NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

A SIMULATION AND EVALUATION OF
NATO STANDARDIZATION AGREEMENT
(STANAG) 4214

by

Michael A. Dorko
and
Robert G. Schultz

September 1993

Thesis Advisor: Michael P. Bailey
Co-Advisor William G. Kemple

REPORT DOCUMENTATION PAGE

1a Report Security Classification: Unclassified		1b Restrictive Markings
2a Security Classification Authority		3 Distribution/Availability of Report Approved for public release; distribution is unlimited.
2b Declassification/Downgrading Schedule		
4 Performing Organization Report Number(s)		5 Monitoring Organization Report Number(s)
6a Name of Performing Organization Naval Postgraduate School	6b Office Symbol *(if applicable)* 30	7a Name of Monitoring Organization Naval Postgraduate School
6c Address *(city, state, and ZIP code)* Monterey CA 93943-5000		7b Address *(city, state, and ZIP code)* Monterey CA 93943-5000
8a Name of Funding/Sponsoring Organization	6b Office Symbol *(if applicable)*	9 Procurement Instrument Identification Number
Address *(city, state, and ZIP code)*		10 Source of Funding Numbers

Program Element No	Project No	Task No	Work Unit Accession No

11 Title *(include security classification)* A SIMULATION AND EVALUATION OF NATO STANDARDIZATION AGREEMENT (STANAG) 4214

12 Personal Author(s) Michael A. Dorko and Robert G. Schultz

13a Type of Report	13b Time Covered	14 Date of Report *(year, month, day)*	15 Page Count
Master's Thesis	From To	1993, September	125

16 Supplementary Notation The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

17 Cosati Codes			18 Subject Terms *(continue on reverse if necessary and identify by block number)*
Field	Group	Subgroup	Simulation, Communications, Networks, MODSIM, Object-Oriented, Anti-Looping

19 Abstract An object-oriented simulation model is developed to evaluate the effectiveness of NATO Standardization Agreement (STANAG) 4214, which promulgates the protocol for international telephone call routing and directories for tactical communications. The model simulates communication systems using the STANAG 4214 protocol to isolate discrepancies which could lead to the inability to successfully complete calls within the system. The model also simulates protocol modifications created to correct existing discrepancies and verifies their effectiveness in making the protocol more robust. Results show that these modifications improve STANAG call completion rate from a potential low of under 70 percent to 100 percent, while simultaneously easing the restrictions on lateral communication connections. The model is menu-driven with both graphical and hard copy output, making it useful to network planners, protocol designers, and tactical communications officers.

20 Distribution/Availability of Abstract X unclassified/unlimited __ same as report __ DTIC users		21 Abstract Security Classification Unclassified
22a Name of Responsible Individual Micheal P. Bailey and William G. Kemple	22b Telephone *(include Area Code)* 408-656-2085 408-656-2191	22c Office Symbol 30/Ba 30/Ke

DD FORM 1473,84 MAR 83 APR edition may be used until exhausted security classification of this page

All other editions are obsolete Unclassified

Approved for public release; distribution is unlimited.

A Simulation and Evaluation of NATO Standardization Agreement (STANAG) 4214

by

Michael A. Dorko
Lieutenant, United States Navy
B.S., United States Naval Academy, 1986

and

Robert G. Schultz
Lieutenant, United States Navy
B.S., Belmont College, 1985

Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
September 1993

Authors: ______________________
Michael A. Dorko

____
Robert G. Schultz

Approved by: ______________________
Michael P. Bailey, Thesis Advisor

____
William G. Kemple, Co-Advisor

____
Michael G. Sovereign, Second Reader

____
Peter Purdue, Chairman,
Department of Operations Research

ABSTRACT

An object-oriented simulation model is developed to evaluate the effectiveness of NATO Standardization Agreement (STANAG) 4214, which promulgates the protocol for international telephone call routing and directories for tactical communications. The model simulates communication systems using the STANAG 4214 protocol to isolate discrepancies which could lead to the inability to successfully complete calls within the system. The model also simulates protocol modifications created to correct existing discrepancies and verifies their effectiveness in making the protocol more robust. Results show that these modifications improve STANAG call completion rate from a potential low of under 70 percent to 100 percent, while simultaneously easing the restrictions on lateral communication connections. The model is menu-driven with both graphical and hard copy output, making it useful to network planners, protocol designers, and tactical communications officers.

TABLE OF CONTENTS

LIST OF FIGURES

EXECUTIVE SUMMARY

The Joint Interoperability Engineering Organization (JIEO) is responsible for ensuring communication systems interoperability with United States allies, including North Atlantic Treaty Organization (NATO) allies. JIEO is also responsible for NATO Standardization Agreements (STANAGs) and their implementation by the U.S., including STANAG 4214 (STANAG 4214, 1985), which deals with international telephone call routing and directories for tactical communications.

STANAG 4214 was developed to allow international routing between highly mobile tactical area telephone networks. The requirement for STANAG 4214 was established when it was recognized that units would be continually relocating, and that international forces would be distributed throughout the command structure. To properly route telephone calls, a system had to be developed that would allow unique identification of each unit (formation). The protocol set forth in STANAG 4214 was designed to meet this requirement.

Unfortunately, several nations have had difficulty in interpreting STANAG 4214. These difficulties resulted in various attempts by some of these countries to analyze the effectiveness of STANAG 4214, all of which were unsuccessful.

These failed analyses, combined with results of international training exercises which revealed that the STANAG 4214 protocol had not been adequately tested, left JIEO with serious concerns about the validity of the protocol. There were also concerns about the strict limitation of inter-unit connections which could be established under STANAG 4214 protocol. As a result of these concerns, JIEO requested the Operations Research Department, Naval Postgraduate School, Monterey, Ca, to evaluate the STANAG 4214 protocol methodology and to develop rules which would allow for more lenient guidelines on the establishment of inter-unit connections. JIEO also requested rules to ensure calls within a system utilizing STANAG 4214 protocol would not be handled more than once by any unit.

To meet these objectives, an object-oriented computer simulation model called TACFONE-NATO was developed. The model is menu driven with both graphical and hard copy output. TACFONE-NATO incorporates all the original STANAG 4214 protocol and allows the option of implementing several modifications that improve survivability of the area communication networks and the overall effectiveness the STANAG 4214. TACFONE-NATO, in conjunction with a mathematical program, was used to analyze the effectiveness of the STANAG 4214 protocol, isolate discrepancies in the protocol, and to develop and test the rules requested by JIEO.

The analysis revealed one discrepancy in the current protocol which can be remedied through a change in STANAG 4214. The analysis also verified the need for rules which ensure that calls within a system are not handled more than once by any unit. Additionally, by using the model's ability to verify modifications to the STANAG 4214 protocol, rules were successfully developed which ensure no multiple handling of calls by any unit and also allow for more leniency on the establishment of inter-unit connections. These rules improved STANAG call completion rate from a potential low of under 70 percent (without rules to ensure multiple handling of calls by any units) to 100 percent, while simultaneously easing the restrictions on inter-unit connections.

TACFONE-NATO will be a powerful tool used at JIEO and other NATO facilities. TACFONE-NATO will allow Communication System Network Managers of international forces to quickly obtain all information required to number a Communication System in accordance with STANAG 4214 protocol and to thoroughly test a proposed communication system *before* assets are dedicated to it.

I. INTRODUCTION

The Joint Interoperability Engineering Organization (JIEO) is responsible for ensuring interoperability of communication systems with United States allies, including North Atlantic Treaty Organization (NATO) allies. JIEO is also responsible for NATO Standardization Agreements (STANAGs) and their implementation by the U.S., including STANAG 4214 (STANAG 4214, 1985), which deals with international telephone call routing and directories for tactical communications.

STANAG 4214 was developed to allow international routing between mobile tactical area telephone networks. The need for STANAG 4214 was established when it was recognized that units would be not only be relocated, but also would be re-distributed throughout the command structure including attachment to other nation's commands. In order to properly route telephone calls, a system had to be developed that would allow unique identification of each unit(formation) within mixed national structures.

The result was the International Routing and Directory rules that are defined in STANAG 4214. Several nations, including the United States, have implemented the rules and procedures defined in the STANAG 4214. In 1987, Norway began the development of their Digital NATO Interface for tactical telephone communication systems. In their attempts to implement STANAG 4214, they had considerable difficulty interpreting the document. Several years were spent addressing the sections of the STANAG that could be potentially misconstrued. The United States held the position that the STANAG 4214 was generally clear, but the issues brought up by Norway caused some concern about the United States' interpretation.

JIEO reviewed the results of international training exercises to determine if there had been any problems encountered with the actual implementation and use of the STANAG 4214 protocol. It was determined from the results of these training exercises which utilized the STANAG 4214 protocol, that the STANAG 4214 protocol had not been fully tested and validated.

In 1991, the United Kingdom proposed modifications to the STANAG 4214 that would enhance area communication networks survivability. These proposed changes also needed to be evaluated to determine if they were compatible with the current STANAG 4214 protocol.

At this point, JIEO determined that a study should be pursed to determine the actual effectiveness of the STANAG 4214 protocol and the proposed changes. It would be difficult to determine the actual effectiveness of the STANAG 4214 protocol thorough operational testing due to the size of communication system that it is designed to address; such a system would only exist if a major multi-national NATO force were mobilized to meet some real threat. The cost of establishing such a communication system for a one-time test would be prohibitive and would require member nations to use equipment that is currently utilized elsewhere. Furthermore, a complete and thorough testing of the rules would require numerous setups of various configurations. It would be extremely expensive in both time and assets.

A more cost effective method of evaluating the STANAG 4214 protocol methodology and proposed changes is computer simulation. A simulation model called TACFONE-NATO, was developed for this purpose. It is written in the object-oriented simulation language MODSIM (MODSIM 93). Object-oriented simulation means that modular blocks are used to emulate certain actions of physical things, these blocks of code are grouped together into an "object" which inherits the ability to perform these actions. The "object" also contains whatever information is required to carry out these actions. Object-oriented simulation was used to simulate the crucial elements of the communications equipment used in the telephone networks addressed by the STANAG 4214. The use of an object-oriented language made it much easier to construct an accurate representation of reality with this simulation. The model is controlled through a graphical user interface (GUI) and produces both graphical and hard copy output. TACFONE-NATO incorporates all of the original STANAG 4214 protocol and allows the option of implementing several modifications that improve survivability of the area communication networks and the overall effectiveness of STANAG 4214. These modifications developed by the authors will be discussed later. TACFONE-NATO can also be used by the network managers to produce the numbering scheme for a network, or to test a proposed numbering scheme that does not completely follow the STANAG 4214 protocol.

The interpretation of STANAG 4214 protocol used in developing TACFONE-NATO, the TACFONE-NATO model itself, the proposed changes evaluated and the results of the evaluation will be discussed in the following sections. The goal of this thesis is to develop an object-oriented simulation of the STANAG 4214 protocol with potential modifications, to analyze the effectiveness of the protocol and the modifications, and to make recommendations based on this analysis.

II. STANDARDIZATION AGREEMENT (STANAG) 4214

In this chapter the terms necessary to discuss the STANAG 4214 protocol will be defined to allow for concise understanding. The aim of the STANAG 4214 will also be presented. As previously discussed, there has been difficulty in interpreting and understanding the STANAG 4214 protocol, therefore the exact interpretation used in developing TACFONE-NATO will also be discussed in depth in this chapter.

A. TERM DEFINITIONS

All the terms defined below are in the context of the STANAG 4214. The definitions may not follow conventional meanings, but allow for concise understanding in the context of this discussion.

1. Formations

Any military unit that is connected in a communication system, as discussed below, is considered a formation. All formations are capable of sending and receiving calls as well as forwarding calls to other formations. Each formation may have numerous telephones within its system but is considered a single unit because all calls are routed through a central communications terminal. A formation is considered under command of another formation if its external communication needs are served by that formation.

a. *Networks*

Formations are connected into hierarchial tree structures called networks, see Figure 1.

b. Host Formations

The root of the network tree is called the Host Formation, see Figure 2. All formations in the network are served by the Host Formation's communication system and therefore are under "command" (as discussed earlier) of the Host Formation. This communications setup may or may not reflect actual operational or administrative chains of command.

c. Primary and Secondary Formations

The formations directly beneath the Host Formation in the network with a direct connection to the Host are considered formations under command and are called Primary Formations. The formations beneath the Primary Formations are called Secondary Formations, see Figure 2.

d. Communication Systems

A group of networks connected together at the Host Formation level comprise what is called a Communication System (CommSys), see Figure 3.

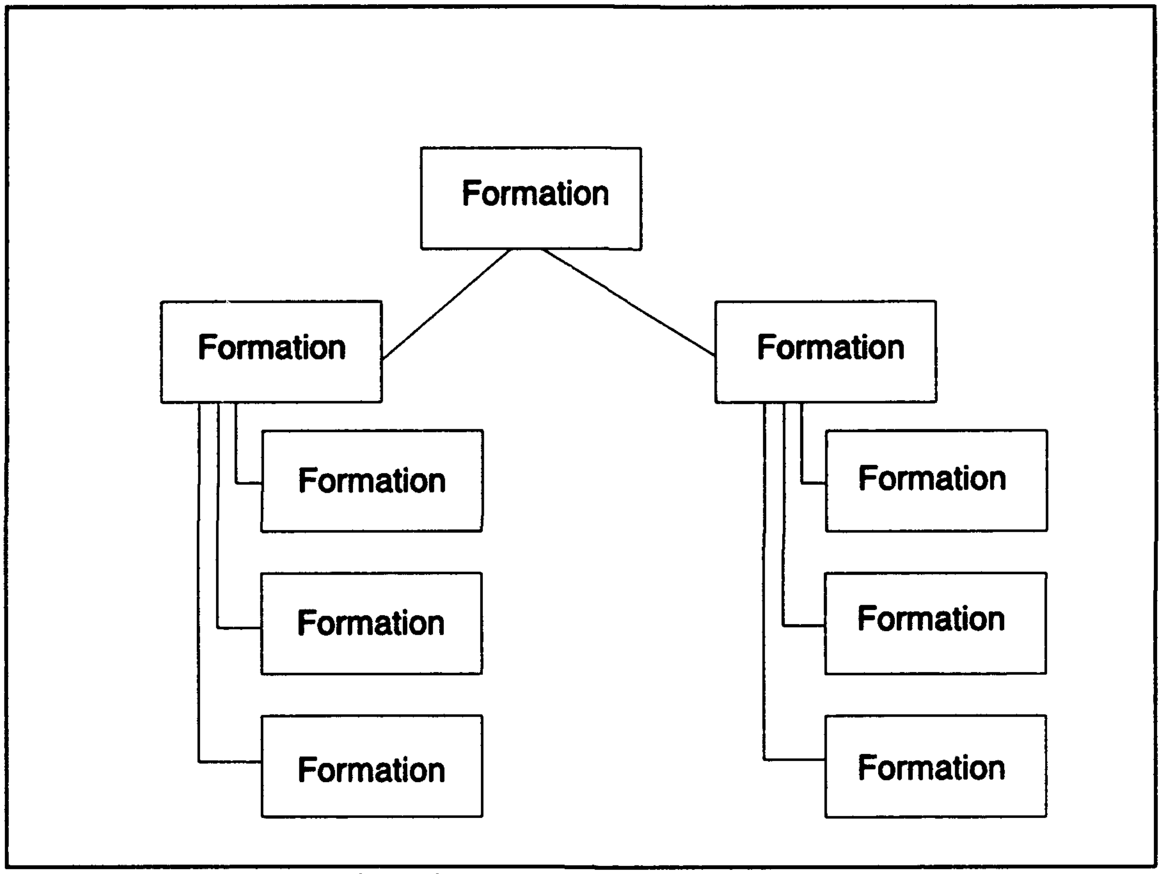

Figure 1 A communication network.

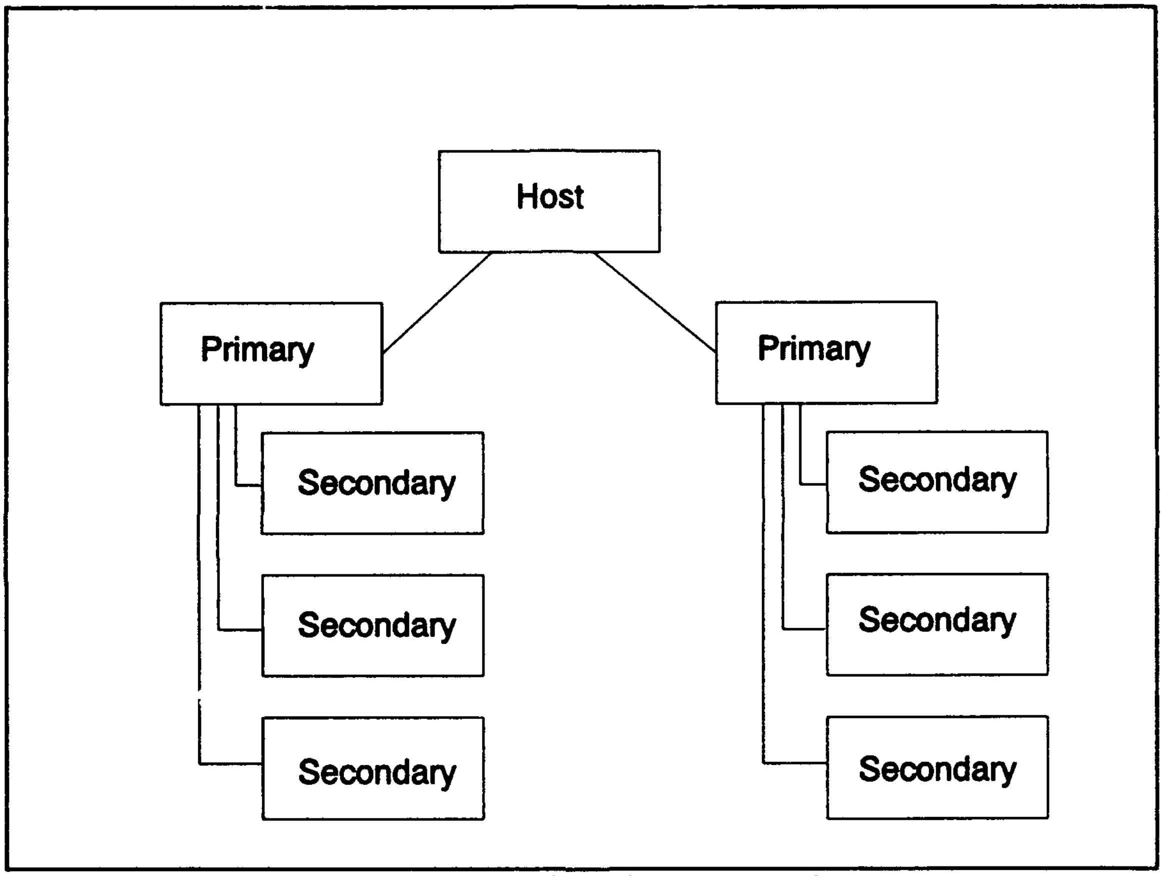

Figure 2 Levels of a communication network.

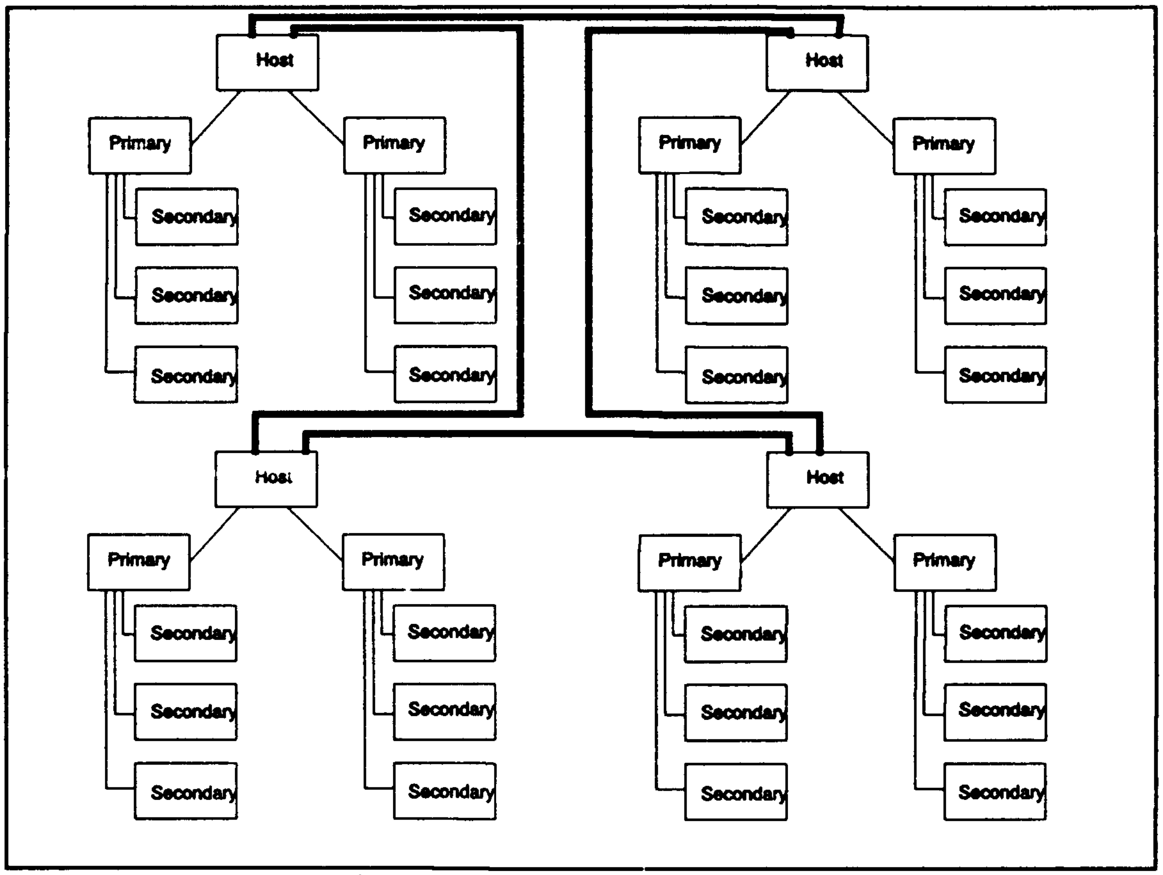

Figure 3 A communication system.

