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MODELING AND ANALYSIS OF

POST-CONFLICT RECONSTRUCTION

THESIS

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AFIT/GOR/ENS/04-10

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Wright-Patterson Air Force Base, Ohio

AFIT/GOR/ENS/04-10

MODELING AND ANALYSIS OF POST-CONFLICT RECONSTRUCTION

THESIS

Presented to the Faculty

Department of Operational Sciences

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Operations Research

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March 2004

AFIT/GOR/ENS/04-10

MODELING AND ANALYSIS OF POST-CONFLICT RECONSTRUCTION

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Abstract

The forces at play in reconstruction operations are a complex system of time phased interlocking cause and effect relationships that are not thoroughly understood. A model capable of capturing the general dynamics involved in post-conflict reconstruction would provide insight to decision makers regarding potential policy alternatives. This research effort demonstrates the viability of using systems dynamics modeling techniques to simulate the establishment of public order and safety in a post-conflict reconstruction operation (Phase IV operations). A high level generic framework is developed that can be used as a general template for modeling post-conflict reconstruction. It is then demonstrated with a notional test case based on the OIF AOR.

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MODELING AND ANALYSIS OF POST-CONFLICT RECONSTRUCTION

I. Introduction

Background

The term post-conflict reconstruction denotes the process of putting the pieces of

civil society back together after a conflict. It includes the rebuilding of both physical

infrastructure and the rebuilding of the intangible socioeconomic institutions that make

civilized society possible (Harme and Sullivan,2002:89). The establishment of the rule of

law, good governance, and social and economic well being falls under the purview of

post-conflict reconstruction (Harme and Sullivan, 2002:89). Information on post-conflict

reconstruction spans the literature on peacekeeping, peace enforcement, nation building,

and stability operations (Dobbins, McGinn, Crane, Jones, Lal, Rathmell, Swanger, and

Timilsina, 2003:1).

The United States launched its first large scale efforts at post-conflict

reconstruction in Germany and Japan following the Second World War (Dobbins *et al.*,

2003:xiii). The result of the efforts of the U.S. and its allies were stable and prosperous

democracies in both Germany and Japan. The success of these operations demonstrated

that post-conflict reconstruction could succeed, that democracy was transferable, and that

military forces could be used to underpin rapid, fundamental, and enduring societal

change (Dobbins *et al.*, 2003:xiii).

Since the end of the Cold War the United States has become involved in increasingly ambitious post-conflict reconstructions (Dobbins *et al.*, 2003:xv). The rise of international terrorism has highlighted the potential threat to U.S. security posed by failed or failing states (Harme and Sullivan, 2002:85). Failed states can be used as sanctuaries for terrorists (Harme and Sullivan, 2002:85); it is a stated national security objective of the United States to "eliminate terrorist sanctuaries and havens" (*National Security Strategy for Combating Terrorism*, 2003:22). One way that the international community can deny terrorists these safe havens is by intervening and reconstructing an effective government in the previously ungoverned territory of a failed state (Harme and Sullivan, 2002:88).

Success in a post-conflict reconstruction depends on nearly simultaneous progress in the four "pillars" of post-conflict reconstruction: (1) security, (2) justice and reconciliation, (3) social and economic well-being, and (4) governance and participation (Feil, 2002:98). Progress in all four of these areas is inextricably linked (Feil, 2002:98). If progress in one area is to endure it must be accompanied by progress in the other areas. Nevertheless, "security, which encompasses collective and individual security to the citizenry" and those establishing security, "is the foundation on which success in the other issue areas rests" (Feil, 2002:98).

The establishment of security in a post-conflict environment is of critical importance to the success of a reconstruction operation (Play to Win, 2003:4). When the international community intervenes in a post-conflict environment it is often the security vacuum at the heart of the situation that acted as the catalyst for the intervention (Play to

Win, 2003:10). The term security "addresses all aspects of public safety, particularly the establishment of a safe and secure environment and the development of legitimate and stable security institutions" (Play to Win, 2003:10).

Recently the United States has become involved in large scale post-conflict reconstructions in both Afghanistan and Iraq. These operations face the daunting task of simultaneously addressing the four pillars of post-conflict reconstruction and, in both countries, the establishment of security has emerged as a critical issue (Grymes, 2003:1;United Nations/World Bank, 2003:3). For instance, in Afghanistan establishing security is "the overriding and supreme requirement for continued progress towards stability" (Grymes, 2003:1). Currently, the government of Afghanistan cannot provide its population with basic protections and services that the government of a modern nation-state is expected to provide (Grymes, 2003:7). A tool that could provide insight to decision makers about how to employ their resources more effectively to successfully establish security could save money and lives.

Problem Statement

The forces at play in a post-conflict reconstruction are complex, and do not fall under the purview of any single academic discipline. The study of post-conflict reconstruction is inherently interdisciplinary; military theorists, economists, sociologists, relief organization personnel, political scientists, and operations research analysts have all made contributions to the understanding of post-conflict reconstruction. Unfortunately,

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all of the interlocking cause and effect relationships involved in a post-conflict reconstruction are not thoroughly understood.

A model capable of capturing the dynamics involved in a post-conflict reconstruction would be helpful in providing insight to decision makers about what policies should be followed to produce a desirable outcome to a post-conflict reconstruction. It could help countries that have been shattered by war to put the pieces of civil society back into place, while saving valuable resources such as money and, more importantly, lives. A first step towards developing a comprehensive post-conflict reconstruction model would be the development of a model that can simulate the initial establishment of security in a post-conflict reconstruction.

