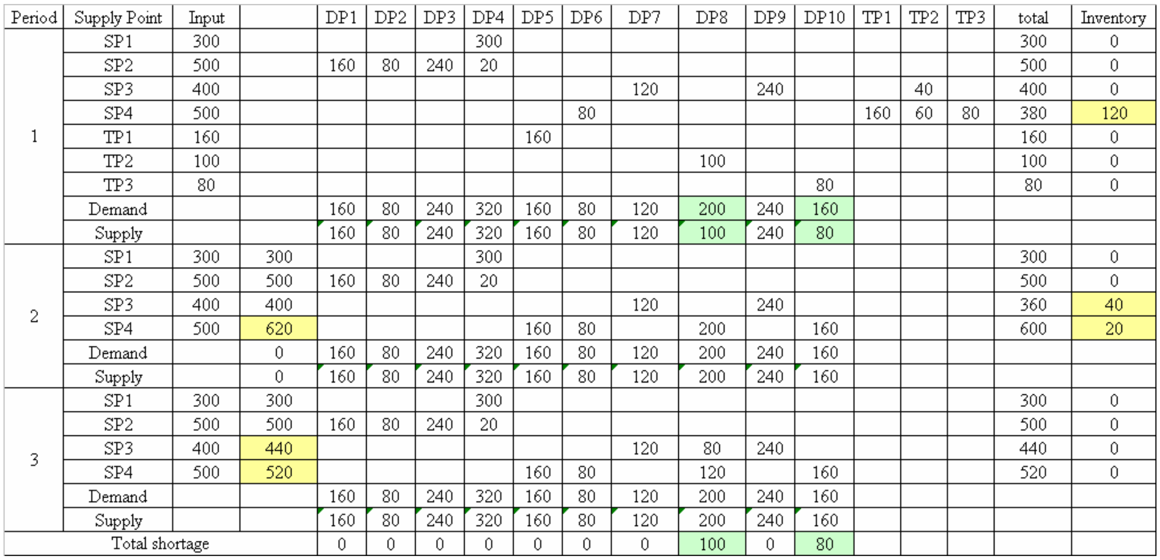
Period	Supply Point	Input		DP1	DP2	DP3	DP4	DP5	DP6	DP7	DP8	DP9	DP10	TP1	TP2	TP3	total	Inventory
1	SP1	1000		300	150		550										1000	0
	SP2	0															0	0
	SP3	1000				442.5				107.5		450					1000	0
	SP4	1000					50		150	117.5				210	262.5	210	1000	0
	TP1	210						210									210	0
	TP2	262.5									262.5						262.5	0
	TP3	210											210				210	0
	Demand			300	150	450	600	300	150	225	375	450	300					
	Supply			300	150	442.5	600	210	150	225	262.5	450	210					
2	SP1	1100	1100	300	150		600			50							1100	0
	SP2	0	0														0	0
	SP3	1000	1000			362.5				175	12.5	450					1000	0
	SP4	1000	1000					300	150		250		300				1000	0
	Demand		0	300	150	450	600	300	150	225	375	450	300					
	Supply		0	300	150	362.5	600	300	150	225	262.5	450	300					
3	SP1	1100	1100	300	150		600			50							1100	0
	SP2	0	0														0	0
	SP3	1000	1000			450				100		450					1000	0
	SP4	1000	1000					280	150	7.5	262.5		300				1000	0
	Demand			300	150	450	600	300	150	225	375	450	300					
	Supply			300	150	450	600	280	150	157.5	262.5	450	300					
Total shortage				0	0	95	0	110	0	67.5	337.5	0	90					