2. Connections

a. *Trunks*

The line between the formations in the Figure 4 represents the physical connection or trunks between the formations. The connection can be cable, radio link, satellite link, or other communication links utilized by NATO member nations.

b. *Switches*

The switch is the physical connection point between a formation and a trunk, see Figure 4. There is a separate switch for each trunk that connects the formation to another formation. Each switch contains a routing table that lists the formations that can be reached via that trunk. The routing table does not necessarily reflect the physical connections, but rather the formations that calls are allowed to be routed through. By controlling the routing table lists, the STANAG 4214 protocol can be implemented as written as well as with the modifications that will be discussed in later sections.

c. *Gateways*

If a trunk connects formations from different countries, the switches on each end will contain a gateway, see Figure 4. The gateway converts outgoing calls from the formation's national format to standard NATO format, and from

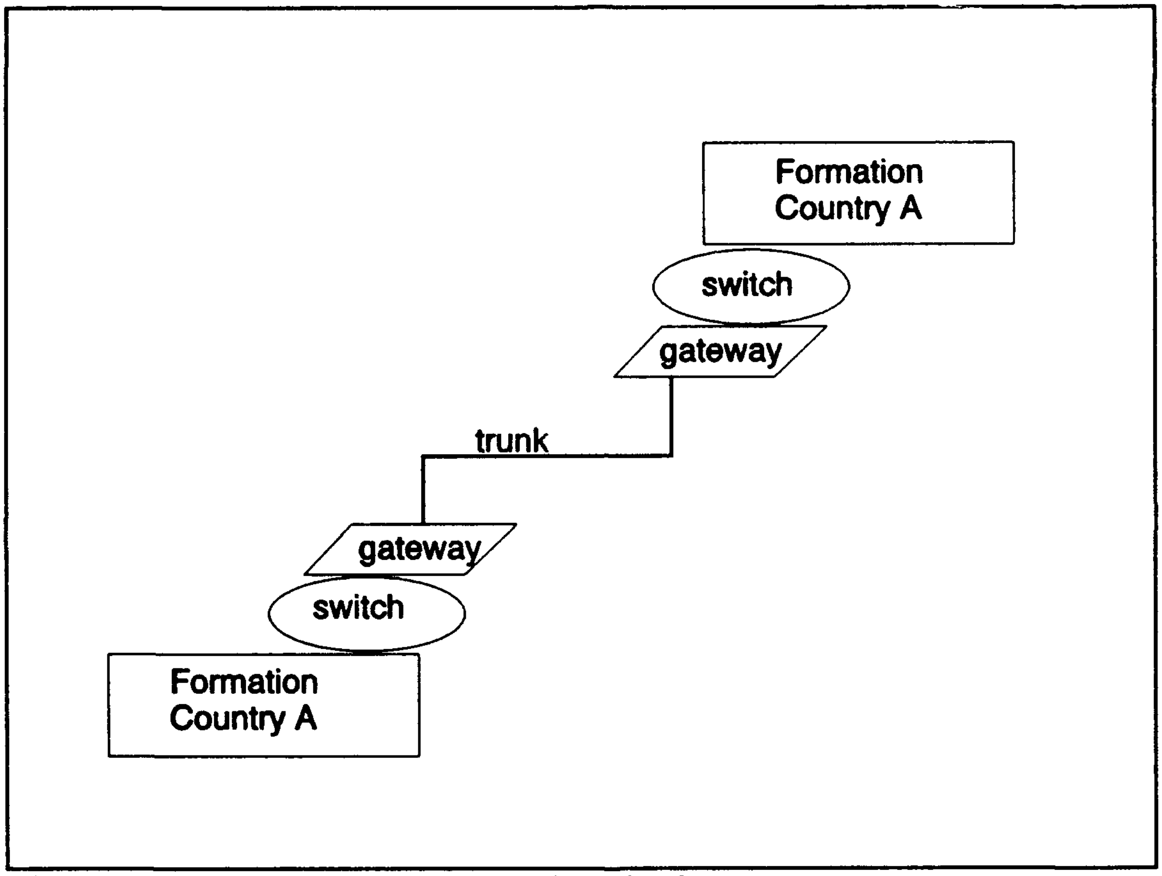

Figure 4 Trunk, Gateway, and Switch.

NATO format to the appropriate national format for incoming calls, see Figure 4.

3. The Routing Prefix

Calls are routed based on a thirteen digit number in NATO tactical systems as opposed to the ten digit system used in the United States' commercial telephones. The number consists of a six digit routing prefix and seven digit local routing number. STANAG 4214 addresses the six digit routing prefix only. The routing prefix is assigned to each formation. It consists of two parts, see Figure 5:

1. The first three digits are the National Indicator (NI), a three-digit code that indicates the country the formation belongs to. The STANAG 4214 delineates a NI for each nation, one for the NATO Tactical Communication System and two spares;

2. The remaining three digits are the Area Code (AC), a three-digit code determined from the communications system topology, the equipment available at the formation, the formation's parent and its Host.

The routing prefix is often called a NIAC, see Appendix A for the complete listing form the STANAG of the ACs and NIs (STANAG 4214,p.B-1-2,1985). Calls are routed between networks using only the AC. Within a particular network routing of calls is based on the entire NIAC to allow decentralized numbering within national systems. The seven digit local routing number is only used within the destination

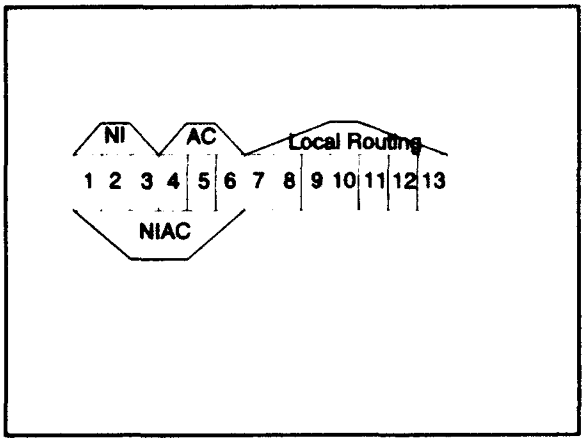

Figure 5 Routing number.

formation, to route a call to the particular subscriber being called.

4. Calls

A transmission generated from one formation to another is referred to as a call. A call can be a normal phone call, a modem call from one computer to another, or various other types of communications that can be completed over telephone systems. All formations under command (all except Host formations) must route their outgoing calls via the formation they are under command of (their parent), unless the destination unit is a formation under their command (one of their children). A call made within a network is routed upward until it reaches a formation that is the parent or grandparent of the destination formation. It then is routed downward to the destination formation which receives the call and routes it to the particular seven digit local routing number. A call for a formation in another network will be routed up to the Host formation and then to the Host formation of the destination formation via other Host formation(s) if necessary. It is then routed downward until it reaches the destination formation and is routed internally as previously discussed.

An example of a typical call within a network follows. A person utilizing a telephone in a Secondary formation's system calls a phone number in a Secondary formation that has a different Primary formation as it's parent, see Figure 6. The originator's formation system determines which switch to route the call through by looking at the switches' routing tables for the destination formation's NIAC. In this case there is only one route to the originator's parent. The call is then routed through that switch and the trunk connected to it. The call goes through the switch at the parent's end of the trunk and the parent formation's system routes the call through yet another switch to the Host. The Host routes the call through the switch and trunk connecting him to the parent of the destination formation, a Primary formation in this case. That Primary formation then routes the call via the switch containing the number for the destination, and the call is received by the destination formation's system. Finally, the call is routed to the phone with the appropriate seven digit local routing number.

A call to a formation in another formation is different in the following ways:

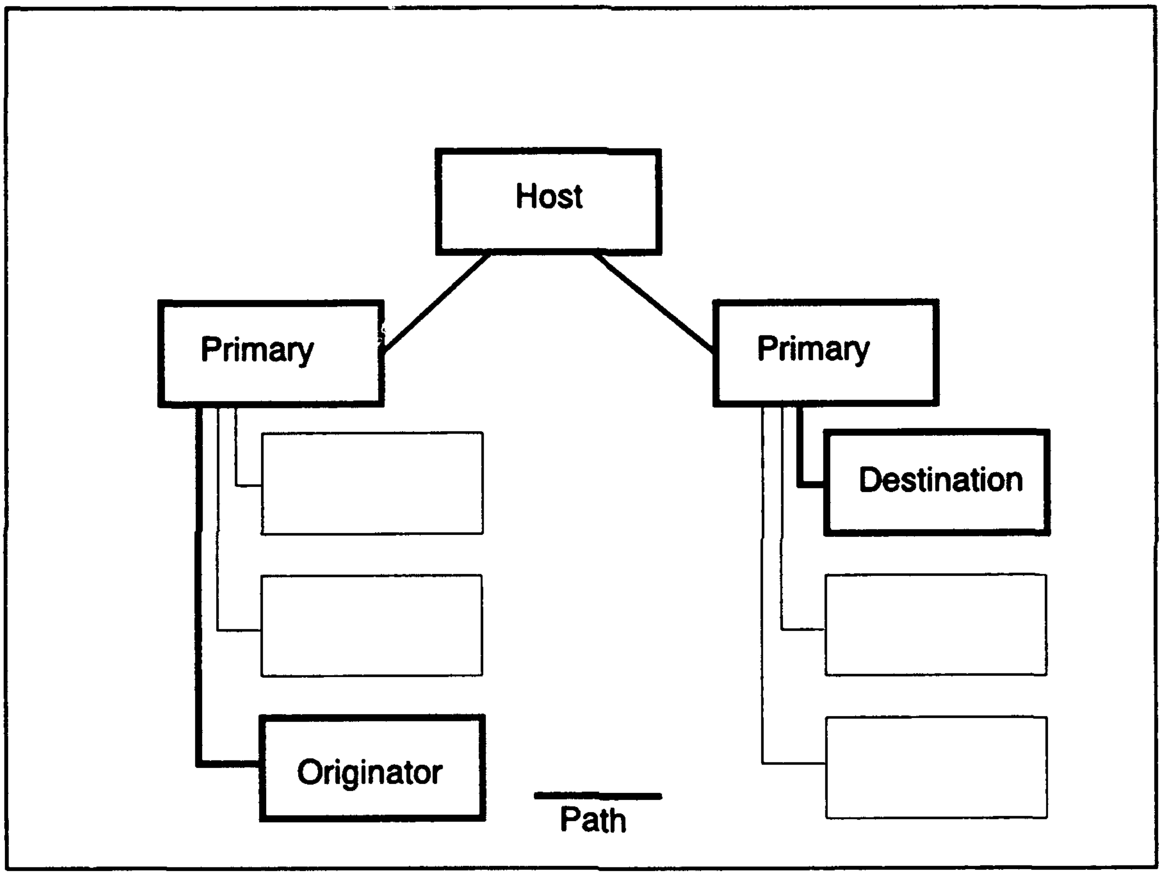

Figure 6 Call internal to network.

1. Once the call reaches the originator's Host, the Host system determines which switch's routing table contains the destination formation AC and routes it through that switch.

2. The call is routed through different Host formation's system until it reaches the Host of the Destination formation.

The call is then handled as discussed in the previous example, see Figure 7.

5. Equipment Capabilities

Two equipment capabilities that are pertinent to formation numbering are:

1. Whether the formation is multiple or single-routing capable;

2. Whether the formation is duplicate-capable or not.

These are discussed in the paragraphs that follow.

a. Multiple or Single Routing-Capable

Equipment is multiple-routing capable if it can route a call to another formation via multiple paths simultaneously. Once the call is successfully completed along any of these paths, all other attempts to route the call along alternate paths are terminated. Since every subscriber's seven digit number is unique for each country, this allows several formations under a multiple-routing formation to have the same NIAC. A call will fail only if all paths attempted are incorrect (not leading to the destination). On the other hand, equipment that is single-routing capable can only route

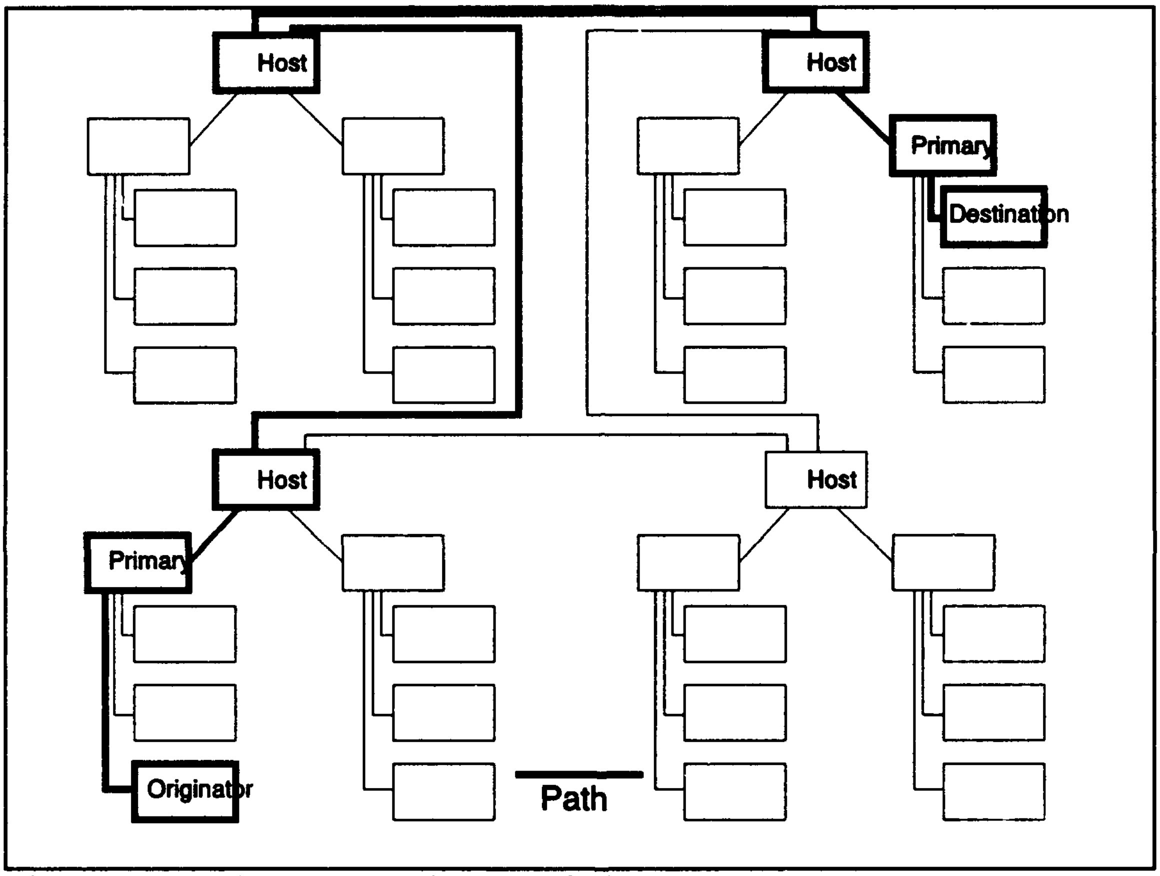

Figure 7 Call external to originator's network.

a call via one path. A call routed by it through an incorrect path will always be a failed call. Therefore, all single-routing capable Hosts or primary formations require all formations below them to have unique NIACs.

b. Duplicate Capable

Equipment that is duplicate capable is able to route a call to another formation with the same routing prefix (NIAC) as its own, while not-duplicate-capable equipment cannot. Since the NI for all formations from one country is the same, formations which are not duplicate capable require all other formations from their nation to have unique area codes (ACs).

B. AIM OF STANAG 4214

The stated aim of the STANAG 4214 is:

> To specify the routing prefixes and their application in order to route calls from one tactical communications network to another one, from one network to the communications network or facilities of a unit under command or vice versa, and even from one communications network via that of a unit under command to the communications network or facilities of a unit under command of a unit under command (STANAG 4214, 1985).

STANAG 4214 also sets forth protocol for strategic network interface numbering, which is not addressed by this study.

1. Requirements for Area Codes

As stated, the main aim of STANAG 4214 is to address how to allocate ACs to formations. There are 100 total ACs to be allocated among the NATO tactical communication systems.

Area Codes are assigned to networks in such a manner that all ACs within any individual network are different from all ACs in all other networks within the communication system. This allows the routing of calls to be based primarily on the AC only. Each network has a set of unique ACs to assign to the formations within it. Therefore, each network will be able to determine which calls are for it's formations based only on the AC.

2. Determination of Area Codes

The determination of ACs is trivial if all formations are multiple routing and duplicate capable. In this case, a single unique area code for each network is all that is required. However, not all nations' communications equipment have these capabilities. Because of this, the STANAG 4214 rules must address all possible combinations of equipment capabilities. With this in mind, the authors of STANAG 4214 worked towards the following goals(STANAG 4214, 1985):

1. Simplify and reduce the amount of information, in particular ACs, held at the switches, and to enable routing on ACs alone between networks;

2. Reduce the amount of information passed across networks when formation information changes;

3. Make ACs as deducible as possible, enabling someone to determine the AC of a formation based on minimal information of the formation's actual position in the communication system;

4. Standardize the information passed across international gateways.

C. STANAG 4214 PROTOCOL INTERPRETATIONS

All ACs for a network are assigned from the Host nation's list of allocated Area Codes, TACFONE-NATO ignores the problem of exceeding the ACs of any particular nation as suggested by JIEO. The number of ACs assigned to a network is based on the communications equipment capabilities of the Host and other formations in the network. If a formation is from the same nation as it's parent, it will receive the AC of its parent regardless of communications capabilities. If a formation's equipment is not duplicate capable, each formation from that nation within the network must receive a unique AC (unless there are parent/child relationships as just discussed). The additional rules which follow apply only to duplicate capable formations with a different nationality than their parent and/or their Hosts.

1. Host Formations

All Host formations are assigned a Master Area Code that corresponds to nine minus the formation's corps number followed by the last two digits of the formation's NI. For example, the United States Fourth Corps would be assigned an AC of 514 - five (nine minus four) followed by 14 (the last two digits of the United States NI of 914).

2. Single-Routing Capable Hosts

Host formations that are single-routing capable require unique routing prefixes (NIACs) for all Primary and

Secondary formations that may foreseeablely be assigned to them. Thus, if there are several formations from the same country within the network, they must all receive distinct ACs. Therefore, the required number of subsidiary ACs (area codes available to formations assigned to a Host in addition to the Master Area Code) is the maximum number of formations from any one foreign nation assigned to the network minus one. The example shown in Figure 8 would require the Host's master AC and three subsidiary ACs for a total of four because the NIACs will uniquely identify all formations within the network.

3. Multiple Routing Capable Hosts

Multiple routing capable Hosts only require subsidiary ACs if there are Primary formations within the network that are single-routing capable or if there is more than one formation from a nation whose equipment is not duplicate-capable. The example shown in Figure 9 would require the Host's master AC and two subsidiary ACs for a total of three.