The overall goal of this research effort was to demonstrate the viability of using system dynamics modeling techniques to simulate post-conflict reconstruction. This was done by constructing a general model for simulating the initial establishment of security in a post-conflict reconstruction, and then by applying the general model to a notional scenario and analyzing the results.

Methodology

System dynamics models represent social systems "as flow rates and accumulations linked by information feedback loops involving delays and non-linear relationships. Computer simulation is then the means of inferring the time evolutionary dynamics endogenously created by such system structures" (Lane, 1997:1037). This research effort explored the previous literature relevant to the simulation of post-conflict

reconstruction with such a model. This includes previous research that has been conducted on post-conflict reconstruction itself and on systems dynamics.

The exploration of the previous research on post-conflict reconstruction focused on studies that have tried to identify or explain the relationships between the influential factors that interact in such an operation. The systems dynamics literature was explored for research that provides insight into how apt a system dynamics model is for the simulation of post-conflict reconstruction.

Based on the previous research done into post-conflict reconstruction, the influential factors involved in a post-conflict reconstruction are identified and the functional forms of their interactions are suggested. These factors and functional relationships are then used in the creation of a general systems dynamics model for simulating post-conflict reconstruction. This model was then applied to a notional scenario based on Operation Iraqi Freedom.

Summary

This introduction explained the relevance of this research effort and outlined its approach. The relevant literature on nation building and systems dynamics modeling is presented in Chapter II. The methodology for the construction of a general post-conflict reconstruction model is discussed in Chapter III. The general model is then applied to a notional scenario in Chapter IV. Conclusions are drawn and areas for further research are identified in Chapter V.

II. Literature Review

Introduction

This chapter provides an overview of the literature relevant to the development of a post-conflict reconstruction model. Concepts of systems dynamics are first introduced. Various sources are then summarized to provide insight into the relationships underlying the establishment of security in a post-conflict reconstruction.

Systems Dynamics Literature

As was mentioned in the first chapter, system dynamics models represent social systems as webs of level values and rate of change interconnected by non-linear relationships, information feedback loops, and time delays (Lane, 1997:1037). System dynamics modelers build these interconnected webs of level values (i.e., state variables) and flow rates (i.e., rates of change) to represent how the various parts of complex systems interact with each other. Once the model is built to represent the complex system of interest, computer simulation is used as "the means of inferring the time evolutionary dynamics endogenously created by such system structures" (Lane, 1997:1037).

The study of system dynamics owes a great deal to the work of J. W. Forrester. In 1961 Forrester effectively founded the study of system dynamics with the publishing of his seminal work *Industrial Dynamics*. In it, Forrester explained how the operations of a

firm can be simulated as a system of level values and flow rates connected by information feedback loops (Forrester, 1961:67).

In *Industrial Dynamics* Forrester used a generic multistage distribution system as the subject of his example model. The multistage distribution system was modeled as a factory, a factory warehouse, a distribution center, and a retail outlet. Customers order goods at the retail outlet and the goods are delivered in one week. Replacement stock orders from the retail outlet to the distribution center take three and one-half weeks to process at the retail outlet, one week to fill at the distribution center, and one week to be shipped from the distribution center to the retail outlet. Replacement orders from the distribution center to the factory warehouse take two and one-half weeks to process at the distribution center one week to fill at the factory warehouse and two weeks to ship to the distribution center. It takes one week to process an order from the factory warehouse to the factory and six weeks to change the factory's production rate (Forrester, 1961:22). This system is illustrated by figure 2.1.

Forrester used this model to simulate how a multistage distribution system operates. He demonstrated that the delays and information feedback loops in the system cause long order backlogs and inefficiencies if a mild fluctuation in the customer demand of plus or minus 10% from fall to spring is introduced (Forrester, 1961:26).

Legend

$\bigcirc$ n   Delay of n weeks

⟵   Flow of Goods

⟵---   Flow of Orders

Orders from customers
(assumed rate)

Delivery of goods
to customers
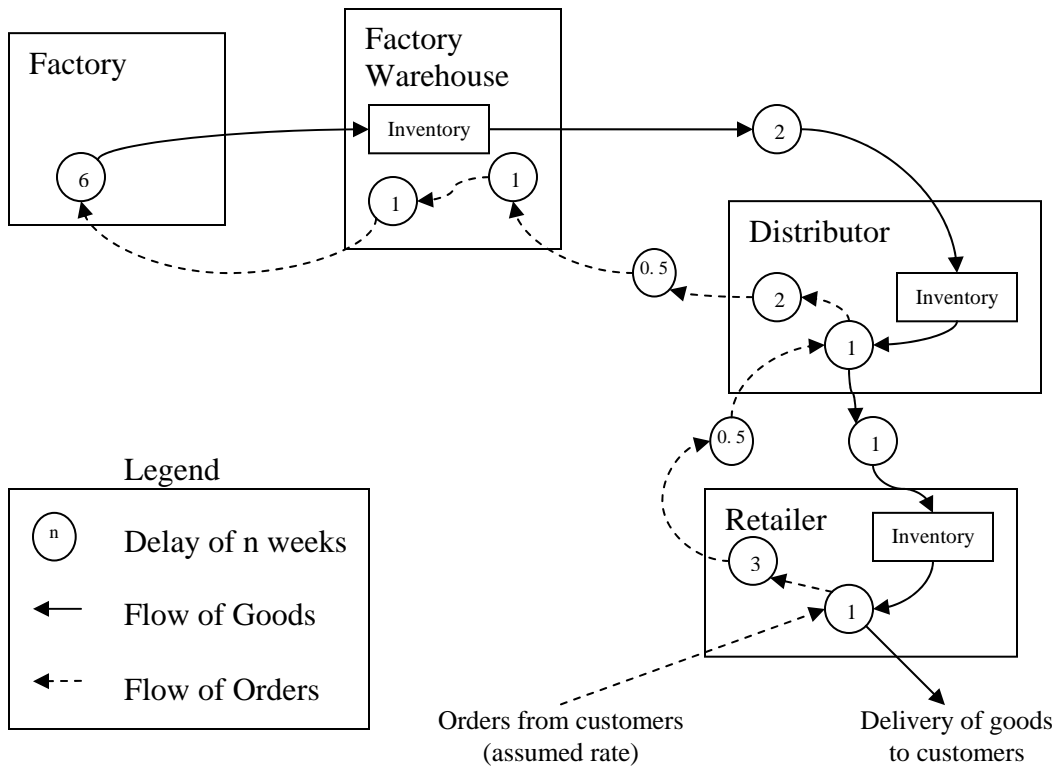
Source: Forrester, 1961: 22