Table E- 7: The results of scenario S2 for commodity #3



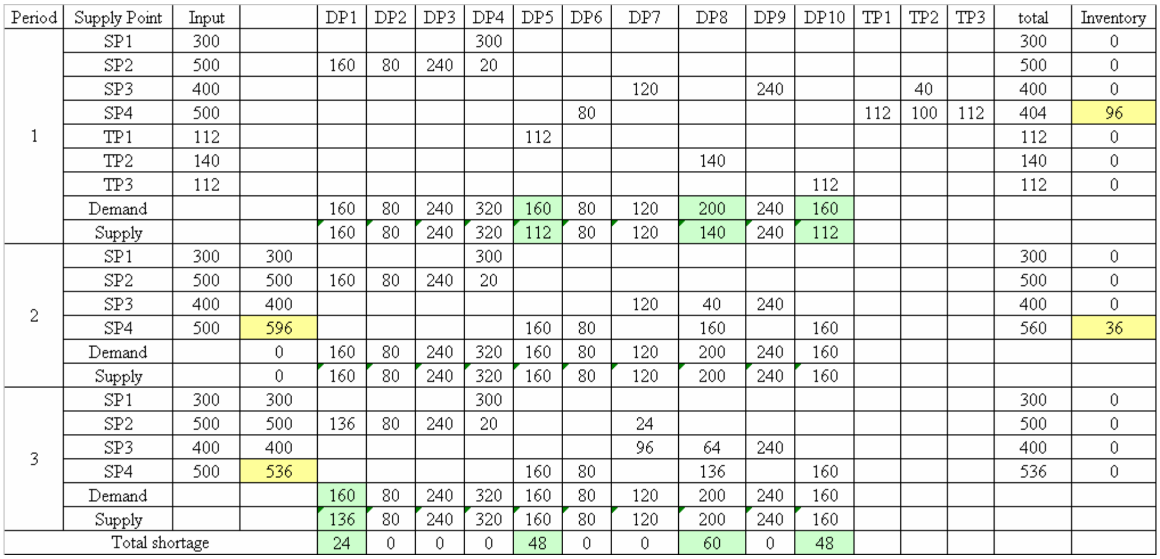
Period	Supply Point	Input		DP1	DP2	DP3	DP4	DP5	DP6	DP7	DP8	DP9	DP10	TP1	TP2	TP3	total	Inventory
1	SP1	300					300										300	0
	SP2	500		160	80	240											480	20
	SP3	400								120		240			40		400	0
	SP4	500					20		80					160	140		400	100
	TP1	160						160									160	0
	TP2	180									180						180	0
	TP3	0															0	0
	Demand			160	80	240	320	160	80	120	200	240	160					
	Supply			160	80	240	320	160	80	120	180	240	0					
2	SP1	300	300				300										300	0
	SP2	500	520	160	80	240	20			20							520	0
	SP3	400	400							100		240					340	60
	SP4	500	600					160	80		200		160				600	0
	Demand		0	160	80	240	320	160	80	120	200	240	160					
	Supply		0	160	80	240	320	160	80	120	200	240	160					
3	SP1	300	300				300										300	0
	SP2	500	500	160	80	240	20										500	0
	SP3	400	460							120	100	240					460	0
	SP4	500	500					160	80		100		160				500	0
	Demand			160	80	240	320	160	80	120	200	240	160					
	Supply			160	80	240	320	160	80	120	200	240	160					
Total shortage				0	0	0	0	0	0	0	20	0	160					