4. Primary Formations Under Multiple Router Hosts

Primary formations under multiple-router Hosts are assigned the Host's master area code. The only exception to this rule is when there are Primary formations whose communications equipment is not duplicate-capable. In this case, the first formation from a nation is assigned the Host's master AC and any additional formations from that nation are

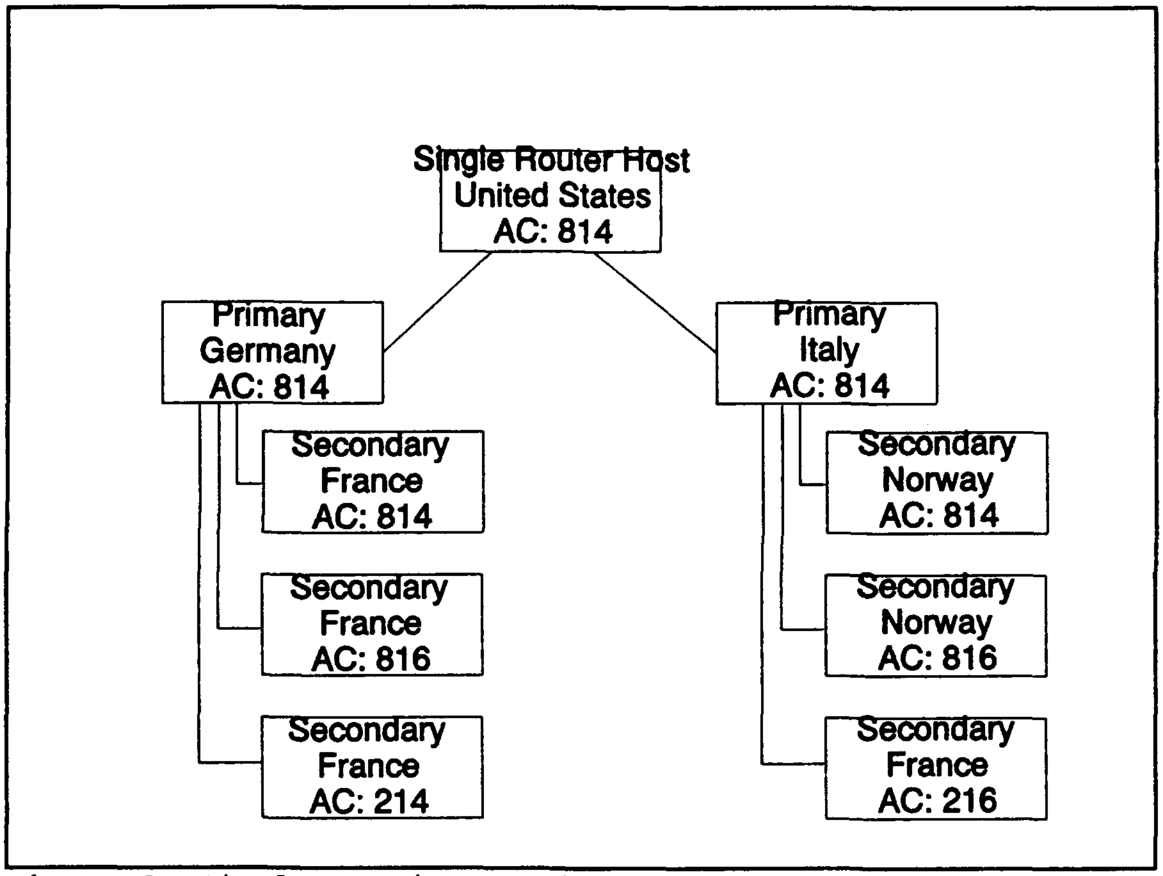

Figure 8 Single-routing capable Host.

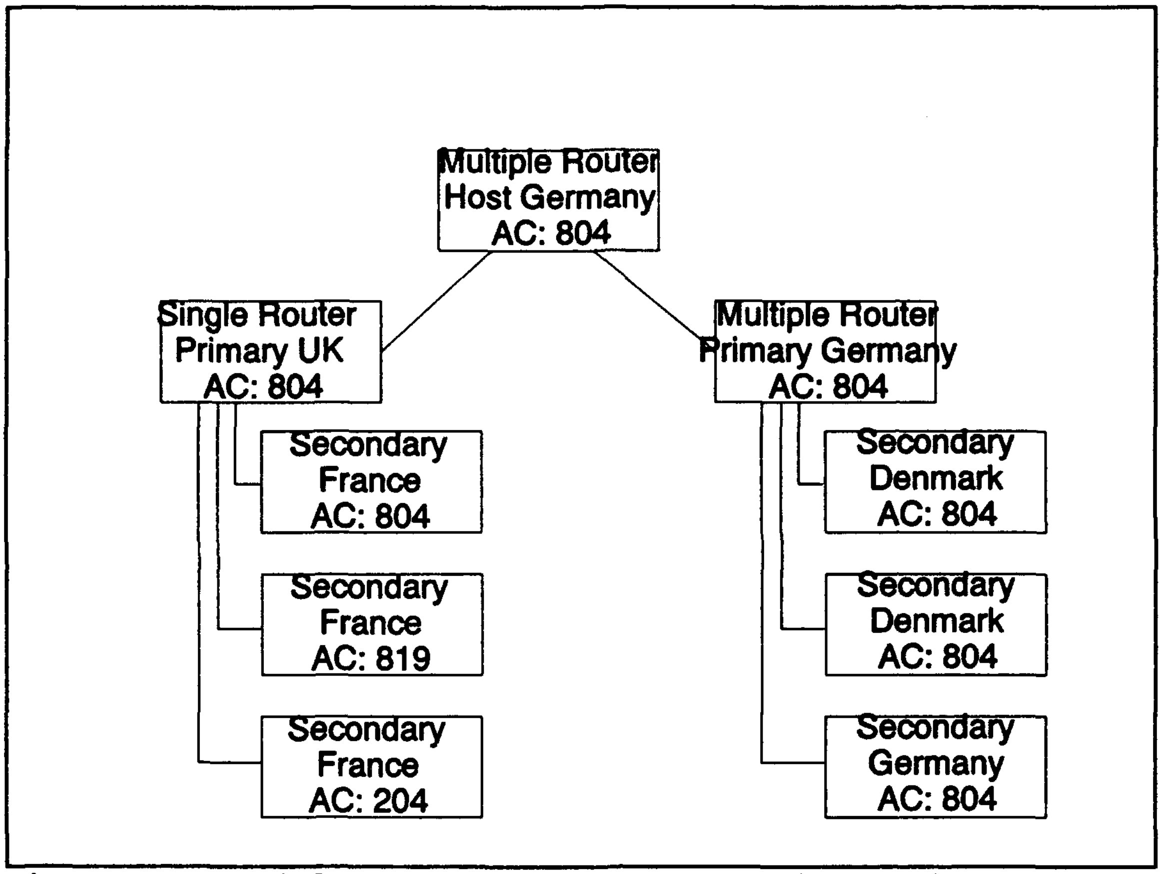

Figure 9 Multiple-routing capable Host with a single-router Primary.

assigned distinct ACs. The example in Figure 10 shows a network with a multiple-router Host with all duplicate-capable Primaries, therefore, requiring only the master AC. The example in Figure 11 shows a network with a multiple-router Host with two Primaries that are not duplicate-capable and from the same country, therefore, requiring the Host's master AC and one subsidiary AC.

5. Primary Formations Under Single Router Hosts

The first Primary formation from each nation under a single-router Host is assigned the Host formation's master AC. Additional formations from the same nation will be assigned unique subsidiary ACs from the list allocated to the Host nation, see Figure 8 for an example.

6. Secondary Formations

Area codes for Secondary formations are dependent on the communications equipment characteristics of the Host formation, its Primary (topologically parent) formation and the formation itself.

a. *Host Formation and Primary Formation are Both Multiple Routing Capable*

A Secondary formation with its Host formation and Primary formation both multiple-routing capable is assigned the AC of its Primary formation, see Figure 12 for an example.

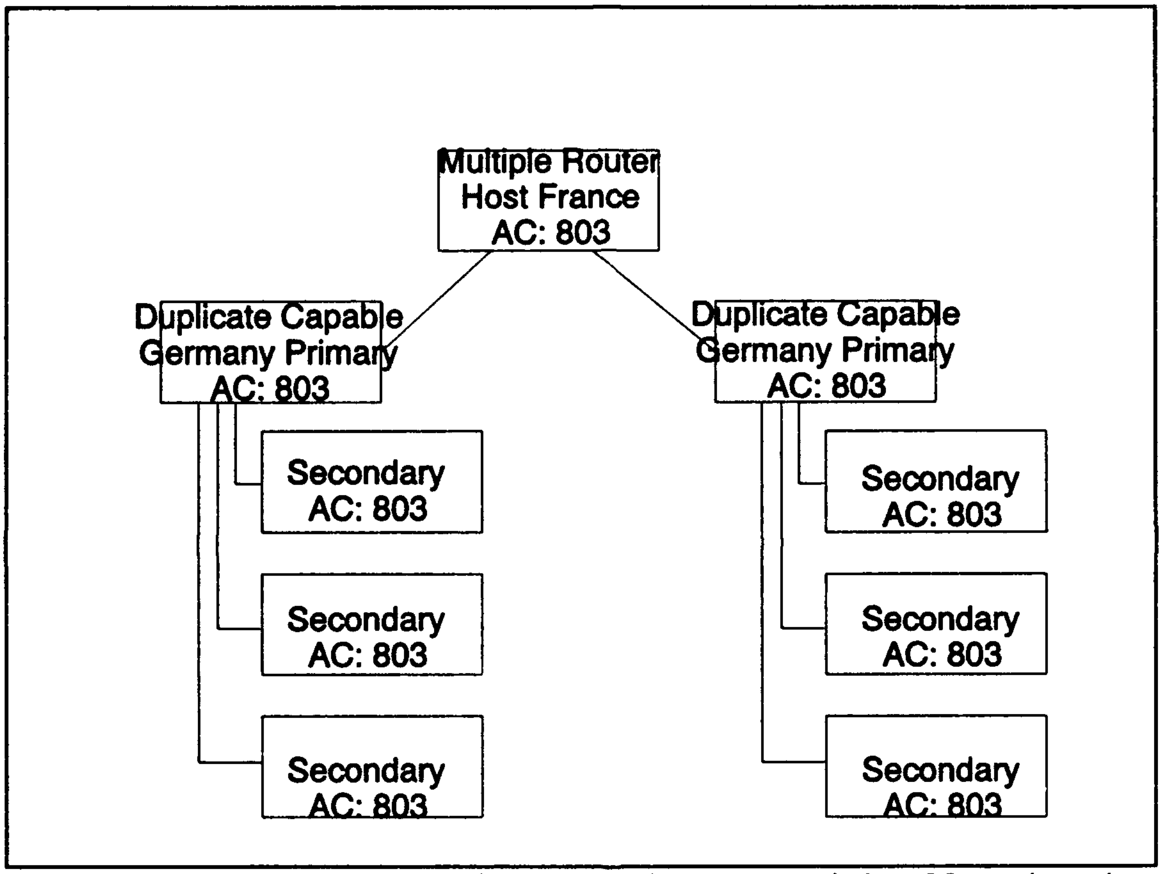

Figure 10 Multiple-routing capable Host with all Primaries duplicate-capable.

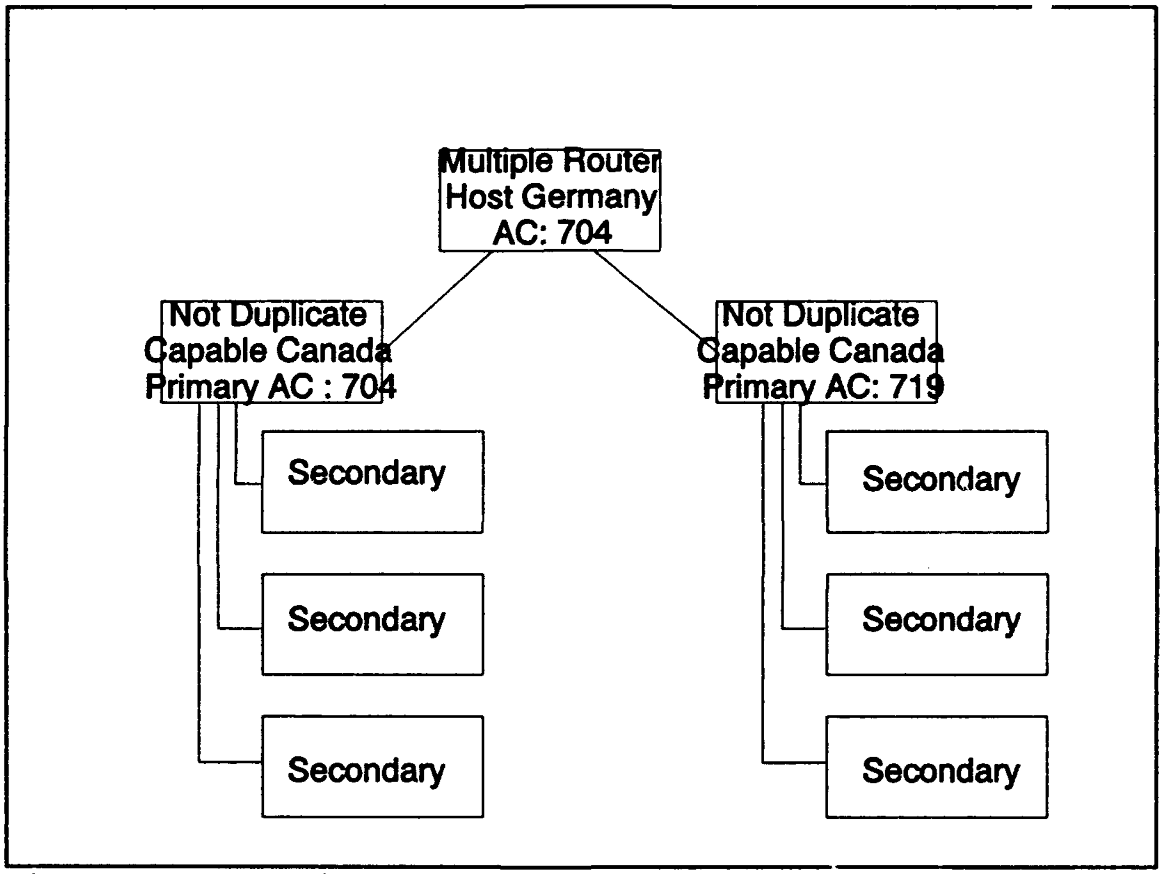

Figure 11 Multiple-routing Host with two not duplicate-capable Primaries.

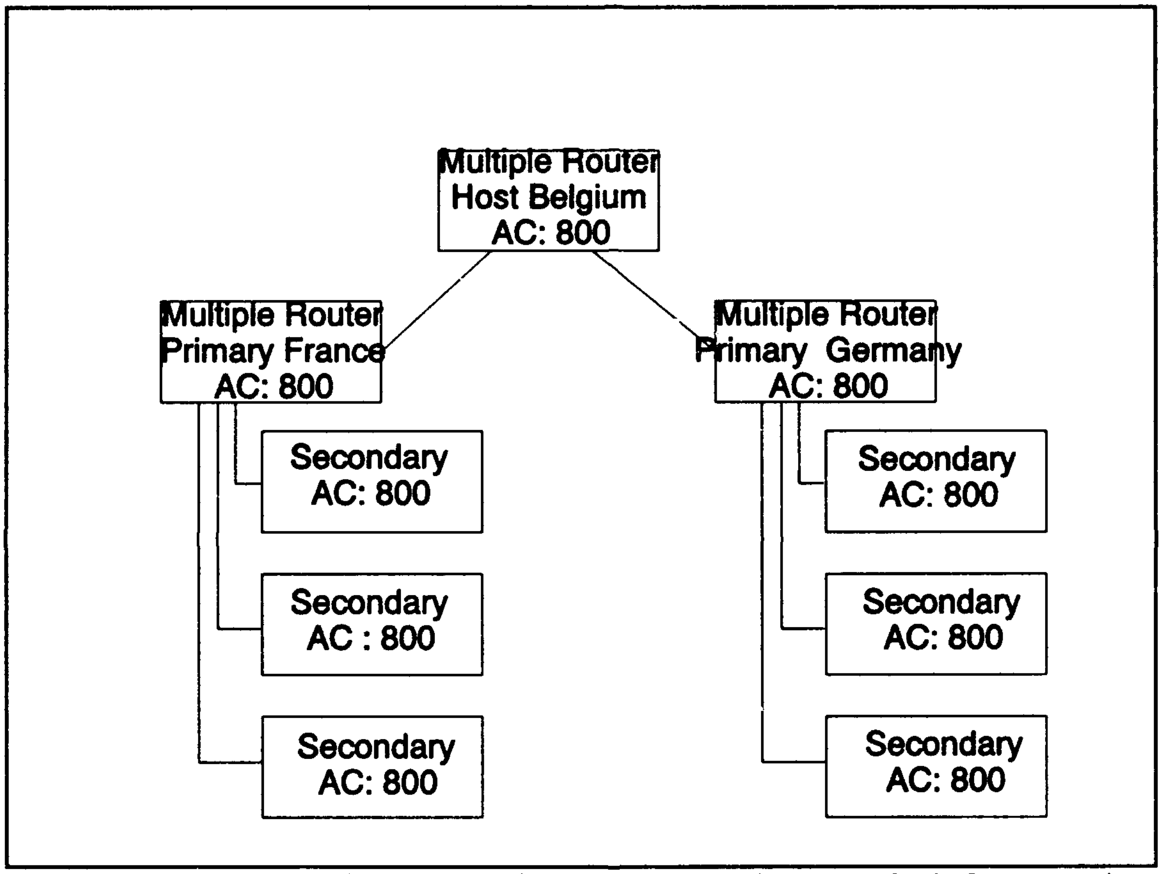

Figure 12 Multiple-routing Host with multiple-routing Primaries

b. *Host Formation and/or Primary Formation are Single Routing Capable*

A Secondary formation whose Host is multiple-routing capable but whose Primary is only single-routing capable must receive an area code which is unique from all other formations of the same nation under that particular Primary. As previously stated, a Secondary formation whose Host formation is only single-routing capable is assigned a unique AC from all other formations from the same nation in the Host's network, see Figure 8.

7. Other Rules

In addition to the above listed rules, STANAG 4214 also directs that each Host formation be assigned three subsidiary ACs regardless of the formations used to make up the network. This added rule is not reflected by the TACFONE-NATO model because the numbering method created for TACFONE-NATO determines the exact number of subsidiary ACs needed for each network. Also, the STANAG protocol allows an option whereby a single-router Host with a multiple-router Primary may assign all Secondary formations of that Primary the same AC if there is no possibility of them moving up to the Primary level. In authors' view, due to the dynamic force structures involved the requirement for this option cannot necessarily be guaranteed, so this option was not considered or utilized in this study.

D. SUMMARY

The terminology introduced in this chapter will allow for more concise discussion in this and following chapters. The protocol interpretation presented in this chapter gives a plain language version of the complicated set of rules laid out in the STANAG 4214. As can be seen from the discussion of the protocol, there are numerous situations that can arise in the configuration of communication systems and therefore an extensive set of rules is required to cover all contingencies. The complexity of the rules makes the task of modeling the protocol much more difficult, as will be discussed in the following chapter.

III. MODELING THE NATO COMMUNICATION SYSTEM

The problem of modeling the NATO communication system and the process generating and routing all possible calls is very large and complex. Because the system is composed of independent pieces of equipment whose functions can be emulated, it lends itself to being modeled and analyzed utilizing an object-oriented simulation language. Accordingly, the TACFONE-NATO model was written in object-oriented modeling and simulation language MODSIM (MODSIM 93). TACFONE-NATO simulates a communication system's crucial elements in order to allow the implementation of the STANAG 4214 protocols. The entire model was designed to represent the physical equipment and the actual process of sending and receiving calls, but only at the level of fidelity for each element that was required for this study. Therefore, some elements that are modeled may not exactly reflect the actual equipment or process simulated, but for the purposes of the study reflect accurately the portion that affects numbering formations and routing calls. The model is completely supported with graphics, which promotes ease of use and simplifies the analysis of results.

A. Basic Model Objects

A description of the basic building blocks of TACFONE-NATO follows. They simulate the crucial elements of a communication system that are required to evaluate the STANAG 4214 protocol.

1. Communication System

A communication system consists of a set of networks, inter-connected only through their Host formations. These interconnections create at least a minimally connected graph of all networks (Figure 13) and may create up to a fully connected graph (Figure 14).

2. Networks

A network is a hierarchically constructed tree of formations with a maximum of three levels, this is the maximum number of levels the STANAG 4214 protocol addresses. The only connections allowed between formations in a network are the ones that follow this tree structure. Therefore, the Secondary formations only have one connection, with their parent (Primary) formation. The Primary formations have one connection with each of their children (Secondaries) and one connection with their Host formation. Each Host formation has one connection with each of his child Primary formations and connections to other Host formations, depending on the topology of the communication system.