Figure 2.1. Systems Dynamics Model of a Multistage Distribution system

By simulating the operations of a distribution system in this way Forrester was
able to demonstrate that the time phased interactions and non-linear relationships that
often exist in information feedback loop systems can lead to counter-intuitive behavior
that can be difficult to manage. In some instances, policies that are implemented based
on conventional wisdom or their intuitive appeal may end up producing the opposite of
their intended result. *Industrial Dynamics* suggested how these systems can be simulated
so that better policies can be developed.

In 1969 Forrester expanded the scope of system dynamics with his book *Urban Dynamics* where he applied the tools of system dynamics to the problem of urban stagnation (Forrester, 1969:1). In *Urban Dynamics* Forrester simulated how a city proceeds through stages of rejuvenation and decay in order to determine what policies could be followed to encourage revitalization and prevent economic stagnation (Forrester, 1969:1). To accomplish this Forrester structured his model as a system where urban components of industry, housing, and people interact and develop over time (Forrester, 1969:1). This model is far more complex than the relatively simple model employed in *Industrial Dynamics*. A full discussion of Forrester's urban dynamics model is beyond the scope of this paper. However, it is important to note what Forrester was able to achieve with his urban dynamics model.

Using the building blocks of level values, flow rates, information feedback loops, and time delays introduced in *Industrial Dynamics*, Forrester was able to create a model of a generic city that was capable of endogenously simulating the dynamics of urban decay and revival (Forrester,1969:129 and Lane,1997:1255). With his model, Forrester was able to experiment with various policies and determine what types of programs tended to encourage urban renewal. Forrester's model provides "powerful insights into the structural causes behind urban stagnation" (Lane,1997:1255). Some critics found some of Forrester's conclusions to be counter-intuitive (Lane,1997:1255). For example, Forrester's conclusion that, instead of rejuvenating depressed inner cities, a low-cost housing construction program actually contributes to urban decline (Forrester, 1969:67).

With the publishing of *World Dynamics* in 1971, Forrester again demonstrated the versatility and usefulness of the system dynamics methodology, by using it to simulate the interactions and "mutual interplay between [the world's] demographic, industrial, and agricultural subsystems" (Forrester, 1971:vii). Before *World Dynamics* was published most studies on the sustainability of world development focused on the isolated effects of each of the subsystems (Forrester, 1971:vii). *World Dynamics* used the modeling techniques of system dynamics to study the interaction of these subsystems to ascertain their overall effects on each other, demonstrating that system dynamics was a useful tool at synthesizing disparate fields of study into a single model that taken as a whole is greater than the sum of its subsystems (Forrester, 1971: vii).

Forrester's work in *Urban Dynamics* and *World Dynamics* is highlighted here because it illustrates the range of problems to which system dynamics techniques may be successfully applied. System dynamics methods are designed to allow for the simulation of complex systems. These methods are uniquely suited for the simulation of complex social systems like the functioning of a government or the dynamics of international development (Forrester,1969:107). Complex social systems are characterized by their "interlocking structure of feedback loops" (Forrester,1969:107). They typically are of higher order, nonlinear, contain both positive and negative feedback loops, and "bring together many factors which, by quirks of history, have been compartmentalized into isolated intellectual fields" (Forrester,1969:109).

Recently, systems dynamics methods have been applied to the military sphere through the Strategic Management System (STRATMAS), a program that uses systems

dynamics and other models to improve command and control (Woodcock, 2003:111).

Woodcock and other researchers involved in the development of STRATMAS have

identified the need for "more integrated functional and coordinated command processes,"

and have proposed the use of validated models in support of "rapid situation assessment

and proactive command and control and crisis management" (Christensson and

Woodcock,2002:2).

In a recent paper entitled "Perceptual and Societal Dynamical Models for

Compliance and Peace Building" Woodcock argues that "Neuro-Archeology" can be

used to "provide insights that may facilitate the process of compliance and peace

building" (Woodcock, 2003:112). "Neuro-Archeology" is defined as the process of

discovering "artifacts of the activities of the human brain . . . in the writing or other

activities produced by the individual concerned" and using these artifacts to reconstruct

the internal dynamics and models that may have been responsible for their creation

(Woodcock, 2003:112). Trotsky's description of the Russian Revolutions of 1917 is then

used to construct a systems dynamics model of the overthrow of the Tsarist government

in Russia (2003:128). Woodcock concludes that such models could help provide

understanding of how individuals perceive "the complex problems with which they are

faced", and that such understanding could support the process of compliance and peace

building "in an uncertain, complex and dangerous world" (2003:135).