Table E- 8: The results of scenario S2-2 for commodity #3



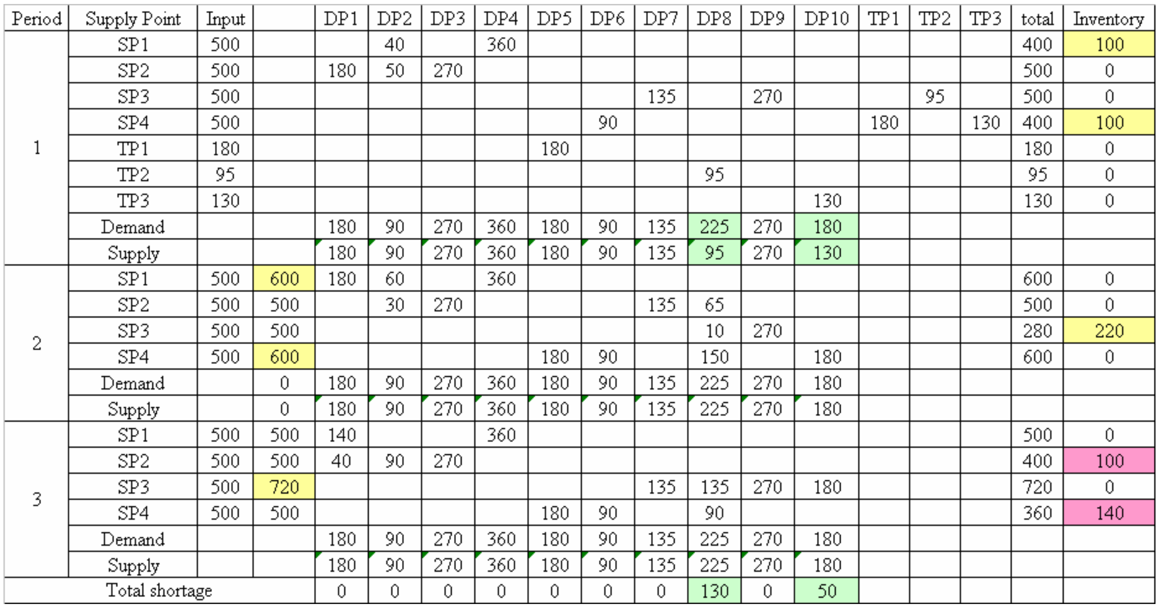
Period	Supply Point	Input		DP1	DP2	DP3	DP4	DP5	DP6	DP7	DP8	DP9	DP10	TP1	TP2	TP3	total	Inventory
1	SP1	300					300										300	0
	SP2	500		160	80	240	20										500	0
	SP3	400								120		240			40		400	0
	SP4	500							80					160	60	80	380	120
	TP1	160						160									160	0
	TP2	100									100						100	0
	TP3	80											80				80	0
	Demand			160	80	240	320	160	80	120	200	240	160					
	Supply			160	80	240	320	160	80	120	100	240	80					
2	SP1	300	300				300										300	0
	SP2	500	500	160	80	240	20										500	0
	SP3	400	400							120		240					360	40
	SP4	500	620					160	80		200		160				600	20
	Demand		0	160	80	240	320	160	80	120	200	240	160					
	Supply		0	160	80	240	320	160	80	120	200	240	160					
3	SP1	300	300				300										300	0
	SP2	500	500	160	80	240	20										500	0
	SP3	400	440							120	80	240					440	0
	SP4	500	520					160	80		120		160				520	0
	Demand			160	80	240	320	160	80	120	200	240	160					
	Supply			160	80	240	320	160	80	120	200	240	160					
Total shortage				0	0	0	0	0	0	0	100	0	80					