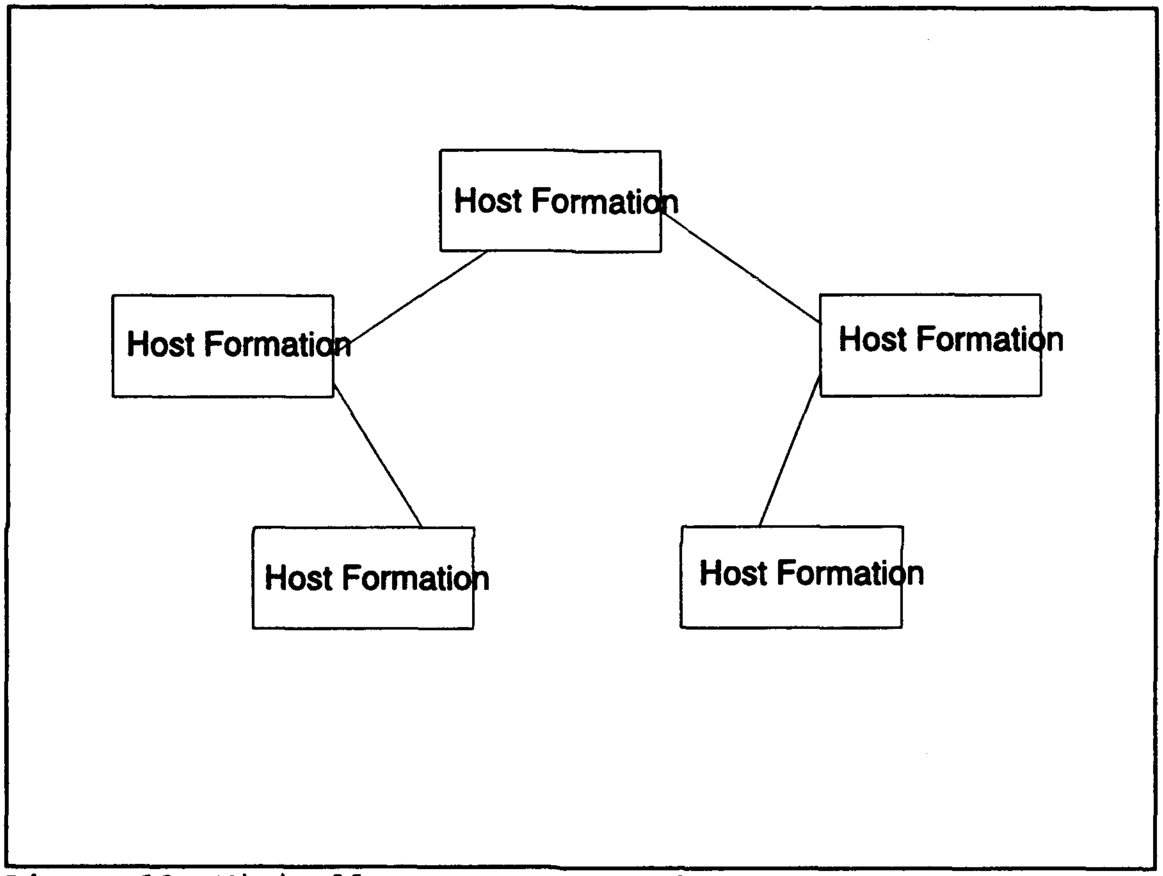

Figure 13 Minimally connected graph.

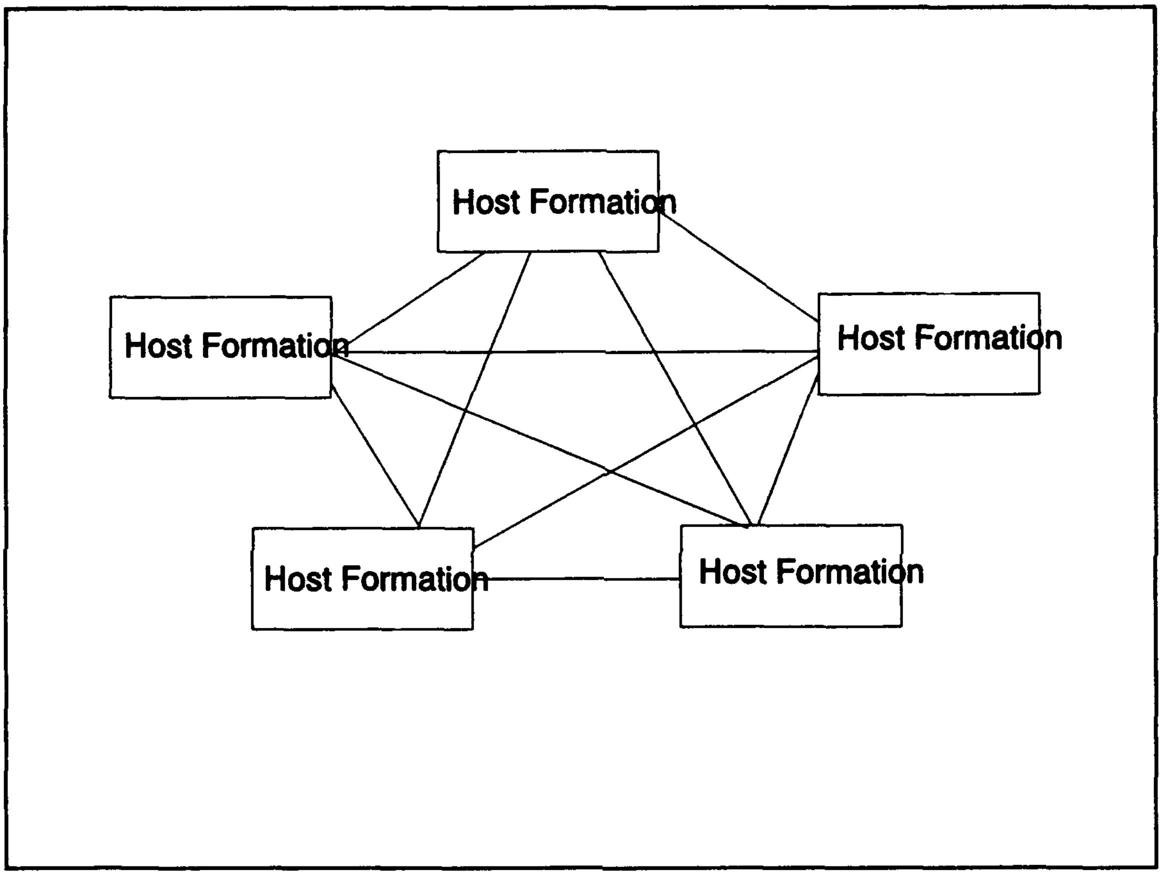

Figure 14 Fully connected graph.

3. Formations

The formations represent the communication systems of different sized military units. Generally, Host level formations represent Corps-sized units, Primary level formations equate to division-sized units and Secondary level formations represent brigade-sized units. The STANAG 4214 protocol does not address units of any smaller size, therefore, TACFONE-NATO does not represent any other unit types.

4. Switches, Trunks and Gateways

The function of gateways are not crucial to the routing protocol addressed by STANAG 4214 and therefore are not modeled. The switches and trunks are modeled to reflect previously discussed definitions. The switches are the connection between the formation and the trunk and contain the routing information for that path from/to the formation. The trunk connects two formations and routes calls between them.

B. NUMBERING THE COMMUNICATIONS SYSTEM

The model numbers the Communication System according to the rules of STANAG 4214 previously discussed. Each formation numbers itself, by determining its own, its parent's and its Host's communication equipment capabilities and applying the applicable STANAG 4214 rule(s) for its numbering.

C. GENERATION OF COMMUNICATION SYSTEMS

TACFONE-NATO will either read in a user-defined force structure or randomly generate a force structure. If the force is user-defined, TACFONE-NATO can automatically number the communication system or the NIACs can be defined by the user and analyzed using TACFONE-NATO. This gives the user the flexibility of analyzing a proposed numbering scheme that does not follow the STANAG rules. The connections between networks at the Host level are either randomly generated by TACFONE-NATO or defined by the user. When the communication system is generated randomly, the number of networks, formations and connections between networks are all randomly determined from preset bounds. The identity of the formations, including nationality, are also randomly determined from the existing units that are available to NATO.

The units available from NATO are determined from the table in the STANAG 4214 (STANAG 4214, p. B-1-2, 1985), see Appendix A. The model starts with this force allocation as it randomly generates a force structure and will not exceed the number of Host formations, three Primary units for each Host, and three Secondaries for each Primary listed in the table. Once the force has been generated and connected, the formations are numbered using the method previously discussed.

D. BUILDING ROUTING TABLES

Once the communication system is generated and has been numbered, the routing tables are initialized for each trunk of each formation. Each network first updates its routing tables internally, then the switches connecting the networks initialize their routing tables. The basic model allows all paths that exist from one network to another to be reflected in the routing tables. STANAG 4214 does not directly address what paths should exist from one network to another, only that it is done in a way "to prevent looping" (STANAG 4214, p. c-2, 1985). The basic model operates this way to provide the ability to measure the effectiveness of anti-looping rules, some of which will be discussed below.

E. GENERATING AND ROUTING CALLS

Calls are generated from every formation to every other formation. The formation routes a call based on the physical limitations of the communications equipment of its nation, as well as the contents of its switches' routing tables. Between networks, calls are only routed via one path (single-routed). The call tracks all formations that it is routed through to reach its destination. There are several circumstances where a call fails to reach its destination, each creating a unique diagnostic problem. These circumstances will be discussed later.

F. GRAPHICS

The TACFONE-NATO model utilizes the SIMGRAPHICS (MODSIM 93) portion of MODSIM to display all input and output graphically. The model is controlled through mouse-driven graphical user interfaces making it quite user-friendly, compared to all input being entered through the keyboard. The Communication System is displayed graphically using a separate window for each network. Each formation is displayed as a rectangle enclosing its nationality, unit size (corps, division, or brigade), unit number, and NIAC. Trunks are represented as lines between formations,see Figure 15 for an example of a network representation. The set of Host formations are also displayed in a separate window, with inter-host connections displayed as lines, see Figure 16. As each call is routed, the originator formation, the destination formation, and all trunks in the path are colored to allow the user to visually watch the calls progress. The display is frozen when a call fails, which aids in trouble shooting protocol problems.

G. SUMMARY

TACFONE-NATO as presented in this chapter is an object-oriented computer model which simulates the STANAG 4214 protocol, calls, and all equipment required to effectively evaluate the protocol. The model is GUI driven and user-friendly. Complete instructions and more extensive

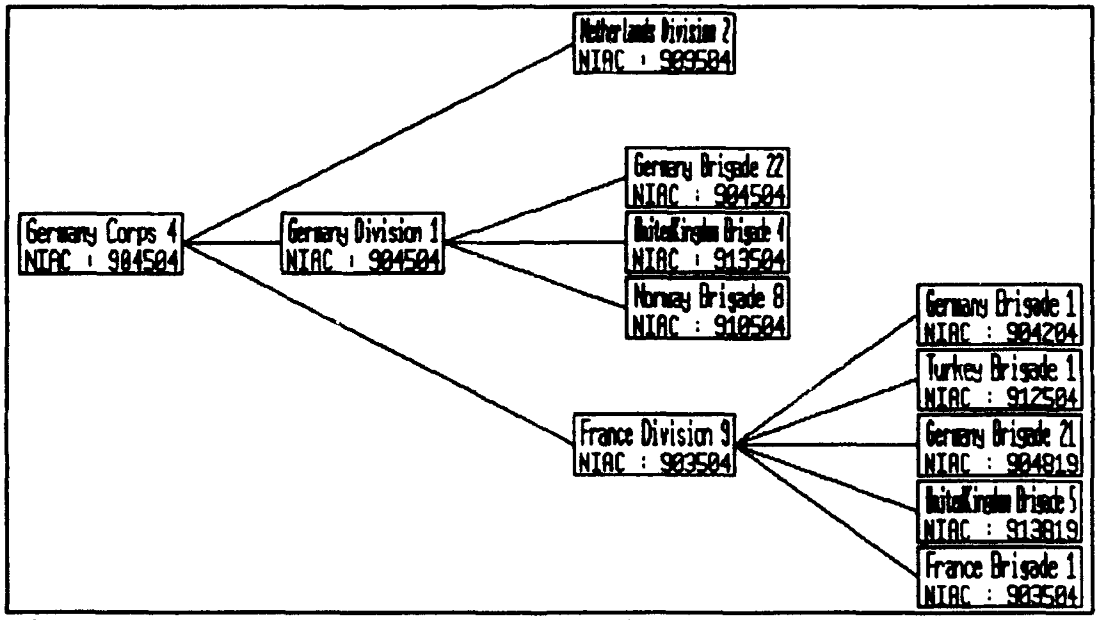

Figure 15 A network representation.

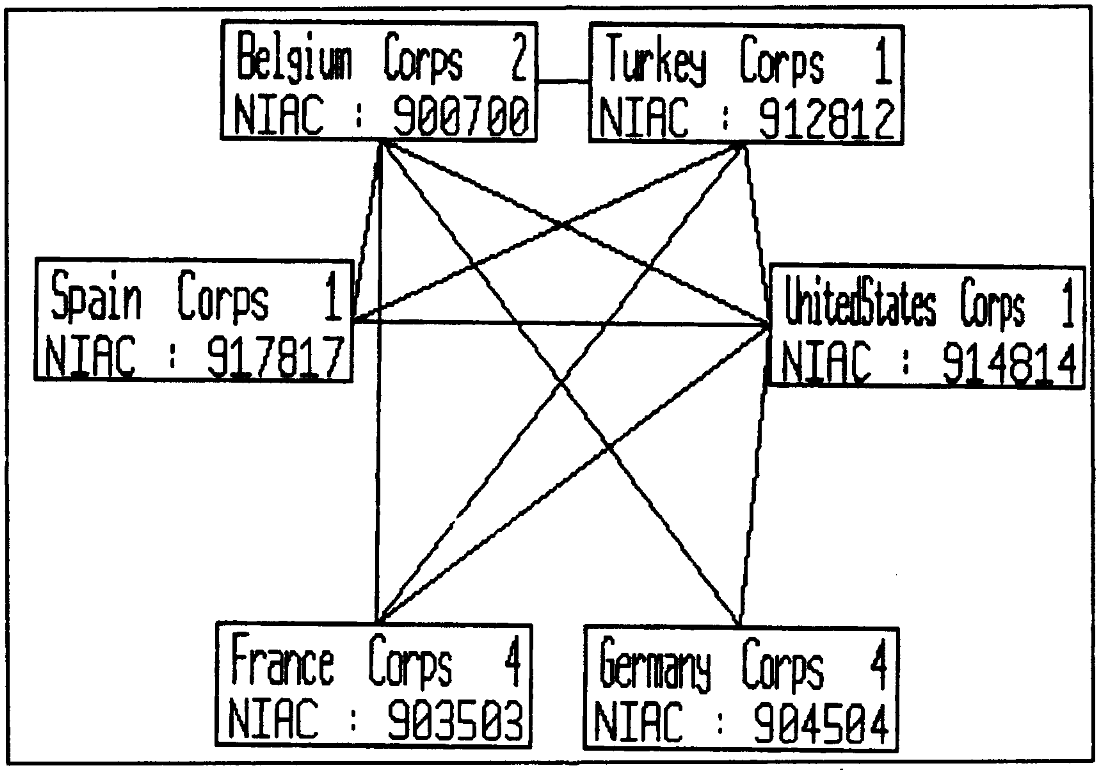

Figure 16 Communication system representation.

explanations of the use of the model is given in the user's manual in Appendix B.

IV. CAPABILITIES ADDED TO THE BASIC MODEL

JIEO was very interested in the development of *anti-looping rules* and in exploring the effects of allowing *lateral connections*. In this chapter these critical issues will be defined and some proposed techniques for dealing them will be discussed.

A. Anti-Looping

STANAG 4214 explicitly states that routing tables between the Host formations must "not allow loops to exist" (STANAG 4214, p. C-2, 1985). A loop occurs when a call arrives at a formation which has already handled it. Figure 17 depicts routing tables which provide the possibility of a loop. Here, Host five initiates a call to Host one, selecting to route the call through Host three, who in turn routes it through Host two. At this point, Host two's routing tables allow him to either route the call to Host one or through Host five. If the route through Host five is selected, a loop occurs since Host five has already handled the call. The bold path in Figure 17 illustrates this occurrence. While the STANAG states not to allow loops, it does not provide any methods of doing so. Here, rules are developed for building routing

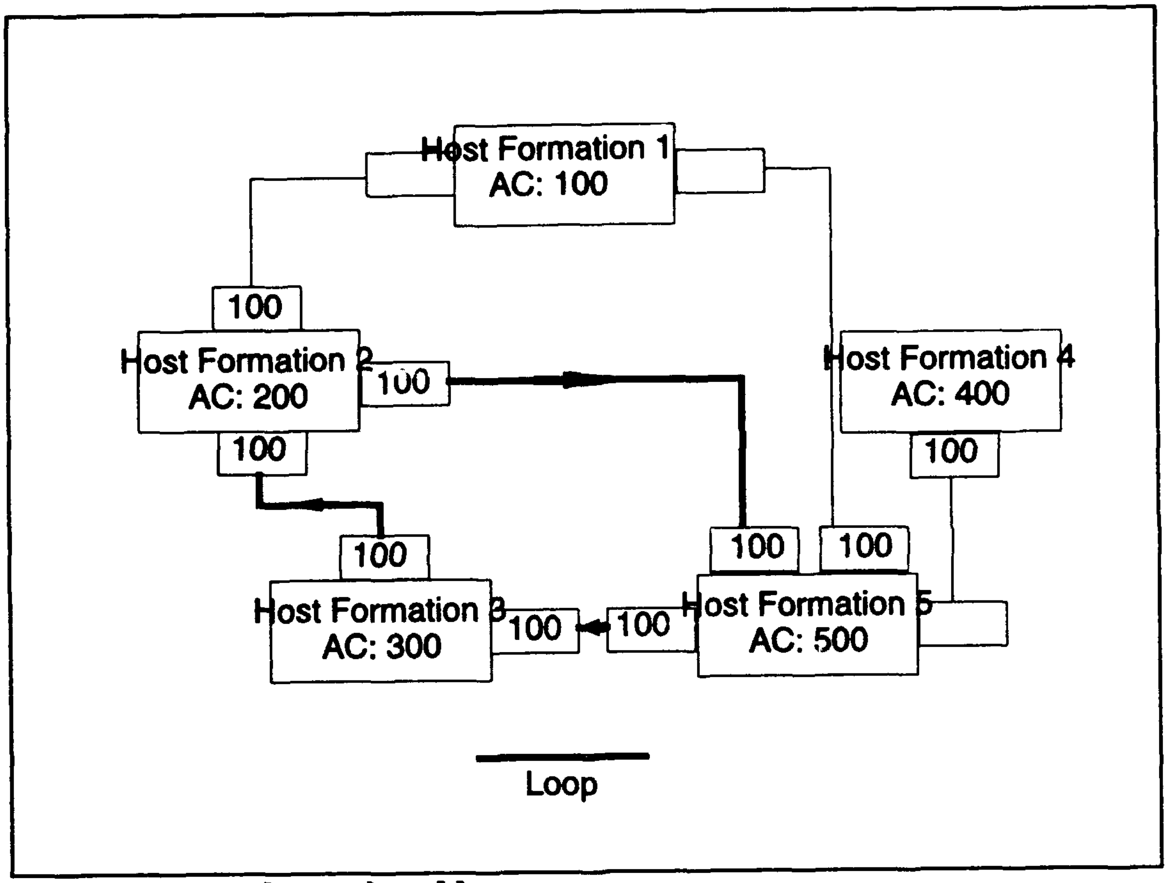

Figure 17 A looped call.

tables between Host formations which ensure that looped calls are not possible.

1. Objectives of the Rules

A simple solution to the problem would be to build the routing tables such that there was only one path from each Host to all others. While this would certainly avoid looping, it is not particularly desirable because it removes all possible redundancy which the physical system may be able to support. Of course, the more redundancy allowed, the greater the potential for creating the possibility of a loop. In light of this, rules were sought to build routing tables such that:

1. There exists at least one path from each Host to every other Host.

2. There is no potential for a looped call.

3. Maximum redundancy is achieved under the following constraints:

   a. Maximize the minimum number of switches through which a Host can route to any other Host. That is, for a six Host Communication System, it is preferred for a Host to be able to route to all other Hosts through two switches rather than to be able to route to three Hosts through five switches, but to the other two through only one. The goal is to "spread the wealth" for redundancy.

   b. Shorter paths are sought for redundancy before longer ones. That is, it is more desirable to have a three step path than a four step path between two Hosts.

2. Proposed Solution Techniques

a. *Complete Enumeration*

Since the number of Hosts being dealt with was fairly small (a maximum of six), an attempt was made to fully enumerate the various combinations of routing tables possible and compare them. To ensure this would be feasible for all Communication Systems which could be constructed with six or fewer Hosts, the worst-case scenario of having six Hosts, each connected to every other Host was considered. In this situation there are a total of 30 routing tables to fill, each of which may contain any or all of five different numbers. Assuming that each routing table will contain the Host number to which it is connected, four spaces are left in each routing table which may or may not contain a number. With a total of 30 tables, this leaves 120 unique spaces with a go/no-go decision as to whether to or not to put in a number. This results in a total of 2^{120} (equals approximately 1.33×10^{36}) possible routing table combinations. If it were possible to fully examine one trillion of these possibilities every second, it would take over four hundred trillion years to examine each possible combination of routing tables. This is obviously infeasible.

b. *Anti-Looping Heuristic*

Since it is infeasible to fully enumerate all possible routing table combinations for all Communication

Systems which could be constructed, and because the problem does not formulate neatly as an optimal-solved mathematical program, a heuristic was developed to meet the previously stated goals. The steps of the heuristic are:

1. For each Host switch which connects to another Host, enumerate all possible non-looping paths to all other Hosts based on the physical structure of the inter-host connections (an inter-host connection is a connection between two different Hosts).

2. For each inter-host switch, add the connected Host to that switch's routing table.

3. Start with any inter-host switch. From all possible two-step paths, choose the one whose destination is in the fewest routing tables of the switch's formation. If a tie exists, randomly select from those tied. If no two step path exists, move on to step (5).