Like the process of world development, urban renewal, and revolution in Tsarist

Russia, a post-conflict reconstruction takes place in a complex evolving social system.

There are various fields of study from military theory, demographics, economics,

political science, and sociology, among others, that make predictions about post-conflict reconstructions and their environments. A post-conflict reconstruction model would have to be populated with data from all these fields of study. A mathematical model capable of capturing the dynamics of a post-conflict reconstruction operation should have the characteristics of a systems dynamics model. It should be nonlinear and higher order, contain both positive and negative feedback loops, and bring together disparate intellectual fields. Post-conflict reconstruction operations are conducted at the edge of anarchy, where the traditional assumptions of economics and political science may not apply. In the past, systems dynamics has been used to successfully model social systems that take place at the nexus of economics, political science, and sociology. If the proper relationships are captured, a system dynamics model can be used to simulate a post conflict-reconstruction.

Post-Conflict Reconstruction Literature

Since World War II the United States has become involved in close to a dozen post-conflict reconstruction operations (Dobbins *et al.*, 2003:2) These operations range from the larger projects of postwar Germany, Austria, and Japan to the shorter and more limited operations in Lebanon, Grenada, and Panama. Over the years these operations, and others like them, have been studied providing key lessons (Dobbins *et al.*, 2003:2).

One of the lessons that has been learned is that security must be established for a post-conflict reconstruction operation to be successful. "Play to Win," the final report of the Bi-partisan Commission on Post-Conflict Reconstruction, concluded that security is

essential to post-conflict reconstruction saying that while "every case is different, there is one constant—if security needs are not met, both the peace in a given country and the intervention intended to promote it are doomed to fail" (p. 4). In the article "Democracy by Force: A Renewed Commitment to Nation Building," von Hippel explains that reestablishing security in a country is one of the fundamental elements required in rebuilding and democratizing states after an intervention (p 106). Even if an intervention is able to successfully strengthen democratic institutions in a state, these "strengthened democratic institutions will not endure unless the state maintains the legal monopoly on force" (von Hippel, 2000:106).

The term security refers to the need to secure "the lives of citizens from immediate and large-scale violence," the need to secure the lives of "international assistors," and the need to "restore the state's ability to maintain territorial integrity" (Play to Win, 2003:10). This encompasses "all aspects of public safety, particularly the establishment of a safe and secure environment and the development of legitimate and stable security institutions" (Play to Win, 2003:10). For the purposes of this study, a military operation aimed at bringing about this security is a stability operation.

Integral to the establishment of a safe and secure environment and to the development of legitimate and stable security institutions is the establishment of the rule of law. In 2000, the commander of the Stabilization Force in Bosnia commissioned the U.S. Army Peace Keeping Institute to prepare a report on the lessons learned in Bosnia on the establishment of the rule of law. The report concluded that for the rule of law to take hold in a post-conflict situation three transitions must take place: the transition "from

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disorder to order", the transition "from a hostile to a permissive environment", and the transition "from institutional incapacity to capacity" (Mac Warner, Mike Dziedzic, Tyler Randolph, Peter Garcia, Susan Remis Silver, and Sandy Levinson, 2000:xi) .

The first transition, "from disorder to order" essentially refers to the cessation of large scale hostilities (Warner *et al..*, 2000:xi). Few gains can be made in establishing the rule of law while widespread combat operations are still taking place. The task of making this transition primarily falls on the shoulders of the military (Warner *et al*., 2000:xi).

The second transition, "from a hostile to a permissive environment" refers to the task of "shaping the environment so that the rule of law can take root" (Warner *et al.*, 2000:xi) . This means ensuring that the current power structures in the state are conducive to the rule of law. "Shaping the environment" is achieved through a combination of military operations conducted in concert with wider civilian political reforms (Warner *et al*., 2000:xi). For instance, if organized crime has taken root and is asserting a strong influence on political power in a state, dismantling that organized crime power structure would be essential to creating an environment in which the rule of law can be established (Warner *et al*.,2000:xi).

The third transition, "from institutional incapacity to capacity" refers to the development of legitimate and secure security institutions, such as police, courts, prisons, border guards, and a civil defense force (Warner *et al*.,2000:xi).   If the institutional capacity to bring criminals to justice while protecting human rights does not exist then there can be no sense of personal safety for the population at large (Perito 2003:3). The

development of these security institutions is essential for the protection of the fundamental rights that make a free and fair civil society possible. Without a sense of personal safety, refugees and internally displaced persons will not return home, former combatants will not lay down their arms and reintegrate into civilian life, farmers and merchants will not engage in food production or business activity, and parents will not send their children to school or seek economic opportunity (Play to Win, 2000:10).

In order to illuminate some of the underlying relationships involved in the establishment of security in a post-conflict reconstruction, this research effort drew on literature and sources from a wide variety of disciplines. In addition to the sources previously discussed, sources on law enforcement, economics, and the mechanics of insurgency and counter-insurgency were consulted.

Information on law enforcement and counter-insurgency operations in a post-conflict environment was drawn from U.S. military doctrine on operations other than war and peace operations, Department of Defense Joint Publications 3-07 and 3-07.3 respectively. Papers by Neumeyer from the *Journal of Peace Research* and Morcan and Reece from the National Bureau of Economic Research were consulted for information on the relationship between crime and the economy.