Table E- 9: The results of scenario S2-3 for commodity #3



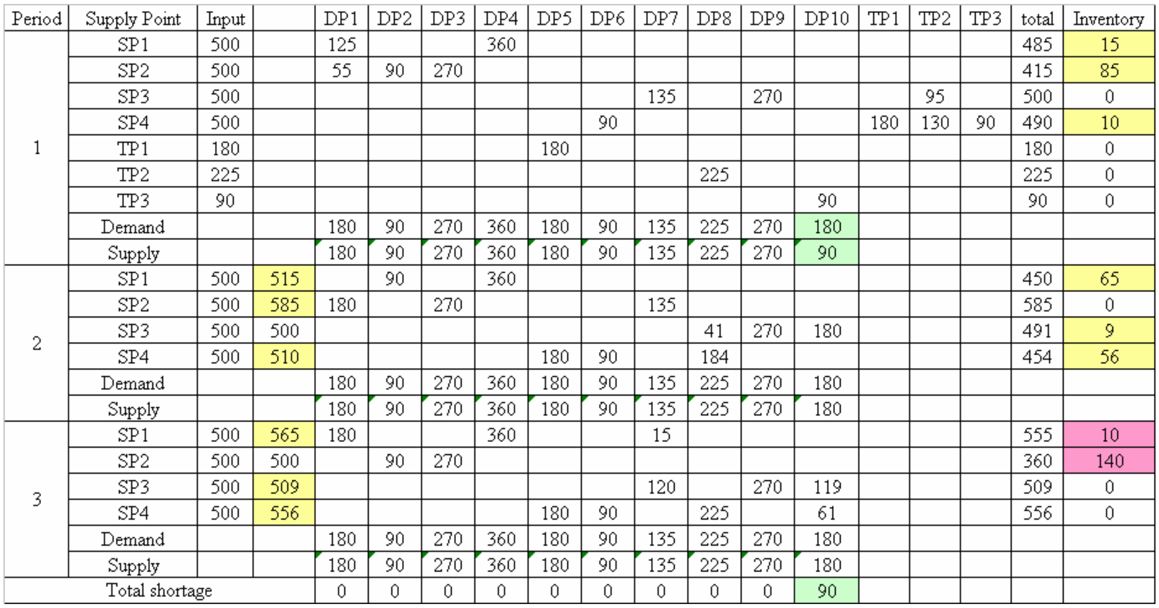
Period	Supply Point	Input		DP1	DP2	DP3	DP4	DP5	DP6	DP7	DP8	DP9	DP10	TP1	TP2	TP3	total	Inventory
1	SP1	300					300										300	0
	SP2	500		160	80	240	20										500	0
	SP3	400								120		240			40		400	0
	SP4	500							80					112	100	112	404	96
	TP1	112						112									112	0
	TP2	140									140						140	0
	TP3	112											112				112	0
	Demand			160	80	240	320	160	80	120	200	240	160					
	Supply			160	80	240	320	112	80	120	140	240	112					
2	SP1	300	300				300										300	0
	SP2	500	500	160	80	240	20										500	0
	SP3	400	400							120	40	240					400	0
	SP4	500	596					160	80		160		160				560	36
	Demand		0	160	80	240	320	160	80	120	200	240	160					
	Supply		0	160	80	240	320	160	80	120	200	240	160					
3	SP1	300	300				300										300	0
	SP2	500	500	136	80	240	20			24							500	0
	SP3	400	400							96	64	240					400	0
	SP4	500	536					160	80		136		160				536	0
	Demand			160	80	240	320	160	80	120	200	240	160					
	Supply			136	80	240	320	160	80	120	200	240	160					
Total shortage				24	0	0	0	48	0	0	60	0	48					

Table E- 10: The results of scenario S2 for commodity #4



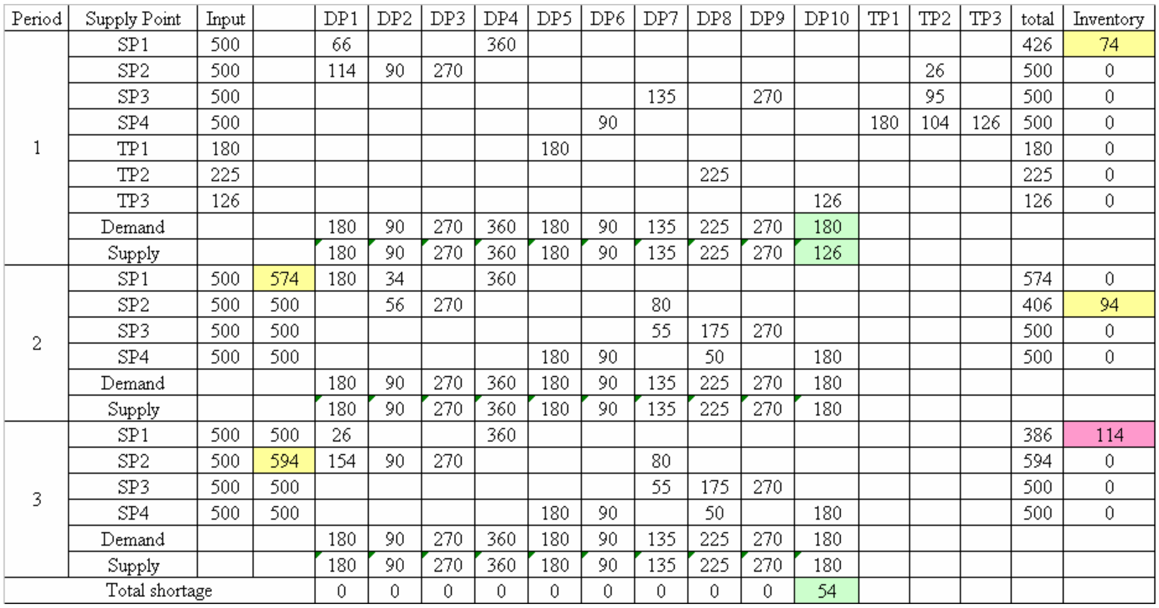
Period	Supply Point	Input		DP1	DP2	DP3	DP4	DP5	DP6	DP7	DP8	DP9	DP10	TP1	TP2	TP3	total	Inventory
1	SP1	500			40		360										400	100
	SP2	500		180	50	270											500	0
	SP3	500								135		270			95		500	0
	SP4	500							90					180		130	400	100
	TP1	180						180									180	0
	TP2	95									95						95	0
	TP3	130											130				130	0
	Demand			180	90	270	360	180	90	135	225	270	180					
	Supply			180	90	270	360	180	90	135	95	270	130					
2	SP1	500	600	180	60		360										600	0
	SP2	500	500		30	270				135	65						500	0
	SP3	500	500								10	270					280	220
	SP4	500	600					180	90		150		180				600	0
	Demand		0	180	90	270	360	180	90	135	225	270	180					
	Supply		0	180	90	270	360	180	90	135	225	270	180					
3	SP1	500	500	140			360										500	0
	SP2	500	500	40	90	270											400	100
	SP3	500	720							135	135	270	180				720	0
	SP4	500	500					180	90		90						360	140
	Demand			180	90	270	360	180	90	135	225	270	180					
	Supply			180	90	270	360	180	90	135	225	270	180					
Total shortage				0	0	0	0	0	0	0	130	0	50					