4. Check to see if adding this destination to the switch's routing table will cause a loop based on the destinations currently in all the other inter-host switches' routing tables. If not, add the destination to the switch's routing table. If it does cause a loop, remove this path from all possible two step paths and repeat step (3).

5. Repeat steps 3-4 for each inter-host switch.

6. Repeat steps 3-5 until all possible two step paths have been examined to see if they cause a loop.

7. Repeat steps 3-6 for all possible three step paths, then for all possible four step paths,..., and finally for all possible (n-1) step paths; where n is the number of Hosts in the Communications System.

NOTE: When conducting step (3) for paths of three or more steps, ignore all paths whose destination is already in the switch's routing table.

Only paths of length (n-1) or shorter need be examined since any longer path would necessarily form a loop. Checking all paths up to length (n-1) ensures that in the worst case of only a (n-1) step path existing between two Hosts, they will still be able to reach each other. In fact, a more in-depth check of this algorithm shows that, assuming at least a minimum spanning tree is formed by the inter-host connections, each Host will be able to reach every other Host. This can be shown by assuming Host *j* cannot reach Host *k* with at least one non-looping path. This would imply that none of the Hosts connected to Host *j* could reach Host *k* with a non-looping path, since if one could, a non-looping path from *j* could be formed by adding the link from *j* to the Host which could reach *k*. By inductively continuing in this manner, it can be shown that if Host *j* cannot reach Host *k* by a non-looping path, then no Host in the Communication System can. But this is not possible since *k* is connected to a least one other Host in the Communication System. Therefore, it is not possible for Host *j* not to be able to reach Host *k* with at least one non-looping path. Since this applies to any two Hosts, each Host will be able to reach every other Host.

It is also clear that this heuristic ensures that no loops will exist since this is checked prior to adding any number to a routing table. Furthermore, the selection process in step (3) of the heuristic is conducive to maximizing the minimum number of switches through which a Host can route to any other Host. The iterative process of checking for the smallest-step paths first also contributes to including shorter paths before longer ones. Thus, the heuristic promotes all of the stated goals.

B. Lateral Connections

The STANAG 4214 protocol does not allow for connections between units other than parents and children and between Hosts. Any connection established between units other than between Hosts or between a parent and child is defined as a *lateral connection*. The reason STANAG 4214 does not allow lateral connections is the increased risk of looped calls. However, units not connected under current STANAG 4214 protocol may be in close physical proximity, and it may be very desirable for these units to have a communications link between them for local logistical traffic. The current STANAG 4214 protocol does not allow for such a link. Here, routing table rules are developed that allow for lateral connections to be established without resulting in possible loops.

1. Recommended Rules

Rules were desired which would cover any possible lateral connection. That is, Primary to Primary, Secondary to Secondary, Host to a non-child Primary, Host to Secondary, and Primary to a non-child Secondary. Furthermore, it was desired for the rules to work whether the lateral connection existed between formations within the same network or between formation in different networks. Additionally, it was undesirable for the rules to in any way restrict the number of lateral connections allowed as this would become very confusing.

The rules developed to meet these requirements are as follows:

1. No call shall be allowed to route downwards in a network's hierarchical structure to make use of a lateral connection.

2. No call, after using a lateral connection shall be allowed to route upwards in a network's hierarchical structure.

3. No call shall be routed through more than one lateral connection.

In TACFONE-NATO, these rules are enforced through the construction of the routing tables, as opposed to each call tracking its use of lateral connections. Because of this, if there are more than two formations from any nation in a network which are numbered the same (implies that the Host is multiple-routing and the nation is duplicate-capable), and anv two of these are laterally connected, the above rules may be violated. However, even with this feasible "breaking of the rules", there will be no looping. The only possibility of looping when routing tables are used to enforce these rules is if four or more formations from a single-routing nation are numbered the same and are laterally connected in such a manner as to allow looping via the lateral connections alone. This means that for there to be a problem with the enforcement of these rules through routing table construction, ***all*** of the following must occur:

1. Multiple-routing Host.

2. **Four or more** formations from a single-routing, duplicate-capable nation in the network **be numbered the same**.

3. The existence of enough lateral connections between these formations such that the lateral connections themselves provide the possibility of a loop.

The existence of this unique set of circumstances would is highly improbable and would rarely, if ever, be realized in an actual Communication System. Therefore, in the opinion of the authors, enforcing the previously stated rules through routing table construction is valid for all Communication Systems which may reasonably be assembled.

These rules somewhat localize the use of lateral connections, but this is not unreasonable since it is likely that the main purpose for establishing a lateral connection would be for local traffic between two formations not otherwise connected. These rules **do** prevent looping (with the exception of the improbable unique case stated above) for **any number** of **any type** of lateral connections and also provide for maximum additional redundancy without putting restrictions on the number of or types of lateral connections allowed.

C. SUMMARY

Two of the issues of greatest concern to JIEO were anti-looping rules and the effects of lateral connections. This chapter presented the methods used to develop anti-looping rules and routing table rules which allow for lateral connections. TACFONE-NATO always implements the lateral connection rules (if no lateral connections exist they have no impact) and allows for the option of implementing the anti-looping rules.

V. DEDUCING ERRORS IN THE PROTOCOL

The heart of the analysis of the STANAG 4214 protocol lies in determining the overall effectiveness of the protocol and in detecting and isolating errors in the protocol. This chapter discusses the methodology employed to accomplish these tasks.

A. ANALYSIS FOR A SINGLE COMMUNICATIONS SYSTEM

The basic procedure executed by TACFONE-NATO is as follows:

1. Construct a reasonable force composition for the operation, choosing:

    a. Country

    b. Level of unit

    c. Unit capabilities

2. Construct a reasonable NATO chain of command for this force.

3. Construct a reasonable set of physical connections between pairs of units.

4. Assign telephone numbers to each of the formations.

5. Construct the proper routing table associated with each switch in each formation.

6. Attempt a call from each formation to every other formation, recording the outcome.

This procedure will be henceforth known as a **single-system check**. Note that there is a one-time construction of the NATO force structure, and one assignment of nationality for each formation in a single-system check. TACFONE-NATO allows for a single run of the single-system check or for the single-system check to be executed over and over, using the ability to sample random variates to generate different force structures and nationalities for each check.

B. ANALYSIS OF OVERALL EFFECTIVENESS

Determining the overall effectiveness of the STANAG 4214 protocol does not require knowledge of how many potential failures may occur in the protocol under various circumstances. It does not even require knowledge of what the causes of any failure are. This is because the number and type of feasible failures does not take into account the likelihood that situations which cause these failures would actually exist in a communication system. Furthermore, just because a path exists in the routing tables which leads to a failure does not mean that a call will always take that path. Indeed, actual calls may rarely follow paths which lead to failures. Because of this, the measure of effectiveness developed for the STANAG 4214 protocol was the mean percentage of successfully completed calls when each formation called every other formation once in a random communication system.

To determine a good estimate of the mean percentage of successfully completed calls for a random communication system using the STANAG protocol, the following procedure was used:

1. Generate a random Communications System

2. Make a good estimate** of the mean number of successful call for that communications system when each formation calls every other formation once, with each call following only one feasible path (when more than one feasible path exists randomly choose one of them).

3. Record the estimated mean number of successful calls.

4. Iterate until enough estimated means from different communication systems have been collected to build a 95% Confidence Interval for the grand mean whose bounds are within ten percent of the estimated grand mean. Ensure that a minimum of 30 Communication Systems are used for the normality assumption.

**To determine a "good estimate" for a single Communication System: make all calls and determine the percent successful; repeat until enough data points have been collected to build a 95% Confidence Interval whose bounds are within ten percent of the estimated mean percent of successful calls for that Communications System; ensuring that at least 30 samples are collected for the normality assumption.

Additionally, all of the data points used to build the above estimates were collected for comparisons of high and low percentages of calls successful. This provided some insight of the variability of the protocol's success rate on various communication systems.

C. GRAPHICAL CAUSE IDENTIFICATION

To completely validate the protocol, all causes of any possible failure must be isolated. The simplest way to isolate the cause of detected failures is by using the graphical display developed for TACFONE-NATO. TACFONE-NATO's graphical display provides a usable problem diagnosis tool which allows users to employ their intuition to identify failure causes.

A method for generating failed call displays was developed to show a graphical representation of failed calls on screen. The display, which continually shows the calls being routed, freezes when an attempted call fails. The originator, path, and intended destination light up in unique colors so they can easily be identified. By analyzing the characteristics of the formations involved, it may be possible to intuitively deduce what the problem is. This tool proved to be of tremendous value for both debugging TACFONE-NATO and in helping to identify problem areas in the STANAG 4214 protocol.

D. ISOLATING CAUSES FOR FAILURES

When a large number of failures exist, it is impractical to attempt to intuitively determine all the causes of failure using the graphical display. Even when only a small number of failures occur, intuition may fail to yield a cause for failures. To assist in isolating causes for failures in these cases, a mathematical program was developed to single out the most likely set(s) of circumstances which lead to failures. The development of this program will now be discussed.

1. Possible Outcomes and Assignable Causes for Errors

Each call can experience one of three outcomes:

1. Be complete as specified.

2. Arrive at a formation which has already handled the call (loop).

3. Arrive at a formation which has no way of reaching the destination (dead-end).

Each simulated call n involved had an originating formation $f_{n,o}$, and a destination formation $f_{n,d}$. Each call could have many feasible paths based on the routing tables. Each of these feasible paths will be referred to as an *attempt* for call n. To validate the protocol and routing table entries, all feasible paths must be examined. Therefore, each call is repeated until all feasible paths have been examined. Each attempt records its journey through the network, building $\mathbf{f}_m = (f_{m,o}, f_{m,1}, \ldots, f_{m,e})$, where $f_{m,i}$ is the i^{th} formation relaying attempt m. If the attempt is completed, $f_{m,e} = f_{m,d}$.

Now record:

$$X^m = \begin{cases} 1 \text{ if attempt is successful;} \\ 2 \text{ if attempt loops;} \\ 3 \text{ if attempt dead-ends.} \end{cases}$$

The path $\mathbf{f}_m$ and the value of X indicate where the trouble-causing switches are (i.e., routing tables at these switches may be causing looping or dead-ends). Table 1 shows some prime suspects for different completion outcomes.

TABLE 1 LIKELY CAUSES FOR FAILED CALLS

X^m	Prime Suspects
1	none
2	loop includes $(f_i, f_{i+1}, \ldots, f_k = f_i)$, at least one outgoing switch should omit at least one entry
3	f_{i-2} switch overstates formations reachable f_{i-1} switch overstates formations reachable f_i has at least one switch which has an omission
2 or 3	f_d numbered incorrectly

The prime suspects for each type of failure can now be examined to attempt to determine which formation characteristics, as defined in the next section, the STANAG 4214 protocol has trouble in handling.

2. ANALYZING ERROR DATA

The objective of this part of the analysis is to determine the causes of incomplete calls (attempts). Incomplete calls arise because of one or more mistakes in the formation of the routing tables in the switches, or in ambiguous or incorrect formation area code assignments. Each formation has key characteristics which determine the method used to assign its area code (number the formation) and the manner in which it forms its routing tables.

The key characteristics of any formation are:

1. ROLE: Host(H), Primary(P), or Secondary(S);

2. NATV: true(T) if native to (same nationality as) parent, false(F) if not;

3. DUP: true(T) if duplicate-capable, false(F) if not;

4. HRT: single-routing(S) if Host is single-routing, multiple-routing(M) if Host is multiple-routing;

5. PRT : single-routing(S) if Parent is single-routing, multiple-routing(M) if Parent is multiple- routing.

Each failed call is caused by some shortcoming of the numbering rules or routing tables which arise from some combination of these characteristics. For example, it is possible, albeit improbable, that something is wrong with the rule for numbering any Secondary formation. It is also possible that secondary formations which have nationalities which are different from their parent, and whose parent is multiple-routing, are not all numbered correctly. The objective of the analysis is to distinguish the precise combination of characteristics under which calls are not reliably routed to a formation.

3. ALGORITHMIC CAUSE IDENTIFICATION

It is reasonable to assume that the "most common" kev characteristics for likely suspect formations of failed attempts are the most probable to be those which the STANAG 4214 protocol has difficulty handling. This makes it desirable to determine which are the "most common" characteristics for likely suspects of failed attempts. Visual inspection of output files would be one way to do this, but for a large number of failed attempts, this would be very tedious and time consuming. Therefore, a mathematical program was developed to aid in finding the "most common" key characteristics of a set of likely suspects.

For each failed attempt m, collect the likely suspects for attempt m in accordance with Table 1. Now let

$$a^m_{ROLE,NATV,DUP,HRT,PRT} = \begin{cases} 1 & \text{if a prime suspect formation for attempt } m \text{ has properties ROLE, NATV, DUP, HRT, and PRT} \\ 0 & \text{if the combination ROLE, NATV DUP, HRT, and PRT does not describe a prime suspect for attempt } m \end{cases}$$

Let $a^m_{ROLE,.,.,.,.}$, be a similar indicator variable for the ROLE of each prime suspect for attempt m, with $a^m_{.,NATV,.,.,.}$, $a^m_{ROLE,.,DUP,.,.}$, $a^m_{ROLE,NATV,.,.,PRT}$, etc., similarly defined. For example, if the only likely suspect for failed attempt one was a duplicate-capable, Secondary formation from the same country as its Primary, with both its Host and Primary formations multiple-routing, then the following a^1's would be assigned the value of one: $a^1_{S,T,T,M,M}$, $a^1_{S,T,T,M,.}$, $a^1_{S,T,T,.,M}$, $a^1_{S,T,.,M,M}$, $a^1_{S,.,T,M,M}$, $a^1_{.,T,T,M,M}$, $a^1_{S,T,T,.,.}$, $a^1_{S,T,.,M,.}$, $a^1_{S,T,.,.,M}$, $a^1_{S,.,T,M,.}$, $a^1_{S,.,T,.,M}$, $a^1_{S,.,.,M,M}$, $a^1_{.,T,T,M,.}$, $a^1_{.,T,T,.,M}$, $a^1_{.,T,.,M,M}$, $a^1_{.,.,T,M,M}$, $a^1_{S,T,.,.,.}$, $a^1_{S,.,T,.,.}$, $a^1_{S,.,.,M,.}$, $a^1_{S,.,.,.,M}$, $a^1_{.,T,T,.,.}$, $a^1_{.,T,.,M,.}$, $a^1_{.,T,.,.,M}$, $a^1_{.,.,T,M,.}$, $a^1_{.,.,T,.,M}$, $a^1_{.,.,.,M,M}$, $a^1_{S,.,.,.,.}$, $a^1_{.,T,.,.,.}$, $a^1_{.,.,T,.,.}$, $a^1_{.,.,.,M,.}$, $a^1_{.,.,.,.,M}$. The a^1's representing all other characteristic combinations would be zero.

Now let $z_{ROLE,NATV,DUP,HRT,PRT}$ be a similarly indexed decision variable with values as follows:

$z_{ROLE, NATV, DUP, HRT, PRT}$ = 1 if problems arise in implementing STANAG 4214 for formations with properties ROLE, NATV, DUP, HRT, and PRT;

0 if formations with properties ROLE, NATV, DUP, HRT, and PRT are handled correctly.

These variables will be referred to as cause conclusion indicators. If one conclusion is a refinement of another (e.g., H,.,.,S,S is a refinement of H,.,.,.,.), the more general conclusion indicator is referred to as a *composite* conclusion, while the refinement is a *constituent conclusion* of the more general one. These variables will be used in a simple set-covering-like optimization which will have as its solution the likely set of causes (the ones which occurred most frequently) for the given set of failed attempts. Since it is reasonable that the two different types of failures (loops and dead-ends) would be caused by different problems, the sets of likely suspects will be grouped by the type of failure they were a suspect for. The optimization problem will be solved for each of these groups separately.

Consider the following mathematical program constraint set:

$$1 \le \sum_{\Omega} z_{ROLE, NATV, DUP, HRT, PRT} \, a^{m}_{ROLE, NATV, DUP, HRT, PRT} + u_m \qquad (1)$$

for each failed attempt m, where Ω is the set of all possible combinations $ROLE, NATV, DUP, HRT, PRT$ with $ROLE \in \{H, P, S\}$, $NATV \in \{T, F\}$, $DUP \in \{T, F\}$, $HRT \in \{S, M\}$, and $PRT \in \{S, M\}$.

The u_m corresponds to not being able to assign a cause to failure *m*. By convention, this is called a zero-factor conclusion. This set of constraints will produce a combination of *z*'s and *u*'s which *cover* all of the failed attempts. That is, for each failed attempt *m*, either u_m is selected or at least one of failed attempt *m*'s likely suspects has the characteristics defined by at least one of the *z*'s selected. Furthermore, it is preferred to have information which is as precise as possible; accepting $z_{S,.,.,.,.}$ as one is less desirable than accepting $z_{S,T,T,.,.}$, which, in turn, is less desirable than accepting $z_{S,T,T,S,S}$. The objective is to produce a set of decision variables which give as much information as possible. On the other hand, if $z_{H,T,T,S,S}$, $z_{P,T,T,S,S}$, and $z_{S,T,T,S,S}$ are all one, what really exists is a situation where they should all be zero, and $z_{.,T,T,S,S}$ should be one. A set of costs will now be constructed, along with some more constraints so that the program produces a set of indicated causes which are both parsimonious and precise.

Let the number of *constituent* conclusions for each conclusion variable be counted and denoted by $n_{ROLE,NATV,DUP,HRT,PRT}$. By definition, let $n_{ROLE,NATV,DUP,HRT,PRT} = 1$ for all five-factor indicators. Then

$$\begin{aligned} n_{.,NATV,DUP,HRT,PRT} &= n_{H,NATV,DUP,HRT,PRT} \\ &\quad + n_{P,NATV,DUP,HRT,PRT} \\ &\quad + n_{S,NATV,DUP,HRT,PRT} \\ &= 3 \end{aligned}$$

because the first factor has three states. Similarly,

$$n_{ROLE,\ .,\ DUP,HRT,PRT} = 2$$

because the second factor has only two states. That is, a four-factor n equals the number of options for the missing factor. Continuing in this manner, one can show

$$\begin{aligned} & n_{ROLE,NATV,.,.,.} \\ &= n_{ROLE,NATV,T,.,.} + n_{ROLE,NATV,F,.,.} \\ &= n_{ROLE,NATV,.,S,.} + n_{ROLE,NATV,.,M,.} \\ &= n_{ROLE,NATV,.,.,S} + n_{ROLE,NATV,.,.,M} \\ &= 8, \end{aligned}$$

and so forth.

The basic cost structure is now constructed so that the cost of concluding a four-factor conclusion variable is true is slightly larger than the cost of proclaiming that all of the constituent conclusions are true. This will promote specificity. Continuing in this spirit, conclusions with less factors will be made just slightly more costly than all of the constituent conclusions. To accomplish this let

$$b_{ROLE,NATV,DUP,HRT,PRT} = n_{ROLE,NATV,DUP,HRT,PRT} + 0.01$$

be the *basic cost* of concluding $z_{ROLE,NATV,DUP,HRT,PRT}$ equals one.

While this basic cost structure will result in determining the most specific characteristics for the likely suspects, it does not guarantee that the **most common** characteristics will be identified. Consider a group of likely suspects for a failed attempt with all but one of the suspects having identical five-factor characteristics. Both of the feasible five-factor conclusion variables have the same positive cost and both would cover the failed attempt. Since the goal is to minimize cost, the mathematical program will only allow one of the conclusion variables to take on the value one. Since each of the conclusion variables have the same cost under the basic cost structure, the mathematical program would be just as happy to chose the lone suspect's five-factor conclusion as the five-factor conclusion of all the other suspects. In order to give more weight to conclusions which appear more frequently, the final cost for a particular conclusion is made as follows:

$$c_{ROLE,NATV,DUP,HRT,PRT} = b_{ROLE,NATV,DUP,HRT,PRT} / t_{ROLE,NATV,DUP,HRT,PRT}$$

Where $t_{ROLE,NATV,DUP,HRT,PRT}$ is the maximum of one and the total number of all likely suspects with the given n-fold factor conclusion.