Information on the economics of post-conflict reconstruction was drawn from a variety of sources. The World Bank policy research report entitled *Breaking the Conflict Trap: Civil War and Development Policy* was indispensable as a general reference on civil war and its aftermath. United Nations resolution 53/92 entitled "The Causes of Conflict and the Promotion of Durable Peace and Sustainable Development in Africa"

was a useful source on the approach of the United Nations to post-conflict reconstruction. Dalgaard and Hansen's paper "On Aid, Growth and Good Policies" provided insight on the influential factors for economic growth in low income and post-conflict countries. The 2003 Center for Strategic and International Studies paper by Harme and others on post-conflict reconstruction in Iraq was useful as it identified critical infrastructures and essential services in post-conflict Iraq. Blanchard's book on macroeconomics and Okun's paper on economic growth and unemployment provided insight on the relationship between economic growth and unemployment rates.

Information on the mechanics of insurgency and counter-insurgency was drawn from the concluding report of the Challenges Project and a paper by Epstein and others on "Modeling Civil Violence: An Agent-Based Computational Approach." The Challenges Project was a five year study of multinational peace operation initiated by the Swedish National Defense College, and was useful as a source on measures of effectiveness in peace operations. The paper by Epstein and others presented an agent based model for civil violence and was indispensable as a source on the mechanics of insurgency and counter-insurgency.

Summary

Systems dynamics models represent complex social systems as webs of time phased interconnected level and rate variables. This type of model is well suited for simulating the complex and interconnected environment in which post-conflict reconstructions takes place. The literature relevant to post-conflict reconstruction was

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surveyed and the establishment of security is identified as critical to the success of a post-conflict reconstruction.

III. Methodology

Selection of Variables

In a system dynamics simulation the determination of the model's structure is critical (Forrester, 1969:114). "The first step in modeling is to generate a model that creates the problem" (Forrester, 1969:113). A model must contain "all the interacting relationships necessary to lead the system into trouble" (Forrester, 1969:113). If such a model cannot be created then there is no hope that the system can be restructured to lead the system's internal processes in a different direction (Forrester, 1969:113). In order to simulate the behavior of a complex system, variables must be selected that can represent different aspects of the state of the system.

This study identified 23 state variables for inclusion in the general case of the stability operations model. These variables were selected with the aim that collectively they describe the state of the stability operation adequately enough so that various macro-level policies can be tested using the simulation. These variables were also selected so that, as much as possible, they represent directly measurable real world phenomena. The 23 state variables used in this model fall into six basic categories: (1) the indigenous security institutions, (2) law enforcement, (3) the labor market, (4) insurgent activity and coalition military activity, (5) critical infrastructures, and (6) public opinion.

In a post-conflict reconstruction effort the development of legitimate and stable security institutions is critical to the establishment of a safe and secure environment (Play to Win, 2003:10). Creating a secure environment calls for diverse capabilities that

include "border patrol; customs support; weapons collection; large-scale (belligerent groups) and targeted (indicted persons) apprehension conducted in coordination with police" (Play to Win, 2003:10). Depending on the post-conflict situation, the intervening military will likely have to perform these security duties at the outset of a stability operation, but as the intervening military forces "adapt their roles and force levels to the changing security situation" the indigenous security forces will have to assume increased responsibility or a security gap could develop (Play to Win, 2003:10). This model captures the capacity of the indigenous security institutions by tracking their manning levels. The manning levels of the various security institutions are represented with six state variables: (1) the number of indigenous border patrol personnel, (2) the number of indigenous civil defense personnel, (3) the number of indigenous military personnel, (4) the number of indigenous border patrol personnel in training, (5) the number of indigenous civil defense personnel in training, and (6) the number of indigenous military personnel in training.

Law enforcement capabilities are important in post-conflict situations. "A peace operation must clear the way for the rule of law if a durable peace is to emerge from the disorder of internal conflict" (Warner *et al.* 2000:iii). U.S. *Joint Doctrine for Military Operations Other than War* (MOOTW) says that a foreign internal defense program aimed at assisting another nation against subversion and insurgency may need to combat threats to host nation security such as civil unrest, illicit drug trafficking, and terrorism (JP 3-07, 1995:III-10). These threats and others are often best combated with law enforcement personnel and to that end the U.S. has joint doctrine that governs the training

of indigenous law enforcement personnel (JP 3-07.3, 1999:III-5). This model captures the indigenous law enforcement capacity through two state variables: (1) the number of indigenous police officers and (2) the number of indigenous police officers in training. The effectiveness of anti-crime efforts is gauged in this model through the numbers of criminals and incarcerated criminals in the country; in this model a criminal is defined as anyone who seeks to support themselves through illegal means (i.e. theft, fraud, extortion).

The labor market is included in the model because getting people back to work and establishing some sort of economic normalcy after a conflict is important for creating and maintaining post-conflict security. A report of the UN Secretary-General listed disarmament, demobilization, and reintegration (DDR) of military forces after a conflict as one of the priorities of post-conflict peace building (UN, 1998: paragraph 66). The DDR helps reduce the risk of a return to conflict "both through the direct effects of decreased military expenditure and manpower and through the indirect effects on growth and poverty reduction of budget reallocation and the return of the labor force" (Collier, Elliott, Hegre, Hoeffler, Reynal-Querol, and Sambanis, 2003: 159).

There is a fear among policy makers that the demobilization of large numbers of soldiers will be disruptive and that demobilized soldiers will turn to violent crime to support themselves (Collier *et al.*, 2003:161). The World Bank suggests that the way to mitigate this risk is to provide productive economic opportunities for soldiers who have been demobilized (Collier *et al.*, 2003:161). As a result, it is essential that the provision of jobs and other economic opportunities be emphasized to facilitate the DDR of former

soldiers and the creation of a stable post-conflict environment. The state of the labor

market in this initial model is described by four state variables: (1) unemployed persons

including discouraged workers, (2) non-military non-police government employees, (3)

private sector employees, and (4) the country's per capita gross domestic product.