Table E- 11: The results of scenario S2-2 for commodity #4



Period	Supply Point	Input		DP1	DP2	DP3	DP4	DP5	DP6	DP7	DP8	DP9	DP10	TP1	TP2	TP3	total	Inventory
1	SP1	500		125			360										485	15
	SP2	500		55	90	270											415	85
	SP3	500								135		270			95		500	0
	SP4	500							90					180	130	90	490	10
	TP1	180						180									180	0
	TP2	225									225						225	0
	TP3	90											90				90	0
	Demand			180	90	270	360	180	90	135	225	270	180					
	Supply			180	90	270	360	180	90	135	225	270	90					
2	SP1	500	515		90		360										450	65
	SP2	500	585	180		270				135							585	0
	SP3	500	500								41	270	180				491	9
	SP4	500	510					180	90		184						454	56
	Demand			180	90	270	360	180	90	135	225	270	180					
	Supply			180	90	270	360	180	90	135	225	270	180					
3	SP1	500	565	180			360			15							555	10
	SP2	500	500		90	270											360	140
	SP3	500	509							120		270	119				509	0
	SP4	500	556					180	90		225		61				556	0
	Demand			180	90	270	360	180	90	135	225	270	180					
	Supply			180	90	270	360	180	90	135	225	270	180					
Total shortage				0	0	0	0	0	0	0	0	0	90					

Table E- 12: The results of scenario S2-3 for commodity #4



Period	Supply Point	Input		DP1	DP2	DP3	DP4	DP5	DP6	DP7	DP8	DP9	DP10	TP1	TP2	TP3	total	Inventory
1	SP1	500		66			360										426	74
	SP2	500		114	90	270									26		500	0
	SP3	500								135		270			95		500	0
	SP4	500							90					180	104	126	500	0
	TP1	180						180									180	0
	TP2	225									225						225	0
	TP3	126											126				126	0
	Demand			180	90	270	360	180	90	135	225	270	180					
	Supply			180	90	270	360	180	90	135	225	270	126					
2	SP1	500	574	180	34		360										574	0
	SP2	500	500		56	270				80							406	94
	SP3	500	500							55	175	270					500	0
	SP4	500	500					180	90		50		180				500	0
	Demand			180	90	270	360	180	90	135	225	270	180					
	Supply			180	90	270	360	180	90	135	225	270	180					
3	SP1	500	500	26			360										386	114
	SP2	500	594	154	90	270				80							594	0
	SP3	500	500							55	175	270					500	0
	SP4	500	500					180	90		50		180				500	0
	Demand			180	90	270	360	180	90	135	225	270	180					
	Supply			180	90	270	360	180	90	135	225	270	180					
Total shortage				0	0	0	0	0	0	0	0	0	54					