Recall that if all of the five-factor constituent conclusions are chosen for some four-factor conclusion, it is desired to force the choice of the four-factor conclusion instead. To ensure that conclusions with less factors are chosen when appropriate, the following constraint set must be added to the mathematical program:

$$n_{.,T,T,S,S}z_{.,T,T,S,S} \geq z_{H,T,T,S,S} + z_{P,T,T,S,S} + z_{S,T,T,S,S} - (n_{.,T,T,S,S} - 1) \quad (2)$$

$$n_{.,T,T,S,M}z_{.,T,T,S,M} \geq z_{H,T,T,S,M} + z_{P,T,T,S,M} + z_{S,T,T,S,M} - (n_{.,T,T,S,M} - 1) \quad (3)$$

.
.
.

$$n_{H,T,F,.,.,.}z_{H,T,F,.,.,.} \geq n_{H,T,F,S,.,.}z_{H,T,F,S,.,.} + n_{H,T,F,M,.,.}z_{H,T,F,M,.,.} - (n_{H,T,F,.,.,.} - 1) \quad (4)$$

$$n_{H,T,F,.,.,.}z_{H,T,F,.,.,.} \geq n_{H,T,F,.,.,S}z_{H,T,F,.,.,S} + n_{H,T,F,.,.,M}z_{H,T,F,.,.,M} - (n_{H,T,F,.,.,.} - 1) \quad (5)$$

.
.
.

$$n_{H,.,.,F,.,.,.}z_{H,.,.,F,.,.,.} \geq n_{H,T,F,.,.,.}z_{H,T,F,.,.,.} + n_{H,F,F,.,.,.}z_{H,F,F,.,.,.} - (n_{H,.,.,F,.,.,.} - 1) \quad (6)$$

$$n_{H,.,.,F,.,.,.}z_{H,.,.,F,.,.,.} \geq n_{H,.,.,F,S,.,.}z_{H,.,.,F,S,.,.} + n_{H,.,.,F,M,.,.}z_{H,.,.,F,M,.,.} - (n_{H,.,.,F,.,.,.} - 1) \quad (7)$$

$$n_{H,.,.,F,.,.,.}z_{H,.,.,F,.,.,.} \geq n_{H,.,.,F,.,.,S}z_{H,.,.,F,.,.,S} + n_{H,.,.,F,.,.,M}z_{H,.,.,F,.,.,M} - (n_{H,.,.,F,.,.,.} - 1) \quad (8)$$

.
.
.

$$n_{H,.,.,.,.,.,.}z_{H,.,.,.,.,.,.} \geq n_{H,T,.,.,.,.,.}z_{H,T,.,.,.,.,.} + n_{H,F,.,.,.,.,.}z_{H,F,.,.,.,.,.} - (n_{H,.,.,.,.,.,.} - 1) \quad (9)$$

$$n_{H,.,.,.,.,.,.}z_{H,.,.,.,.,.,.} \geq n_{H,.,.,T,.,.,.}z_{H,.,.,T,.,.,.} + n_{H,.,.,F,.,.,.}z_{H,.,.,F,.,.,.} - (n_{H,.,.,.,.,.,.} - 1) \quad (10)$$

$$n_{H,.,.,.,.,.,.}z_{H,.,.,.,.,.,.} \geq n_{H,.,.,.,S,.,.}z_{H,.,.,.,S,.,.} + n_{H,.,.,.,M,.,.}z_{H,.,.,.,M,.,.} - (n_{H,.,.,.,.,.,.} - 1) \quad (11)$$

$$n_{H,.,.,.,.,.,.}z_{H,.,.,.,.,.,.} \geq n_{H,.,.,.,.,.,S}z_{H,.,.,.,.,.,S} + n_{H,.,.,.,.,.,M}z_{H,.,.,.,.,.,M} - (n_{H,.,.,.,.,.,.} - 1) \quad (12)$$

A check of these constraints shows that if the program selects an entire set of constituent conclusions, the composite conclusion is chosen as well. However, since there would then be a redundancy, the cost structure will ensure that the constituent conclusions will be dropped when possible. Thus, by combining the set-covering constraints (Equation 1) with forced composite constraints (Equations 2-12), the feasible region of a mathematical program is defined. The objective function, given as

$$\min \sum_{\Omega} c_{ROLE,NATV,DUP,HRT,PRT} z_{ROLE,NATV,DUP,HRT,PRT} + \sum_{m=1}^{t} c_{.........} u_m$$

where Ω is defined as before and t is the total number of failed attempts, completes the specification of the mathematical program. This optimization is solved using some of the methods found in Balas (1980) and the General Algebraic Modeling System (GAMS) software package.

E. ANALYSIS OF MULTIPLE COMMUNICATIONS SYSTEMS

As previously mentioned, it is possible to sample random variates to perform single-system checks on numerous different force structures. The data from these single-system checks can then be consolidated to develop a single set of failed attempts from various different communications systems. Using this technique, it is possible to enlarge the set of different equipment combinations checked by the program.

F. SUMMARY

The measure of effectiveness for the STANAG 4214 protocol was defined as the mean percentage of successful calls in a random communication system when each formation calls every other formation once. Additionally, two methods for isolating failure causes were developed: Graphical Cause Identification and a mathematical program.

VI. RESULTS

This chapter will discuss the results obtained from using TACFONE-NATO to assist in performing the analyses set forth in Chapter V.

A. RESULTS OF ESTIMATED SUCCESS RATES

Table 2 consolidates the results of the estimated effectiveness of the protocol for a random Communication System in terms of percentage of successful calls when each formation calls every other formation once and the path is randomly chosen when more than one possible path exists. The results for the runs without lateral connections were derived from 30 randomly generated Communication Systems making a total of 2,850,300 simulated calls for each set of rules evaluated.

The lateral connection rules were tested on six randomly generated Communication Systems with each formation being connected to every other formation (i.e., every possible lateral connection was made). The purpose of connecting all formations was to put the maximum amount of stress on the lateral connection rules, regardless of how unlikely it would be for this situation to occur. The test for the lateral

TABLE 2 PERCENTAGE OF SUCCESSFUL CALLS.

Rules Invoked	Estimated Expected Success Rate for a Random CommSystem	Low Estimated Rate for a CommSystem	High Estimated Rate for a CommSystem
Basic STANAG (No Anti-Looping)	90.53	66.27	100.00
Basic STANAG With Anti-Looping	99.54	94.04	100.00
Basic STANAG With Anti-Looping & Numbering Change	100.00	100.00	100.00
Basic STANAG With Anti-Looping, Numbering Change & Lateral Connections	100.00	100.00	100.00

connection rules checked each possible path (based on the routing tables) to verify that no possible loops existed.

Table 2 reveals the tremendous improvement obtained by invoking the anti-looping rules set forth earlier. The table also shows that the numbering modification, in conjunction with the anti-looping rules, appears to eliminate all failed calls using the STANAG 4214 protocol. The 100 percent success rate for systems with all possible lateral connections also demonstrates the effectiveness of the lateral connection rules which were imposed on the model.

It should be noted that Table 2 gives the expected success rate for a *random* communication system. The actual expected success rate for a *given* system may vary significantly from these numbers for the basic model and for invoking only the anti-looping rules. It would not vary for the implementation of all rules since in this case *all* systems have a 100 percent expected success rate. For instance, a Communication System with three or fewer Hosts will have no possible loops. Therefore, if no dead-ends were possible, it would have a 100 percent success rate even without invoking the anti-looping rules. On the other hand, a large system with six fully connected Hosts would probably have something near the observed low 66 percent success rate.

Since any system randomly generated was regarded equally as likely to occur, Table 2 weights each Communication System equally in determining the expected success rate for a system. This means that a large system making thousands of calls resulting in perhaps say, a 70 percent success rate, is weighted the same as a small system making only a few dozen calls with a 100 percent success rate. In an attempt to determine the protocol's effectiveness for a random *single call*, the total number of calls made and the total number of successful calls were also collected for each set of rules invoked. These results can be seen in Table 3.

The 80 percent success rate for the basic model compared to the 99.89 percent success rate for the anti-looping rules only in Table 3 shows even more clearly that looping is a problem which must be dealt with. The 99.89 percent success rate for implementing anti-looping rules only, also shows that

TABLE 3 EXPECTED SUCCESS RATE FOR A RANDOM CALL

Rules Invoked	**Total Number of Calls**	**Number of Successful Calls**	**Estimated Success Rate for a Random Call**
Basic STANAG (No Anti-Looping)	2,850,300	2,287,056	80.24
Basic STANAG With Anti-Looping	2,850,300	2,847,303	99.89
Basic STANAG With Anti-Looping & Numbering Change	2,850,300	2,850,300	100.00
Basic STANAG With Anti-Looping, Numbering Change & Lateral Connections	98,622	98,622	100.00

the only rule discrepancy discovered results from a situation which apparently occurs rather infrequently. However, to ensure a 100 percent success rate for any possible communication system, this problem must too be remedied. It is also apparent that the anti-looping heuristic and proposed rule change eliminated all failed calls and that the lateral connection rules worked flawlessly even under the most arduous circumstances.

B. RESULTS OF FAULT ISOLATION PROGRAM

The mathematical program discussed in Chapter V was used for the basic model (no modifications invoked), the basic model with anti-looping (but no other rule modifications), and the basic model with anti-looping and a proposed modification to the protocol. These results will now be discussed.

1. The Basic Model

By far, the greatest problem encountered in the basic model was with looped calls. The list of conclusion variables from the mathematical program included only $z_{HOST,T,\ldots,\ldots}$ (note that Hosts were assumed to be their own parent, hence all Hosts were assigned a "T" for NATV). This showed that Host formations were the most common (and likely the only) factor in looped calls. Hence, anti-looping rules for inter-host connections should be sufficient to eliminate looping.

There was also a problem with dead-end calls. Using both the mathematical program and the graphical display, it was possible to identify a protocol problem with the numbering of duplicate-capable Secondary formations which have a multiple-routing Host and a single-routing Parent (Primary). The problem only occurs when there are other formations from the same country in the network who do not have the same parent, see Figure 18. When this situation occurs, at least two of the like-country formations are numbered the same using STANAG protocol. This results in ambiguity for the single-routing Primary when attempting to route a call to one of these like-numbered formations, as one of the two possible switch choices does not route to the desired formation, see Figure 18. Since the Primary is only single-routing capable, there is at least a 50 percent chance (if each possible switch is chosen with equal likelihood) that the call will fail. The STANAG rule for numbering such Secondaries states:

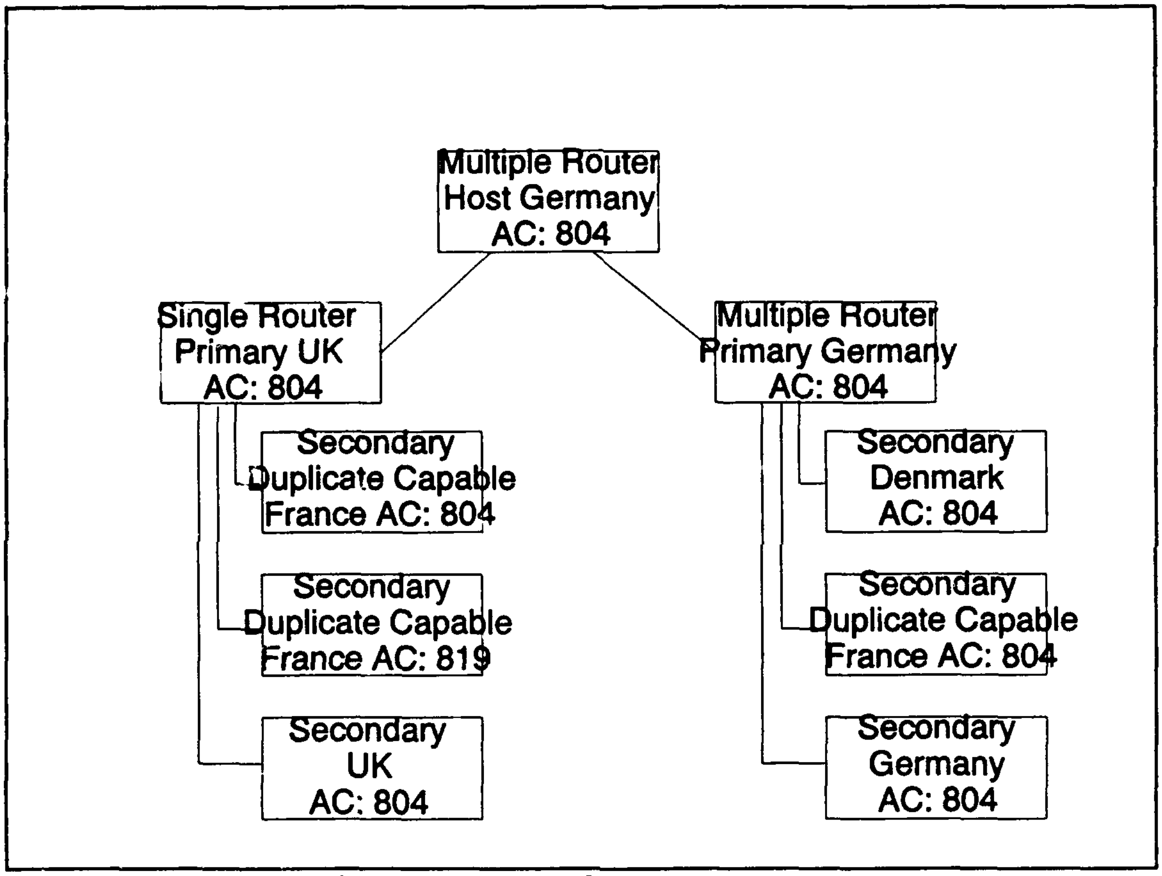

Figure 18 Numbering rule problem.

If the major host formation and/or the formation under direct command are only capable of "single" routing then its secondary formations shall be assigned unique prefixes .... (STANAG 4214, 1985, p.B-6)

This rule was interpreted to mean that all Secondary formations of a single-routing Primary and multiple-routing Host must be numbered uniquely *amongst themselves*. The recommended solution to this problem is to have the STANAG **clearly** state that all such formations must be numbered uniquely from all other formations *in the entire network.*

2. The Model With Anti-Looping Rules Only

After imposing the anti-looping rules (and lateral connection rules) stated previously, no failures were encountered due to looping in communication systems even with lateral connections. However, the problems with dead-end calls persisted.

3. The Model With Recommended Change to STANAG 4214

With the implementation of the recommended change for the numbering problem mentioned earlier, along with the use anti-looping rules and lateral connection rules, no failures of any kind were encountered for numerous randomly generated Communication Systems.

C. SUMMARY

The results of the success rate analysis and the fault isolation analysis reveal that looping is the single most likely cause for failures if it is not dealt with properly. Fortunately, the results also show that the proposed anti-looping rules work flawlessly in preventing looping. Finally, the results also revealed an error in the numbering of duplicate-capable Secondaries with a multiple-routing Host and a single-routing Primary. Further analysis showed that the recommended rule changes alleviated the numbering problem.

VII. CONCLUSIONS AND RECOMMENDATIONS

The primary goals of this study were to test the protocol of STANAG 4214, develop anti-looping rules for inter-host connections, and develop rules to allow for lateral connections within a Communication System without allowing looping. To this end the object-oriented, graphical simulation model TACFONE-NATO was developed. Through the use of this model, in conjunction with a mathematical program developed for additional analysis, the following were accomplished:

1. The need for reliable anti-looping rules was verified.

2. A numbering discrepancy in the STANAG 4214 protocol was discovered and isolated. The discrepancy deals with the numbering of duplicate-capable Secondaries with a multiple-routing Host and a single-routing Primary.

3. Recommended anti-looping heuristic, numbering change and lateral connection rules were tested and verified.

In addition, TACFONE-NATO will allow JIEO and other users to:

1. Automatically number (using STANAG 4214 protocol), build routing tables for a user-defined Communication System and output this information to a user-selected file. The program automatically invokes the lateral connection rules via the building of the routing tables and can also be selected to use the anti-looping heuristic and proposed numbering rule change.

2. Determine the effectiveness of a user defined system which has already been numbered. In this case routing tables will be built by the model (the use of the anti-looping heuristic is determined by the user).

3. View a randomly generated system or user-defined system graphically.

The graphical interface developed for TACFONE-NATO makes the program simple to run and allows for easy selection of user options.

This analysis of STANAG 4214, which required generating over ten million simulated phone calls, reveals that looping is a critical problem which must be avoided and that there is a flaw in the current protocol. However, this analysis also verifies the effectiveness of the protocol when implemented with TACFONE-NATO's anti-looping rules and recommended numbering modification. It is recommended that the anti-looping heuristic developed for and used in TACFONE-NATO be utilized as the means to prevent looping. It is also recommended that STANAG 4214 be modified to incorporate the suggested rule change. Finally, this analysis also shows that lateral connections may be allowed to exist under the rules set forth in Chapter V without degrading the protocol's effectiveness.

LIST OF REFERENCES

Balas, E. and Ho, A., Set Covering Algorithms Using Cutting Planes, Heuristics, and Subgradient Optimization: A Computational Study. *Mathematical Programming*, Vol 12, 1980, pp. 37-60.

STANAG 4214, *Standardization Agreement 4214*: *International Routing and Directory for Tactical Communications Systems* (Edition 1, revised), NATO, 1985.

BIBLIOGRAPHY

Annex F to STANAG 4214 (draft), NATO, 1992.

Bailey, M.P.,and others, *Testing, Evaluating, and Enhancing NATO Tactical Communications Schemes*, paper presented for 1993 WinterSim Conference, San Diego, California, 10 April 1993.

Knight, R.C., *Addressing and Routing for Military Communications*, Technical Note STC TN-234, SHAPE Technical Centre, The Hague, June 1989.

Knight, R.C., *Communications Management and Management Communications* (revised version), Technical Note 259, SHAPE Technical Centre, The Hague, March 1990.

MODSIM Programming Language Reference Manual, CACI Products Division, La Jolla, California, 1993.

SIMGRAPHICS II User's Manual for MODSIM II, CACI Products Division, La Jolla, California, 1993.

STANAG 5046, *Standardization Agreement 5046: The NATO Military Communications Directory System* (Edition 2), NATO, 1985.

APPENDIX A

SUBSIDIARY AREA CODES ALLOCATED TO NATIONS

Nation	Number of Major (Host) Formations	Master ACs	Subsidiary ACs
Belgium	2	800	200, 300, 400
		700	
Canada	1	801	201, 301, 401
Denmark	1	802	202, 302, 402
France	4	803	818, 203, 218
		703	718, 303, 318
		603	618, 402, 418
		503	
Germany	4	804	819, 204, 219
		704	719, 304, 319
		604	619, 404, 419
		504	
Greece	1?	805	205, 305, 405
Iceland	1?	806	206, 306, 406
Italy	3	807	207, 307, 407
		707	
		607	
Luxembourg	1?	808	208, 308, 408
Netherlands	1	809	209, 309, 409
Norway	1	810	210, 310, 410
Portugal	1?	811	211, 311, 411
Turkey	1?	812	212, 312, 412
UK	2	813	213, 313, 413
USA	4	814	816, 214, 216
		714	716, 314, 316
		614	616, 414, 416
		514	
NICS	1	815	-
COMLANDJUT	1	715	315
Spain	1?	817	217, 317, 417

APPENDIX B

USER MANUAL FOR TACFONE-NATO

I. INTRODUCTION

TACFONE-NATO is designed to simulate the STANAG 4214 numbering and routing protocol. It is assumed the user has a working knowledge of STANAG 4214 and is familiar with the terminology used in this document, as well as the thesis on this subject. TACFONE-NATO simulates a communication system's crucial elements in order to allow the implementation of the STANAG 4214 protocols. The entire model was designed to represent the physical equipment and the actual process of sending and receiving calls, but only at the level of fidelity for each element that was required for this study. Therefore, some elements that are modeled may not exactly reflect the actual equipment/process, but for the purposes of testing the STANAG or a different numbering system, it reflects accurately the portion affecting the numbering of formations and routing of calls. The model is completely supported with graphics, which allows for ease of use and simplifies the analysis of results.

The information in this users's manual is presented in the following format:

Chapter I Introduction, Definitions, and Overview

Chapter II Session using TACFONE-NATO

Chapter III Input Files

Chapter IV Output Files.

A. BASIC MODEL OBJECTS

What follows is a description of the basic building blocks of TACFONE-NATO. As discussed previously, these are the crucial elements of a communication system required to evaluate of the STANAG 4214 protocol.

1. Communication System

The communication system consists of a set of networks that are connected only through the Host formations. These networks are connected in such a way to comprise a connected graph of all networks and may be comprised up to a fully connected graph.

2. Networks

A network is a hierarchically constructed tree of formations with a maximum of three levels, called Host, Primary, and Secondary. The only connections allowed between formations in a network are the ones that follow this tree structure. Therefore, under current STANAG 4214 protocol, the Secondary formations only have one connection, which is with their parent (Primary) formation. The Primary formations have one connection with each of their children (Secondaries) and one connection with their Host formation. Each Host formation has one connection with each of his child Primary formations and connections to other Host formations, depending on the topology of the communication system.

3. Formations

The formations represent the communication systems for different sized military units. Generally, Host level formations represent Corps-sized units, Primary level formations equate to division-sized units and Secondary level formations represent brigade-sized units. The STANAG 4214 protocol does not address units of any smaller size, therefore, TACFONE-NATO does not represent any other unit types.

4. Switches, Trunks and Gateways

These elements are modeled to reflect definitions as described in STANAG 4214.

B. NUMBERING THE COMMUNICATIONS SYSTEM

The model numbers the Communications System according to the rules of the STANAG 4214 with the exception of options to be discussed in later sections.

C. GENERATION OF COMMUNICATION SYSTEMS

TACFONE-NATO will either read in a user-defined force structure, or randomly generate a force structure. If the force is user-defined, TACFONE-NATO can automatically number the communication system, or the NIACs can be defined by the user. This gives the user the flexibility to analyze a proposed numbering scheme that does not follow the STANAG rules. The connections between networks at the Host level are either randomly generated by TACFONE-NATO or defined by the user. When the communication system is generated randomly, the number of networks, formations, and connections between networks are all randomly determined from preset bounds. The identity of the formations, including nationality, are also randomly determined from the existing units that are available to NATO. Once the force has been generated and connected, the formations are numbered using the method previously discussed.