The amount of insurgent activity as well as the amount of coalition military

activity are important measures of effectiveness (MOEs) for stability operations.

Examples of MOEs of security in a peace operation include the number of incidents of

hostile fire per week and the number of patrols per week (Challenges Project, 2002:265).

In this model insurgent activity and coalition activity are captured by three state

variables: (1) the number of insurgents in country, (2) the number of detained insurgents,

and (3) the number of coalition troops in country.

"War destroys infrastructure, leaving the population in conditions that increase

the risk of disease" and other humanitarian crises (Collier *et al.*, 2003:169). The critical

infrastructures in this model are infrastructures that are deemed initially essential for

preventing humanitarian crisis and or social unrest. Some critical infrastructures are

country specific, others are universal. Potable water and food distribution infrastructures

are universally critical infrastructures. Shelter, electricity, and fuel among others are

critical in some settings, while not as critical in other settings. For example, in Iraq the

fuel production and distribution infrastructure is deemed critical, as many people rely on

it for cooking and transportation (Hamre, Barton, Crocker, Mendelson-Forman, and Orr,

2003:4). A widespread disruption in the distribution of fuel could lead to increased social

unrest (Hamre *et al.*, 2003:5). In the general model proposed here, food, fuel, water, and

electricity are included as critical infrastructures. When the model is applied in a specific

case it is expected that other critical infrastructures of interest will be identified and

added. Critical infrastructure capacity is represented in this model by four state variables:

(1) the amount of water delivered daily, (2) the amount of food delivered daily, (3) the

amount of fuel delivered daily, and (4) the amount of electricity delivered daily.

The final basic category is the public opinion of the occupation among the

indigenous population. In this category public opinion is represented by two state

variables: (1) the number of people who are dissatisfied with the coalition's occupation

and (2) the number of people who are neutral to or satisfied with the coalition's

occupation. These variables are included to act as proxies for the perceived legitimacy of

the occupation and indigenous government being supported by the occupation. The

development of a legitimate indigenous government is essential to the creation of

sustainable security (Play to Win, 2003:14). "Ultimately, it is the extent to which a

coherent, legitimate government exists – or can be created – that determines the success

or failure of post-conflict reconstruction" (Play to Win, 2003:14).

Rates of Change

The model developed in this study represents a stability operation and its

environment as a network of interconnected level values and rates of change (see Figure

3.1). The level values identify the state of the system while the rates of change describe

how those level values evolve over time. The previous section identified a set of 23 state

variables, or level values, that capture important aspects of the stability operation and its

environment. These level values capture the state of the stability operation but by

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themselves do not develop over time. Each level value has one or more rates of change associated with it. These rates of change determine how the level values evolve over time and together they determine how the entire system evolves over time. Figure 3.1 shows the overall structure of the model.

Tables 3.1 and 3.2 list each of the level values in this model and their associated rates of change. The direction of change column indicates what effect a positive rate of change will have on its associated level value. A plus sign indicates that a positive rate of change will increase the size of the level value, and a negative rate of change will decrease the size of the level value. A minus sign indicates that a positive rate of change will decrease the size of the level value, and a negative rate of change will increase the size of the level value.

Table 3.1: Non-Labor Force Level Values and Associated Rates of Change

Level Value	Direction of Change	Associated Rates of Change
Per Capita GDP	+	Per Capita GDP Growth Rate
Coalition Military Forces	+	Coalition Troop Rate of Change
	-	Coalition Casualty Rate
Amount of Water Delivered Daily	+	Water Infrastructure Development Rate
Amount of Food Delivered Daily	-	Food Infrastructure Development Rate
Amount of Fuel Delivered Daily	+	Fuel Infrastructure Development Rate
Amount of Electricity Delivered Daily	-	Electricity Infrastructure Development Rate
People Who are Dissatisfied with the Occupation	-	Public Opinion Rate of Change
People who are Neutral to or Support the Occupation	+	Public Opinion Rate of Change

Table 3.2: Labor Force Level Values and Associated Rates of Change

Level Value	Direction of Change	Associated Rates of Change
Indigenous Border Patrol Personnel	-	Border Patrol Personnel KIA Rate
	-	Border Patrol Attrition Rate
	+	Border Patrol Personnel Graduation Rate from Training
Indigenous Border Patrol Personnel in Training	+	Recruitment Rate of Border Patrol Personnel Trainees
	-	Border Patrol Personnel Graduation Rate from Training
Indigenous Civil Defense Service Personnel	-	Civil Defense Personnel KIA Rate
	-	Civil Defense Attrition Rate
	+	Civil Defense Personnel Graduation Rate from Training
Indigenous Civil Defense Service Personnel in Training	+	Recruitment Rate of Civil Defense Personnel Trainees
	-	Civil Defense Personnel Graduation Rate from Training
Indigenous Military Personnel	-	Indigenous Military KIA Rate
	-	Indigenous Military Attrition Rate
	+	Indigenous Military Graduation Rate from Training
Indigenous Military Personnel in Training	+	Recruitment Rate of Indigenous Military Trainees
	-	Indigenous Military Graduation Rate from Training
Indigenous Police Officers	-	Police Officer KIA Rate
	-	Police Officer Attrition Rate
	+	Police Officer Graduation Rate from Training
Indigenous Police Officers in Training	+	Recruitment Rate of Police Officer Trainees
	-	Police Officer Graduation Rate from Training
Criminals	+	Rate of Criminal Recruitment
	-	Criminal Apprehension Rate
Incarcerated Criminals	+	Criminal Apprehension Rate
	-	Incarcerated Criminal Release Rate
Unemployed Persons	-	Recruitment Rate of Border Patrol Personnel Trainees
	-	Recruitment Rate of Civil Defense Personnel Trainees
	-	Recruitment Rate of Indigenous Military Trainees
	-	Recruitment Rate of Police Officer Trainees
	-	Rate of Criminal Recruitment
	-	Recruitment Rate of Government Employees
	-	Private Sector Hiring Rate
	-	Insurgent Recruit Rate
	+	Detained Insurgent Release Rate
	+	Incarcerated Criminal Release Rate
Government Employees	+	Recruitment Rate of Government Employees
Private Sector Employees	+	Private Sector Hiring Rate
Insurgents	+	Insurgent Rate of Change
	-	Insurgent Killed or Capture Rate
Detained Insurgents	+	Insurgent Capture Rate
	-	Detained Insurgent Release Rate