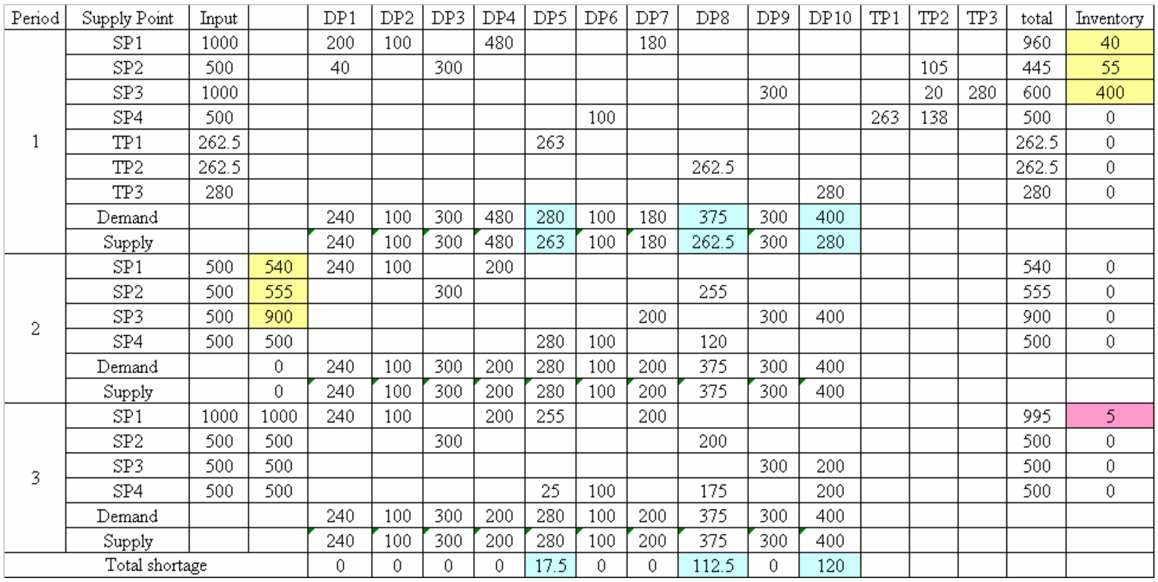
Table E- 13: The results of scenario S2 for commodity #5

Period	Supply Point	Input		DP1	DP2	DP3	DP4	DP5	DP6	DP7	DP8	DP9	DP10	TP1	TP2	TP3	total	Inventory
1	SP1	1000		240	100		480			5							825	175
	SP2	500				300											300	200
	SP3	1000								175		300			375	150	1000	0
	SP4	500							100					280			380	120
	TP1	280						280									280	0
	TP2	375									375						375	0
	TP3	150											150				150	0
	Demand			240	100	300	480	280	100	180	375	300	400					
	Supply			240	100	300	480	280	100	180	375	300	150					
2	SP1	500	675	240	100		200			135							675	0
	SP2	500	700			300				65	335						700	0
	SP3	500	500									300	200				500	0
	SP4	500	620					280	100		40		200				620	0
	Demand		0	240	100	300	200	280	100	200	375	300	400					
	Supply		0	240	100	300	200	280	100	200	375	300	400					
3	SP1	1000	1000	240	100		200	255		200							995	5
	SP2	500	500			300					200						500	0
	SP3	500	500								175	300	25				500	0
	SP4	500	500					25	100				375				500	0
	Demand			240	100	300	200	280	100	200	375	300	400					
	Supply			240	100	300	200	280	100	200	375	300	400					
Total shortage				0	0	0	0	0	0	0	0	0	250					