When the program automatically numbers a user-defined force structure it is possible that a Host nation mat not have enough subsidiary area codes assigned to it. If this occurs, the program will halt and inform the user which nation requires more subsidiary area codes. Adding of area codes can be done by modifying the "AREACODE.DAT" file, see chapter three, INPUT FILES, for further information on how to modify this file.

D. BUILDING OF ROUTING TABLES

Once the communication system is generated and has been numbered, the routing tables are initialized for each trunk of each formation. Each network first updates its routing tables internally, then the switches connecting the networks initialize their routing tables. The basic model allows all paths that exist from one network to another to be reflected in the routing tables. The STANAG 4214 does not directly address what paths should exist from one network to another, only that it is done in a way "to prevent looping". The basic model operates this way to give the ability to measure the effectiveness of anti-looping rules which were added to the model.

E. GENERATING AND ROUTING CALLS

Calls are generated from every formation to every other formation. The formation routes a call based on the physical limitations of communications equipment of its nation, as well as the contents of its switches' routing tables. Between networks, calls are only routed via one path (single-routed). The call tracks all formations that it is routed through to reach its destination. Calls are not allowed to be routed immediately back along a trunk just used to reflect the actual physical limitations.

F. GRAPHICS

The TACFONE-NATO model utilizes the SIMGRAPHICS (MODSIM 93) portion of MODSIM to display all input and output graphically. The model is controlled through the use of graphical user interfaces, all mouse-driven. This eases the use of TACFONE-NATO dramatically, by making it much more user-friendly. The Communication System is displayed on the screen graphically using a separate window for each network. Each formation is displayed as a rectangle with its nationality, unit size (corps, division, or brigade), unit number, and NIAC. All trunks are represented as lines between the formations. The Host formations are also displayed in a separate window with their inter-host connections also displayed as lines. When calls are being routed, the originator formation and the destination formation are uniquely colored and all trunks in the path are also colored to allow the user to visually watch the calls be routed. The display is frozen when a failed call occurs, which aids in the trouble shooting of any protocol problems.

II. A SESSION USING TACFONE-NATO

Figure 1 below shows the basic flow for a run of TACFONE-NATO. The specifics of each of these steps will be discussed in more detail throughout the remainder of this Chapter.

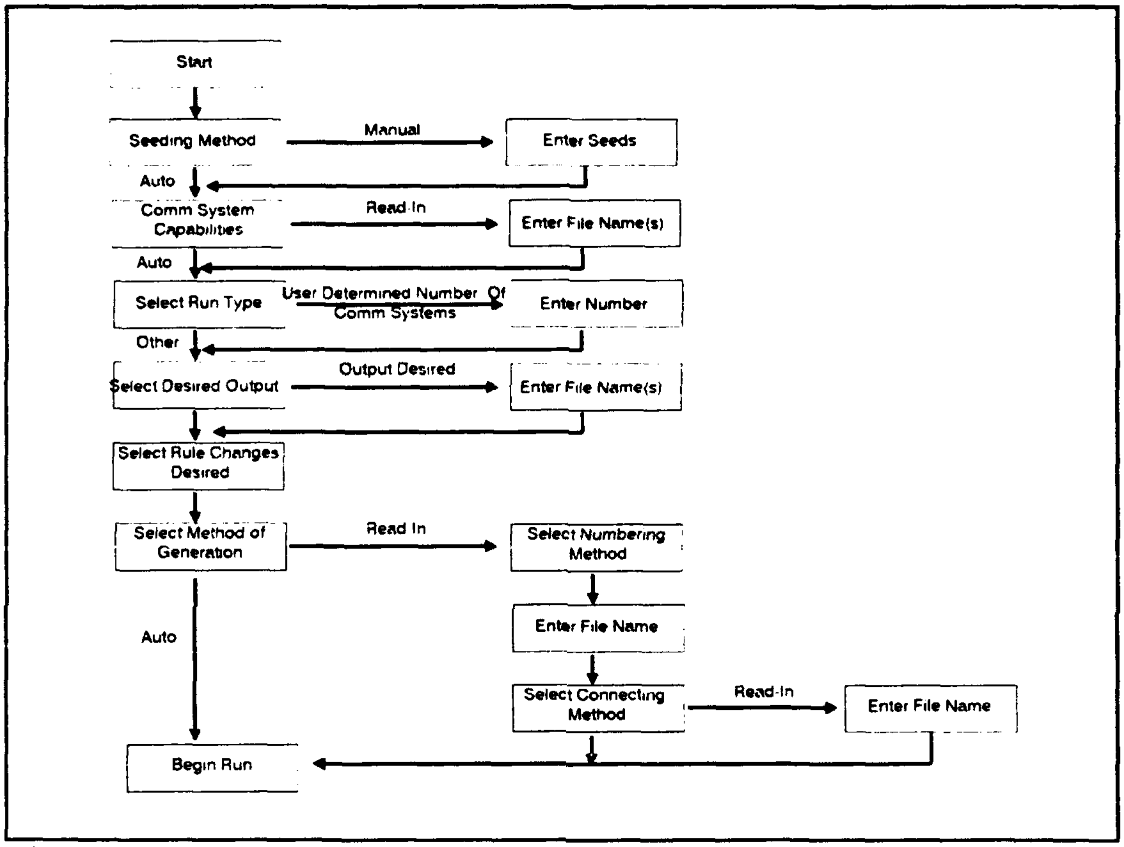

Figure 1 System flow for a run of TACFONE-NATO.

To start the program type TACFONE at the command line in the directory where the executable file and all input files are stored. The first option presented is how to set the random number generator seeds: automatically or manually, see Figure 2.

To pick the option desired, click the appropriate button with the mouse and then click the "click here when choice is complete" button to move on.

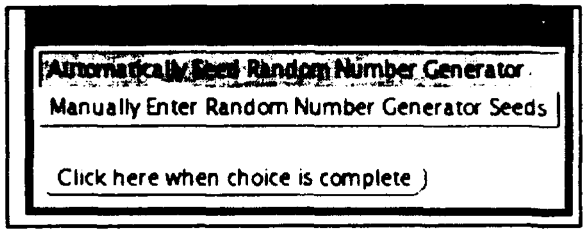

Figure 2: Random Number Generator Seed Choice Box.

The random number generator is used when randomly generating a communication system and when the calls are being routed. If the same seeds for the generators are used for two separate runs, the exact same results will be produced (all other options consistent). The seeds will be set to the same preset numbers every time the automatic seeding is chosen. It is possible to view different randomly generated systems by choosing to manually enter different seeds.

When the manual method for setting the random generator seeds is chosen, the screen snown in Figure 3 will be displayed. There are five random number generators utilized by TACFONE-NATO, which means five seeds are required to be set. To enter a number (seed), place the mouse cursor on the desired line and type in the number. Ensure there are no spaces! To switch to another line,

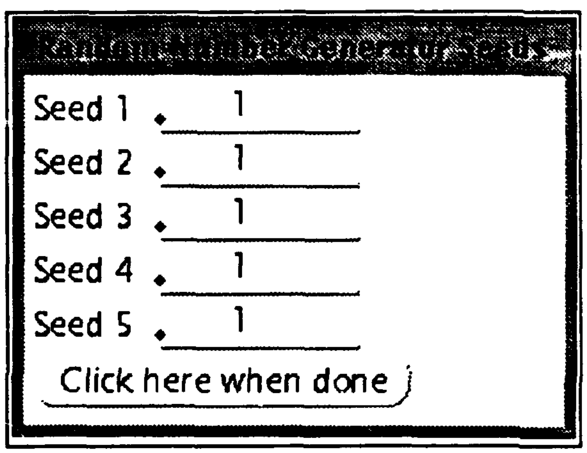

Figure 3 Random Number Generator Seed Entry Box.

use the mouse or the arrow keys. Once all numbers have been entered, click the "click here when done" button with the mouse. The next option presented is whether or not the duplicate-capable, and single/multiple-router information for each country's communications equipment will be read in (to reflect actual capabilities) or be randomly generated by TACFONE-NATO (to allow for more robust testing of the rules). Two choices must be made on this screen, one for each type of capability, (see Figure 4 for the actual screen). Once the choices are made, click the "click when done" button with the mouse.

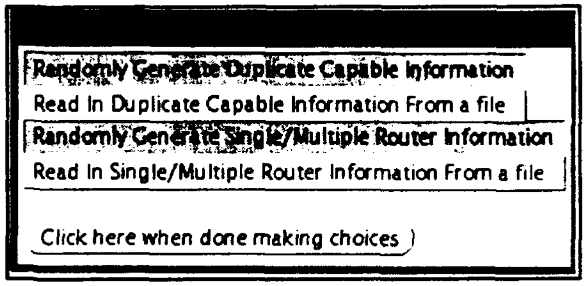

Figure 4 Equipment Characteristics Choice Box.

If either of the options to read in capabilities from a file was selected, Figure(s) 5 and/or 6 will be displayed, depending on the selections. Enter the appropriate file name(s) on the line by clicking on the line and typing the name from the keyboard. Once the file name is entered, click the "click here when file name is entered" button with the mouse.

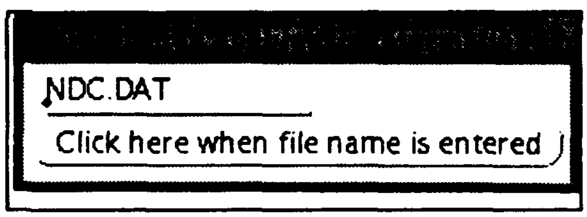

Figure 5 Duplicate Capable Information File Name Box.

The next screen allows for the selection of what type of run is to be conducted, see Figure 7 for an example of this choice.

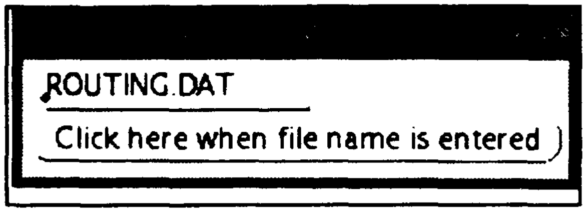

Figure 6 Single Router Information File Name Box.

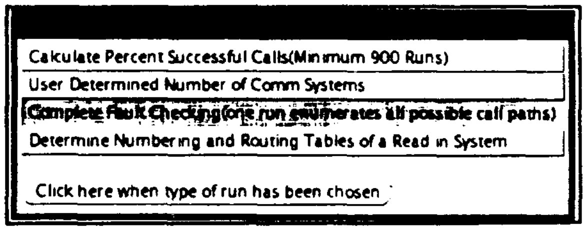

Figure 7 Type Of Run Choice Box.

The choices are defined as:

1. Calculate percent successful Calls. This option requires a minimum of 900 runs and approximately 25 hours to complete. The run randomly generates a communication system and generates calls from each formation to every other formation using only one path to reach it's destination, calculating the percentage of successful calls. The calls are then regenerated at least 30 times until the 95 percent confidence interval for percentage of successful calls is within 10 percent of the estimated mean. The same is done for at least 30 different communication systems to estimate the expected success rate for a random system. Once complete, the statistical data is printed in the output file designated by the user.

2. User determined number of communication systems to be user defined or randomly generated. Calls will be made from every formation to every other formation utilizing only one path to route the call. Dependent on the size of the system and number of failed calls the amount of time required is approximately 2-45 minutes for each communication system.

3. Complete fault checking of a user defined or randomly generated communication system. Calls will be generated from every formation to every other formation utilizing all routes possible to determine if there are any potential failures in the communication system based on it's numbering and the routing table configurations. If there are any failures the attributes of the suspected formations which may have caused the failure are printed in

various files. The file names are printed on the screen at the end of the run. The time required for each communication system is approximately twice as much as option two.

4. Number a user defined communication system. This option will take the user defined communication system and determine the numbering of all the formations and the routing table configurations for each switch. The user can graphically view the system with the graphics option, but no calls will be simulated with this option. This option will require less than two minutes.

Option 1 allows the user to determine the expected operational effectiveness of a set of rules. Option 2 allows the user to look at communication system(s) to see the set-up or generate complete information of that system. Option 3 completely checks a system for any faulting numbering and will help isolate the faults. Option 4 will quickly number a pre-defined system. Select the desired option by clicking on the appropriate button with the mouse and then clicking the "done" button. If "user determined number of communication systems" is selected, the next screen will ask for the number of systems to be generated, see Figure 8. Enter the number by clicking on the line, typing in the number from the keyboard, and then clicking on the "click here when the number is entered" button with the mouse.

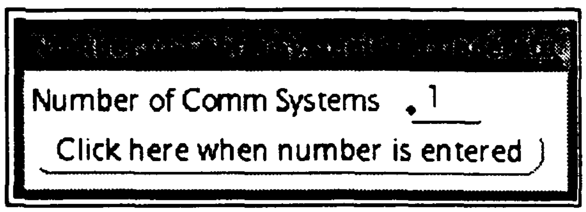

Figure 8 Number of Communication Systems Box.

The next screen offers the options on the hard copy output of the communication system(s), see Figure 9:

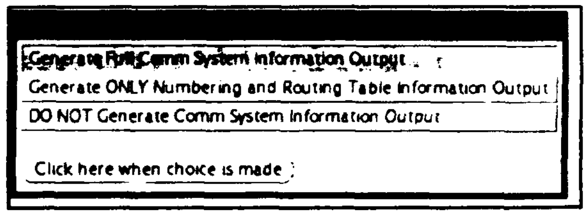

Figure 9 Type of Output Choice Box.

1. Generate full comm system information output. This option will generate the following information for each formation:
   - -country
   - -unit type(Corps, Division,Brigade)
   - -unit number
   - -unit's assigned NIAC
   - -single or multiple-router
   - -duplicate-capable or not
   - -formation's parent.

   For each switch of each formation the following information is provided:
   - -the formation connected to the other end of the trunk
   - -the numbers in the incoming and outgoing routing tables determined via the rules the user selects.

   Also, for each network:
   - -summary listing of the area codes assigned to that network is given.

2. Generate numbering only. This option gives an abbreviated version of the previous listed option. The following information is given for each formation:
   - -country
   - -unit type
   - -unit number
   - -NIAC assigned

   The following information is given for each switch:
   - -the formation connected to the other end of the trunk
   - -the numbers in the outgoing routing table.

3. Do not generate Comm System information Output. This option results in no output file containing information on the physical configuration of the communication system.

The full output option gives all possible pertinent information about the communication system for trouble shooting purposes. The numbering only option outputs only the information necessary to number each formation and set up all routing tables.

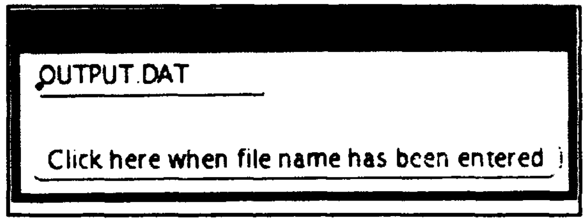

Figure 10 Output File Name Box.

If either of the two types of output is requested, the next screen will ask for the name of the file to which the output will be written, see Figure 10. The procedure for entering the file name is the same as for previous files. The format of the output files is discussed in Chapter IV, OUTPUT FILES.

The next screen asks if statistical output is desired or not. The choice is made in the manner discussed earlier for general output. When statistical output is chosen the following information is provided for each communication system: the number of the communication system, number of calls made, number of successful calls, number of failed calls, and the percentage of successful calls. If more than one communication system is simulated, the same information is given for all communication systems totaled. A 95 percent confidence interval for the estimate of the mean success rate is also given. If statistical output is chosen, the next screen will request the name to which this output will be written. The file name is entered in the same way as for previous files.

The next screen asks whether or not to use the rule modification to STANAG 4214 which corrects an error discovered in the protocol, see Figure 11. The choice is made in the same way as for previous selections.

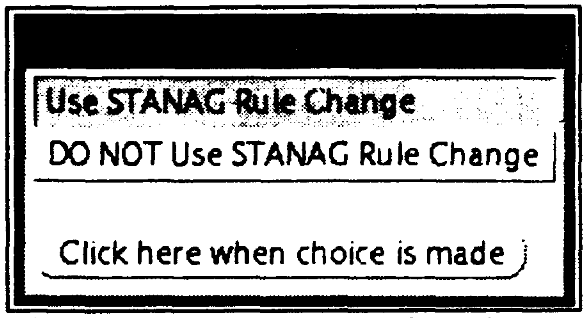

Figure 11 STANAG Rule Change Choice Box.

The following screen gives the choice of whether to utilize the anti-looping rules developed for TACFONE-NATO, see Figure 12. The anti-looping choice will institute an anti-looping heuristic which allows for maximum redundancy between the Host formations while preventing looping. This is implemented through the routing table configurations.

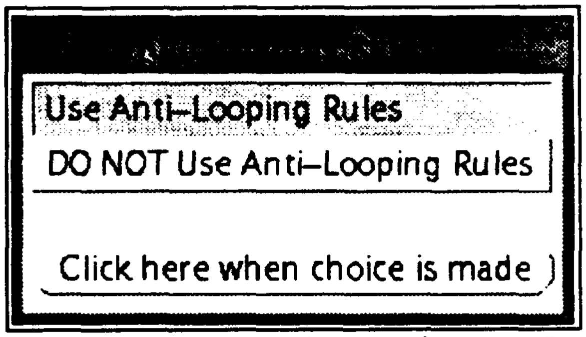

Figure 12 Anti-Looping Rule Choice Box.

The next option presented is how the communication system(s) is (are) to be generated: randomly by TACFONE-NATO, or by reading in a user defined communication system from a file, see Figure 13. The format for the user defined

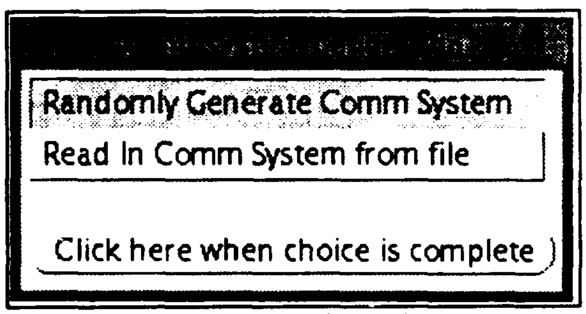

Figure 13 Communication System Generation Choice Box.

communication system file is discussed in Chapter III, INPUT FILES.

If the communication system is to be read in from a file, a choice of how formations are to be numbered is provided. The choices are: manually from the communication system file defined by the user, or automatically by TACFONE-NATO utilizing the STANAG 4214 protocol and the other options selected earlier, see Figure 14. The choice is made in the way as for previous selections. The reading in of user defined numbers allows for the testing of a numbering scheme that may not follow the exact protocol of the STANAG. If the "read comm system from file" option is selected, the program will request the file containing the communication system information.

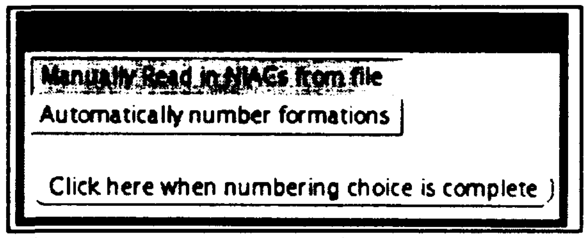

Figure 14 Formation Numbering Choice Box.

The next choice for a communication system being read in from a file is whether to read connections for the system in from a file or for TACFONE-NATO to generate the connections randomly, see Figure 15. The option for reading the connections in from a file allows the user to define exact inter-host connections and also lateral

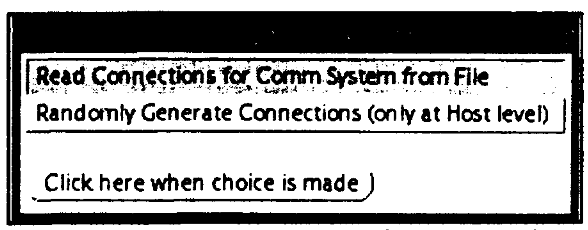

Figure 15 Connection Choice Box.

connections which TACFONE-NATO does not generate randomly (all parent-child connections are always constructed by default).

The model automatically institutes a method of updating the switches' routing tables that will not allow looping to occur with lateral connections. The option of randomly generating the connections will result in connections between the Host formations only, as prescribed by the STANAG 4214 protocol. If connections are to be read in, the program will ask for the name of the file containing the connections data, see Figure 16. The format for this file is discussed in Chapter III, INPUT FILES.

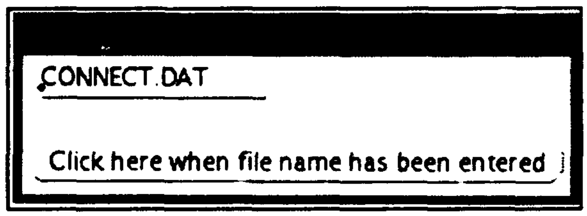

Figure 16 Connection File Name Box.

At this point, based on the initial options chosen, TACFONE-NATO commences the run. All runs present a window containing two level meters that track the real time percentage of calls made and percentage of calls successful to that point. If graphics were chosen, the communication system and the routing of calls will be displayed on the screen as previously discussed. For the user determined number of communication systems option, once the system is generated and drawn, the option to generate calls for the current system or to continue on to the next system is presented, see Figure 17. This option is provided if the user wishes to only observe the communication system set up and then move on to the next system. In either case, any windows can be resized at this point by clicking and dragging the corner. Once the inspection of the system is complete, a click on the appropriate choice for generating or not generating calls is made.