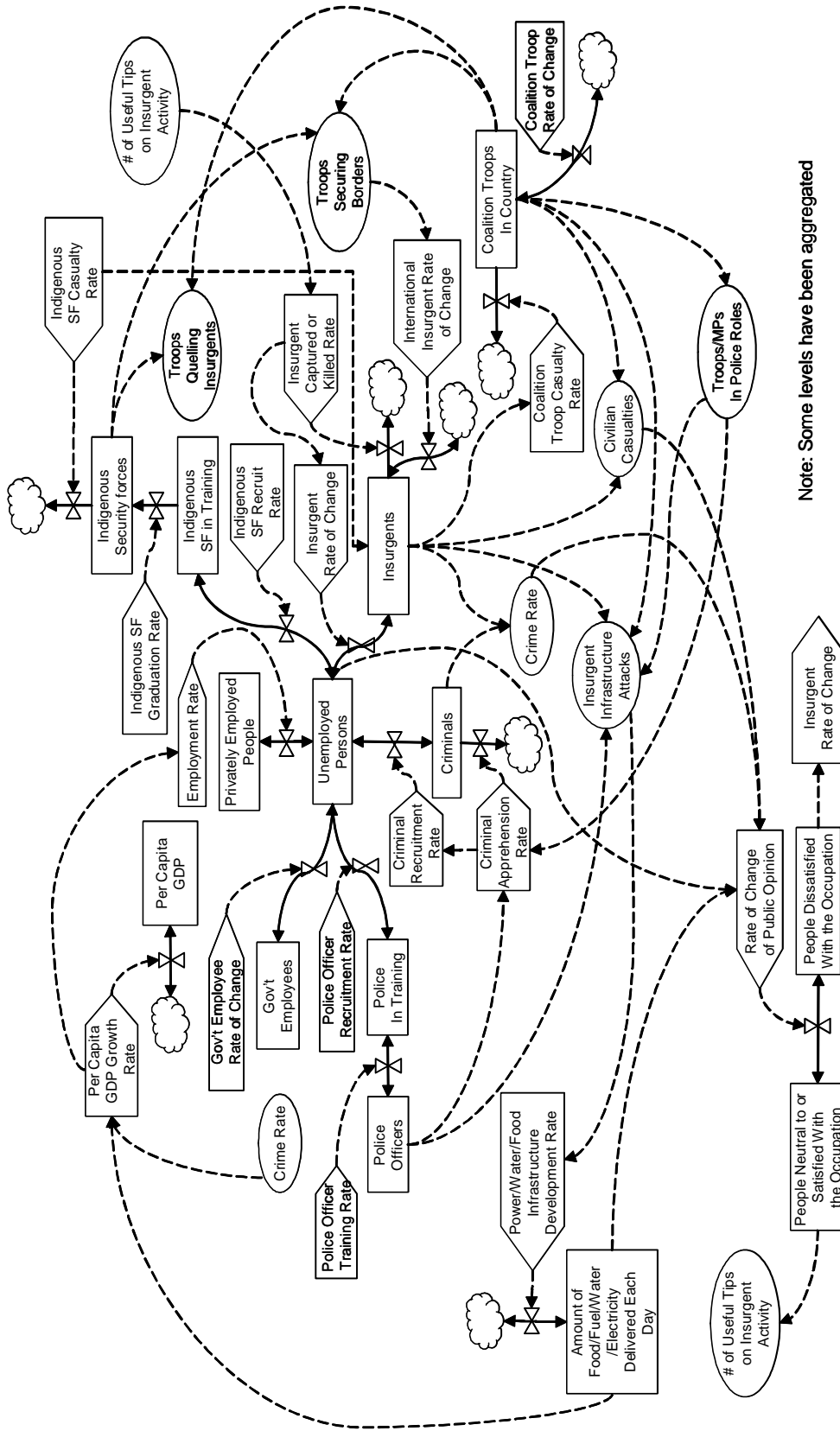Note: Some levels have been aggregated

Figure 3.1: General Post-Conflict Reconstruction Model

Table 3.1 presents the level values and the associated rates of change of public opinion, critical infrastructures, coalition military capability, and the per capita GDP. Table 3.2 presents each of the level values and the associated rates of change for the total labor force of the indigenous population. Everyone in the indigenous country's labor force is categorized as either unemployed, a criminal, an insurgent, a private employee or some form of government employee. In this model these categories are clearly defined and assumed to be mutually exclusive. Unemployed people are defined as discouraged workers and people actively looking for a job. Criminals are defined as people who do not hold a legal job and support themselves through illegal activity. Insurgents are defined as people actively working to thwart the occupation through violence. Insurgents can commit crime, but criminals do not work to thwart the occupation. As the model evolves over time, people move back and forth between the unemployed category and the various categories in accordance with the associated rates of change.