Table E- 14: The results of scenario S2-2 for commodity #5

Period	Supply Point	Input		DP1	DP2	DP3	DP4	DP5	DP6	DP7	DP8	DP9	DP10	TP1	TP2	TP3	total	Inventory
1	SP1	1000		240	40		480										760	240
	SP2	500			60	300											360	140
	SP3	1000								180		300			320	200	1000	0
	SP4	500							100					280	5		385	115
	TP1	280						280									280	0
	TP2	325									325						325	0
	TP3	200											200				200	0
	Demand			240	100	300	480	280	100	180	375	300	400					
	Supply			240	100	300	480	280	100	180	325	300	200					
2	SP1	500	740	240	100		200			200							740	0
	SP2	500	640			300					175		165				640	0
	SP3	500	500								200	300					500	0
	SP4	500	615					280	100				235				615	0
	Demand		0	240	100	300	200	280	100	200	375	300	400					
	Supply		0	240	100	300	200	280	100	200	375	300	400					
3	SP1	1000	1000	240	100		200	255		200							995	5
	SP2	500	500			300					200						500	0
	SP3	500	500								175	300	25				500	0
	SP4	500	500					25	100				375				500	0
	Demand			240	100	300	200	280	100	200	375	300	400					
	Supply			240	100	300	200	280	100	200	375	300	400					
Total shortage				0	0	0	0	0	0	0	50	0	200					

Table E- 15: The results of scenario S2-3 for commodity #5



Period	Supply Point	Input		DP1	DP2	DP3	DP4	DP5	DP6	DP7	DP8	DP9	DP10	TP1	TP2	TP3	total	Inventory
1	SP1	1000		200	100		480			180							960	40
	SP2	500		40		300									105		445	55
	SP3	1000										300			20	280	600	400
	SP4	500							100					263	138		500	0
	TP1	262.5						263									262.5	0
	TP2	262.5									262.5						262.5	0
	TP3	280											280				280	0
	Demand			240	100	300	480	280	100	180	375	300	400					
	Supply			240	100	300	480	263	100	180	262.5	300	280					
2	SP1	500	540	240	100		200										540	0
	SP2	500	555			300					255						555	0
	SP3	500	900							200		300	400				900	0
	SP4	500	500					280	100		120						500	0
	Demand		0	240	100	300	200	280	100	200	375	300	400					
	Supply		0	240	100	300	200	280	100	200	375	300	400					
3	SP1	1000	1000	240	100		200	255		200							995	5
	SP2	500	500			300					200						500	0
	SP3	500	500									300	200				500	0
	SP4	500	500					25	100		175		200				500	0
	Demand			240	100	300	200	280	100	200	375	300	400					
	Supply			240	100	300	200	280	100	200	375	300	400					
Total shortage				0	0	0	0	17.5	0	0	112.5	0	120					

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14. ABSTRACT

Multinational operations are carried out to achieve military and diplomatic objectives in various regions. Such operations derive a great deal of benefits from sharing budgets, political legitimacy, sharing each national experience and technological resources, and so forth. However, a coalition, one structure of multinational operations, often involves serious challenges in such areas as command and control, logistic support, communication and language, training, and intelligence and information due to its ad hoc characteristics. This research reviews general problems in a coalition operation, and develops the Coalition Operation Planning Model to assist coalition commanders or staff in producing an efficient operational plan. In this model, goal programming is employed to formulate the coalition problems with multiple objectives. The proposed model is composed of three sub-models: the Coalition Mission-Unit Allocation Model, the Coalition Mission-Support Model, and the Coalition Mission-Unit Grouping Model. The first sub-model is designed to find an optimized resource allocation by applying the shortest path problem and effectiveness functions. The second sub-model is developed to obtain an optimized logistics support plan by using the multi-commodity network flow. Finally, the third sub-model is designed to combine small units into one workable independent unit by using the quadratic assignment problem. The models are demonstrated with a notional humanitarian assistance operation.

15. SUBJECT TERMS

Multinational Operations, Coalition Operations, Goal Programming, Shortest Path Problem, Multi-Commodity Network Flow, Quadratic Assignment Problem

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