If calls are to be generated for the system, a "start making calls" button will be presented, see Figure 18. This allows for an additional opportunity to resize any windows prior to calls being generated.

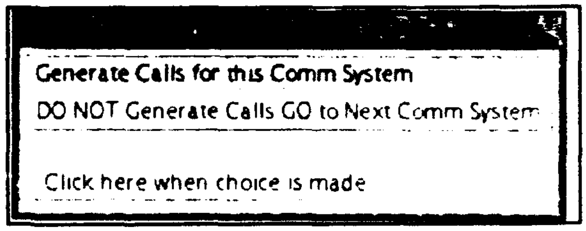

Figure 17 Generate Calls For This Comm System Box.

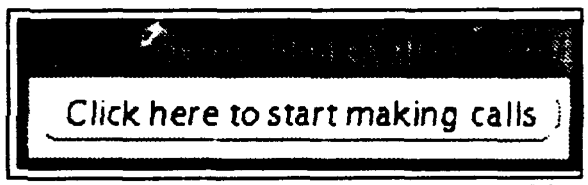

Figure 18 Start Making Calls For System Button.

Once calls are started, the windows will not resize until either a call fails or the calls are completed. If a failed call occurs, any window can be resized to allow for closer inspection of the situation which caused the failure. Once the inspection is complete, a simple mouse click in the "continue" box, will resume the run.

Upon completion of all calls, a button is displayed to "remove this communication system", see Figure 19. This allows the user to inspect the system graphically prior to either moving to the next system or completing the model run. If more then one communication system is to be generatcd, the user will be presented with the option

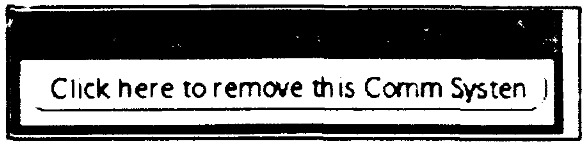

Figure 19 Remove This Comm System Box.

of making calls for each system as they are generated and drawn on the screen. Upon completion of calls for the last communication system, the requested output is written to the appropriate files. The user can then print out these files when desired. The format for the output files is discussed in Chapter IV, OUTPUT FILES.

III. INPUT FILES

Figure 20 summarizes all possible input files used by TACFONE-NATO. Formats for these files will be discussed separately.

<u>REQUIRED FILES (named as below):</u>

AREACODE.DAT--lists subsidiary area codes for each nation.

UNIT.DAT --lists units available from each nation.

<u>OPTIONAL FILES (named as desired):</u>

Routing Capabilities--lists whether each nation's communications equipment is single or multiple-routing capable.

Duplicate Capability--lists whether each nation's communications equipment is duplicate-capable or not.

CommSystem Data --lists the units of a manually generated CommSystem.

Connection Data --lists the connections of a manually generated CommSystem.

Figure 20 Input file types.

A. FILES REQUIRED FOR ALL RUNS

There are two files required for the TACFONE-NATO simulation model to work regardless of the type of run desired. These files are "AREACODE.DAT" and "UNIT.DAT". The names of these files are not negotiable and must be exactly as appears above. The AREACODE.DAT file contains all subsidiary area codes assigned to each nation as per STANAG 4214. The UNIT.DAT file contains information regarding the number of each type of unit available from each nation in assembling a NATO force. The exact format of each file will now be discussed separately.

1. Format For AREACODE.DAT File

The basic format for this file is:

1. A header line at the top of the file (exact wording not critical).

2. A single line for each nation which delineates the area codes for that nation. The format for each line is:

   Name of nation, XXX XXX XXX 0;

   where the XXX's represent subsidiary area codes and the 0 is the last entry on the line. The nations must be listed in the same order as they appear in STANAG 4214, see Figure 21.

As noted, the order of nations must be as in Figure 21. The spelling, including capitalization, for each nation must be exactly as in Figure 21. The exact order of the numbers for each nation is not critical, but it should be noted that those numbers appearing first in the lists will be the first ones used. The 0 at the end of each line is critical as it denotes the end of subsidiary area codes for a particular nation. It is **not** permissible to exclude a country from the list if it has no subsidiary area codes. Instead, simply put a 0 as the only entry in its list of subsidiary area codes (see NatoComm in Figure 21). The list in Figure 21

```
Subsidiary Area Codes for Each Nation
Belgium        200 300 400 0
Canada         201 301 401 0
Denmark        202 302 402 0
France         818 203 218 718 303 318 618 403 418 0
Germany        819 204 219 719 304 313 619 404 419 0
Greece         205 305 405 0
Iceland        206 306 406 0
Italy          207 307 407 0
Luxembourg     208 308 408 0
Netherlands    209 309 409 0
Norway         210 310 410 0
Portugal       211 311 411 0
Turkey         212 312 412 0
UnitedKingdom  213 313 413 0
UnitedStates   816 214 216 716 314 316 616 414 416 0
NatoComm       0
ComLandJut     315 0
Spain          217 317 417 0
```

Figure 21 Example of AREACODE.DAT file format.

denotes the assignments made in STANAG 4214. These numbers may be changed without adversely affecting the model.

2. Format For UNIT.DAT File

The UNIT.DAT file determines the pool of units available for the model to draw from when randomly generating force structures. The basic format for this file is:

1. A header line at the top of the file (exact wording not critical).

2. A single line for each nation which delineates the number of each type of unit available for force construction from that nation. The format for each line is:

    Name of nation, X1 X2 X3;

    where the X1 represents the number of corps available, X2 represents the number of divisions available, and X3 represents the number of brigades available. X3 is the last entry for a line. The nations must be listed in the same order as they appear in STANAG 4214. See Figure 22.

The Number of Corps, Divs, and Brigades for each country			
Belgium	2	6	18
Canada	1	3	9
Denmark	1	3	9
France	4	12	36
Germany	4	12	36
Greece	1	3	9
Iceland	1	3	9
Italy	1	3	9
Luxembourg	1	3	9
Netherlands	1	3	9
Norway	1	3	9
Portugal	1	3	9
Turkey	1	3	9
UnitedKingdom	2	6	18
UnitedStates	4	12	36
NatoComm	1	0	0
ComLandJut	1	0	0
Spain	1	3	9

Figure 22 Example of UNIT.DAT file format.

The order of nations must be as in Figure 22. The spelling, including capitalization, for each nation must be exactly as in Figure 22. It is not permissible to exclude a country from the list if you do not wish it to have any units available. Instead, simply put in 0's for the number of Corps, Divisions, and Brigades available for that nation. Changing the numbers in this file will only change the relative likelihood of randomly choosing units from any particular nation when randomly generating a CommSystem.

WARNING: When randomly generating a communication system, the model replaces any unit which requires a Host to be assigned a new subsidiary area code when the Host nation has no more subsidiary area codes to be assigned. This means that it is possible for the program to go into an infinite loop in search of a unit which does not create this requirement if no such unit exists. Therefore, it is advisable to maintain a relatively wide variety of units available from the different nations.

B. FILES REQUIRED FOR MANUAL INPUT

Additional files may be required if it is desired to manually enter data defining some or all of the aspects of the communication system to be analyzed. These files are not required if these data are to be randomly generated. The formats for these additional files will now be discussed.

1. List of Routing Capability for each Nation

If desired, the routing capability (single-routing or multiple-routing) for each nation's communications equipment can be read in from a file. This file may be named as desired since the program will ask for the name of the file to be read. The default filename is "ROUTING.DAT". The basic format for this file is:

1. A header line at the top of the file (exact wording not critical).

2. A single line for each nation which delineates whether that nation's communications equipment is single-routing capable. The format for each line is:

   Name of nation, BOOLEAN;

   where BOOLEAN represents either a "True" (single-routing) or "False" (multiple-routing) entry. The nations must be listed in the same order as they appear in STANAG 4214. See Figure 23.

Country	Single Routing (T=Single Routing, F=Multiple)
Belgium	True
Canada	False
Denmark	True
France	False
Germany	True
Greece	True
Iceland	True
Italy	False
Luxembourg	False
Netherlands	True
Norway	True
Portugal	True
Turkey	False
UnitedKingdom	False
UnitedStates	False
NatoComm	False
ComLandJut	True
Spain	True

Figure 23 Example of Routing data file format.

Again, the order of nations must be as in Figure 21. The spelling, including capitalization, for each nation must be exactly as in Figure 23. The spelling of "True" and "False" must also be as in Figure 23. It is not permissible to exclude a country from the list, an assignment of "True" or "False" must be made for each nation.

2. List of Duplicate-Capability for each Nation

If desired, the duplicate-capability (duplicate-capable or not duplicate-capable) for each nation's communications equipment may also be read in from a file. This file may be named as desired since the program will ask for the name of file to be read. The default filename is "NDC.DAT". The basic format for this file is the same as for routing capability except that a "True" entry represents not duplicate-capable and a "False" entry represents duplicate-capable, see Figure 24. All comments made about the Routing data file also apply to the not duplicate-capable data file as well.

Country	Not Duplicate Capable (T=NotDupCap, F=DupCap)
Belgium	False
Canada	False
Denmark	True
France	True
Germany	False
Greece	False
Iceland	False
Italy	False
Luxembourg	False
Netherlands	True
Norway	False
Portugal	False
Turkey	False
UnitedKingdom	False
UnitedStates	True
NatoComm	False
ComLandJut	True
Spain	False

Figure 24 Example of Not Duplicate Capable file format.

3. Manually Generated CommSystem

If desired, a manually generated CommSystem may be entered for full analysis or for just numbering and setting up routing tables. A file containing a manually generated CommSystem may be given any name desired since the name of the file to be read will be asked for by the program.

The default filename is "NETWORK.DAT". The format for a manually generated CommSystem is:

1. A header line at the top of the file (exact wording not critical).

2. A single line for each unit in the CommSystem. The format for each line is:

   Level, Country, UnitType, UnitNumber, XXX;

   where XXX is the area code for that unit if it is desired to not have the model automatically number the system. The units are entered in depth-first order: Host1, Primary1 for Host1, Secondary1 for Primary1 of Host1, ..., SecondaryN for Primary1 of Host1, Primary2 for Host1, all Secondaries of Primary2 for Host1, ..., PrimaryK for Host1, all Secondaries of PrimaryK for Host1; Host2, ...

3. A line containing the string:

   "EndOfData".

   Figure 25 illustrates the proper basic format and Figures 26 and 27 show the CommSystem it represents.

Level	Country	UnitType	UnitNumber	AreaCode
Host	UnitedStates	Corps	2	714
Primary	UnitedStates	Division	1	714
Secondary	Germany	Brigade	10	816
Secondary	Germany	Brigade	11	214
Primary	France	Division	4	714
Secondary	Belgium	Brigade	6	714
Primary	Germany	Division	4	714
Host	Germany	Corps	3	604
Primary	Italy	Division	1	604
Primary	Portugal	Division	3	604
Secondary	Luxembourg	Brigade	1	604
EndOfData				

Figure 25 Example of format for reading in a CommSystem.

There is no limit to the number of Primaries may be assigned to a Host or Secondaries to a Primary. The spelling of all words is critical however. "Host", "Primary" and "Secondary" must be spelled and capitalized as shown; the countries must be spelled and capitalized as shown in the

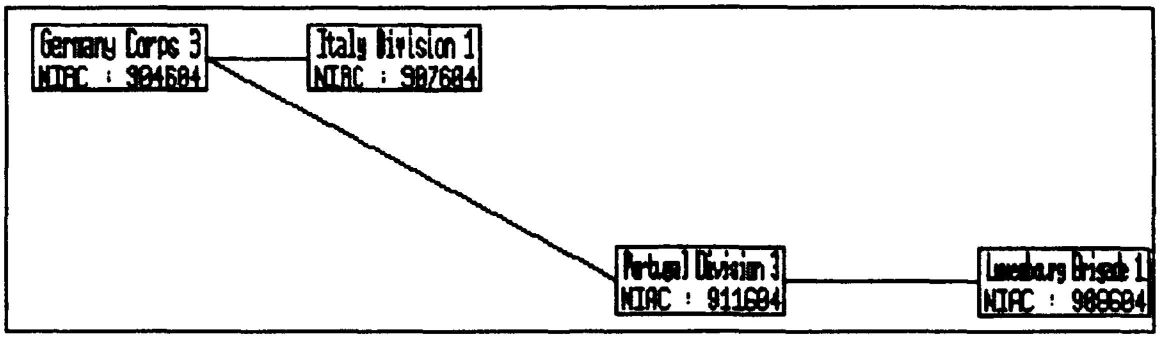

Figure 26 Network 2.

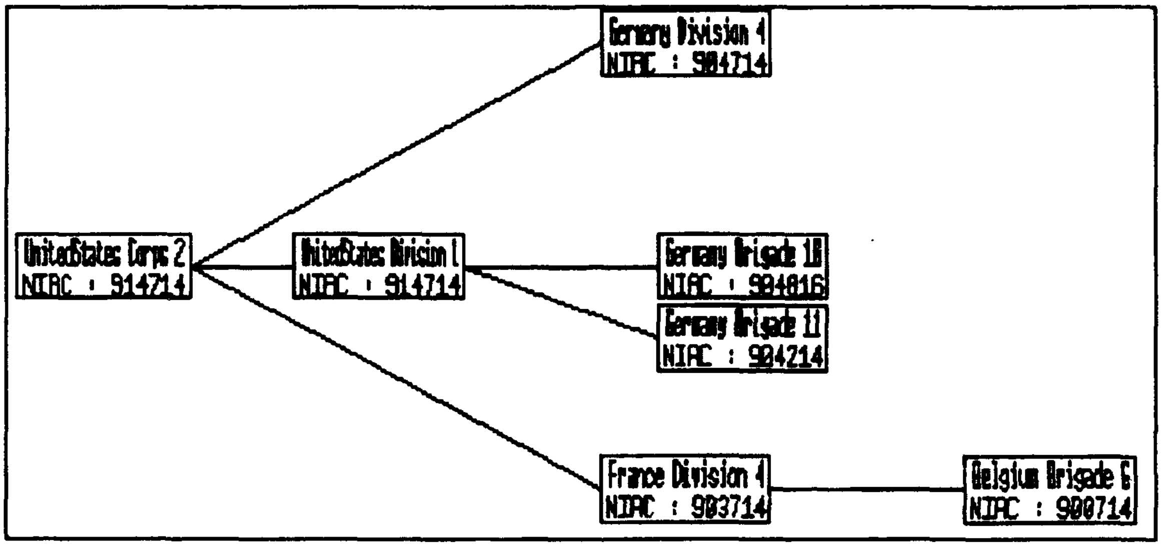

Figure 27 Network 1.

AREACODE.DAT file example (Figure 21), and the spellings for "Corps", "Division", and "Brigade" follow suit. There are no allowed unit types other than "Corps", "Division", and "Brigade". The only restriction on unit numbers is that they must be an unique integer entry. An area code must be assigned even if the program is going to automatically number. It is recommended to simply enter 0 for the area code in this case. All data in the file after the "EndOfData" line will be ignored.

4. Manually Connecting a CommSystem

If desired, when a CommSystem is manually generated, the exact connections between Hosts may be manually entered through a file, rather that have the program randomly generate them. This input file also allows for the insertion of lateral connections. NOTE: All formations will automatically be connected to their parent/children so it is not necessary to put these connections in the file. Only enter inter-host and lateral connections. A file containing the connections for a manually generated CommSystem may be given any name desired since it will be asked for by the program. The default filename is "CONNECT.DAT". The format for a manually connections is:

1. A header line at the top of the file (exact wording not critical).

2. A single line for each connection desired. The format for each line is:

   Country1, UnitKind1, UnitNumber1, Country2, UnitKind2, UnitNumber2;

   where the first three entries identify one of the units to connect and the second three identify the second unit to connect. Figure 28 illustrates the proper basic format.

3. A line containing the string "EndOfData".

Again, spelling of all words is critical and must be as previously mentioned. There is no limit to the number of connections which can be made. The program will not connect

Country1	UnitKind1	Num1	Country2	UnitKind2	Num2
UnitedStates	Corps	2	Germany	Corps	3
Italy	Division	1	Portugal	Division	3
Germany	Brigade	10	Germany	Brigade	11
EndOfData					

Figure 28 Example of format for reading in connections.

two units more than once although an attempt to do so will not harm the program. If an attempt is made to connect a unit to itself or to a unit which does not exist (existing units can be obtained from the file containing the read in CommSystem), the program will notify the user of the problem and terminate execution. It is the user's responsibility to ensure that the Hosts are connected so as to comprise at least a minimum spanning tree. Failure to do this will result in numerous failed (dead-end) calls.

IV. OUTPUT FILES

There are two types of output files that can be chosen in the initial options menus. Both options will have a header that appears as follows:

"This output was generated on: Mon Aug 4 09:15:15 1993".

The date and time will allow the user to identify different runs that may have similar force structures. The first option of generating full communication system output lists the information discussed previously in the format shown in Figure 29.

```
Information For Network 1
Formation Number 1
Formation Level: Host
Country: UnitedStates  Unit Kind: Corps  Unit Number: 2
Not Duplicate Capable   Multiple Routing
National Identifier: 914 Area Code: 604  NIAC:  904604
External Switch 1 is connected to:
Country: Germany  Unit Kind: Corps Unit Number: 3
National Identifier: 904 Area Code: 604  NIAC:  904604
The outgoing routing table contains the following numbers:
604 819 204
The incoming routing table contains the following numbers:
714 816 214
Internal Switch 1 is connected to:
Country: France  Unit Kind: Division Unit Number: 4
National Identifier: 903 Area Code: 714  NIAC:  903714
The outgoing routing table contains the following numbers:
903714 900714 917816
The incoming routing table contains the following numbers:
914714 904816 904214 904714 604 819 204
```

Figure 29 Full Communication System information output

The same information is given for each formation in the communication system. The external switches are switches connecting the formation to formation in another network. The internal switches connect the formation to a formation within it's network.

The option for numbering information only gives an abbreviated version of Figure 29, the information on communication equipment capabilities and incoming routing tables is not given. The switch information is no longer displayed as external and internal, just a listing of the switches, what formation it is connected to and the outgoing routing table contents. An example of this output can be seen in Figure 30.

The Statistical output lists the options chosen for the use of anti-looping rules(or not), the use of the STANAG numbering rule change and the type of run at the top of the

```
Information For Network 1
Formation Number 1
Formation Level: Host
Country: UnitedStates  Unit Kind: Corps  Unit Number: 2
National Identifier: 914  Area Code: 604   NIAC: 904604
Switch 1 is connected to:
Country: Germany   Unit Kind: Corps Unit Number: 3
The outgoing routing table contains the following numbers:
604 819 204
Switch 2 is connected to:
Country: France   Unit Kind: Division Unit Number: 4
The outgoing routing table contains the following numbers:
903714 900714 917816
```

Figure 30 Numbering only information output.

output file. The information provided from each run is the communication system number, the run number, the number of calls made, number of successful calls, number of failures, and the success rate. The same information is provided for the totals of each communication system and the total of all communication systems. The estimated mean percent successful calls, estimated variance and the 95 percent confidence interval are also provided at the top of the output when the type of run is "calculate percent successful calls". Figure 31 is an example of this output file.

Anti-Looping rules not used.
Numbering change implemented.
Only one path checked for each call.

Estimated percent successful for a CommSystem = 90.52407
Estimated Variance of average percent successful = 153.82617
Ninety-five percent Confidence Interval = (86.087169,94.963644)

List of results for each run:

CommSystem	Run	Calls	Successes	Failures	Success Rate
1	1	5852	4075	1777	69.63
1	2	5852	4185	1667	71.51
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
30	29	4970	3950	1020	79.48
30	30	4970	3992	978	80.32

List of results for each CommSystem:

CommSystem	Runs	Calls	Successes	Failures	Success Rate
1	30	175560	123025	52535	70.08
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
30	30	149100	118465	30365	79.45

Total results:

CommSystems	Calls	Successes	Failures	Success Rate
1	2850300	2287056	563244	80.24

Figure 31 Statistical output.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Technical Information Center Cameron Station Alexandria VA 22304-6145	2
2.	Library, Code 052 Naval Postgraduate School Monterey CA 93943-5002	2
3.	Michael A. Dorko 12785 Elmhurst Dr Moreno Valley CA 92555	2
4.	Robert G. Schultz 218 Whorley Dr Nashville TN 37217	2
5.	Michael P. Bailey Department of Operations Research Naval Postgraduate School, Code 30/Ba Monterey CA 93943-5000	1
6.	William G. Kemple Department of Operations Research Naval Postgraduate School, Code 30/Ke Monterey CA 93943-5000	1
7.	Michael G. Sovereign Department of Operations Research Naval Postgraduate School, Code 30/Sg Monterey CA 93943-5000	3
8.	Joint Interoperability Engineering Organization TBBB (SYS INTERGRATION DIV, CTR FOR STDS) Fort Monmouth NJ 07703-5613	2
9.	James R. Tucker LOGICON 145 Wyckoff Rd Eatontown NJ 07724-1842	1