In an effort to make the model easier to explain and understand, it has been divided up into six sub-models. These six sub-models correspond to the six basic aspects of a stability operation identified in the previous section. These are indigenous security institutions, law enforcement, coalition military and insurgent activity, the labor market, critical infrastructures, and public opinion. Figure 3.2 shows a high level representation of the general stability operations model in terms of these six sub-models. The arrows in the figure represent the effects each sub-model has on the other sub-models. Effects may be direct or indirect. As noted by the single and double headed arrows, some interactions have been modeled as one way interactions while others have been formulated as two

way interactions. Of course other modules can be added as desired. In the following six sections the rates of change associated with each of the level values in each of these sub-models are identified and explained.
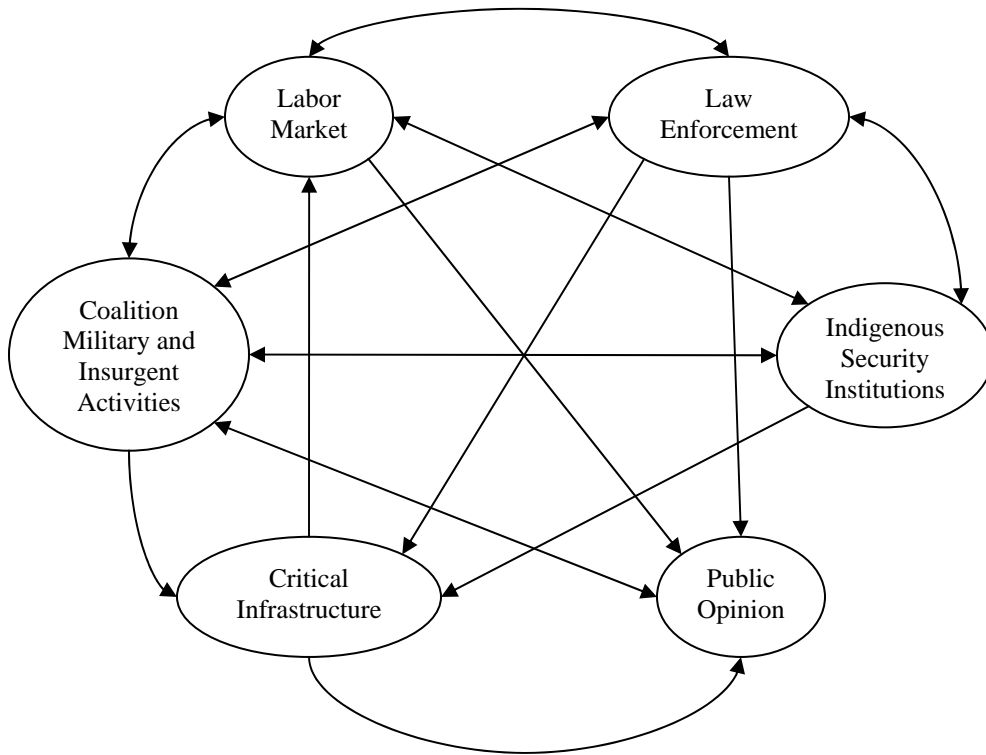
Figure 3.2: Sub-model Connections

Indigenous Security Institutions Sub-model

The indigenous security institutions sub model is comprised of three organizations: (1) the border patrol, (2) the civil defense force, and (3) the indigenous military. Each of these organizations has a different influence on other level and rate values in the model. The level of border patrol personnel affects the number of international insurgents that can slip into the country. The number of civil defense personnel and the number of indigenous military personnel each exert a different

influence on the number successful insurgent attacks on the country's critical infrastructure and the rate at which insurgents are captured or killed.

Figure 3.3 presents the structure of the indigenous security institutions sub-model. The state of the indigenous security institutions is represented by six level values; its development over time is determined by 12 associated rates of change. Level values (i.e. state variables) are represented as rectangular boxes, flows of people are represented as solid arrows, rates of change are represented as arrow boxes (i.e. valves), parametric inputs are represented as dashed arrows, and level values that are exogenous to the model are represented as clouds.

Unemployed persons are recruited into the training programs of the three security services at the rates determined by equations 3.1, 3.2, and 3.3.

Eq. 3.1 $BPRecruitRate(t) \sim BPRRDist\left(\mu_{BP\,Re\,cruitRate}(t), \sigma_{BP\,Re\,cruitRate}(t)\right)$

Eq. 3.2 $CDRecruitRate(t) \sim CDRRDist\left(\mu_{CD\,Re\,cruitRate}(t), \sigma_{CD\,Re\,cruitRate}(t)\right)$

Eq. 3.3 $IMRecruitRate(t) \sim IMRRDist\left(\mu_{IM\,Re\,cruitRate}(t), \sigma_{IM\,Re\,cruitRate}(t)\right)$

These rates are the daily numbers of unemployed people who join the training programs of the border patrol, the civil defense force, and the indigenous military. As unemployed people enter into the training program of each security service they change their employment status. They are re-classified as border patrol trainees, civil defense force trainees, and indigenous military trainees respectively. For example, a border patrol recruitment rate of *x* people per day would increase the border patrol personnel in training level by *x* people per day and decrease the unemployed persons level by *x* people per day.
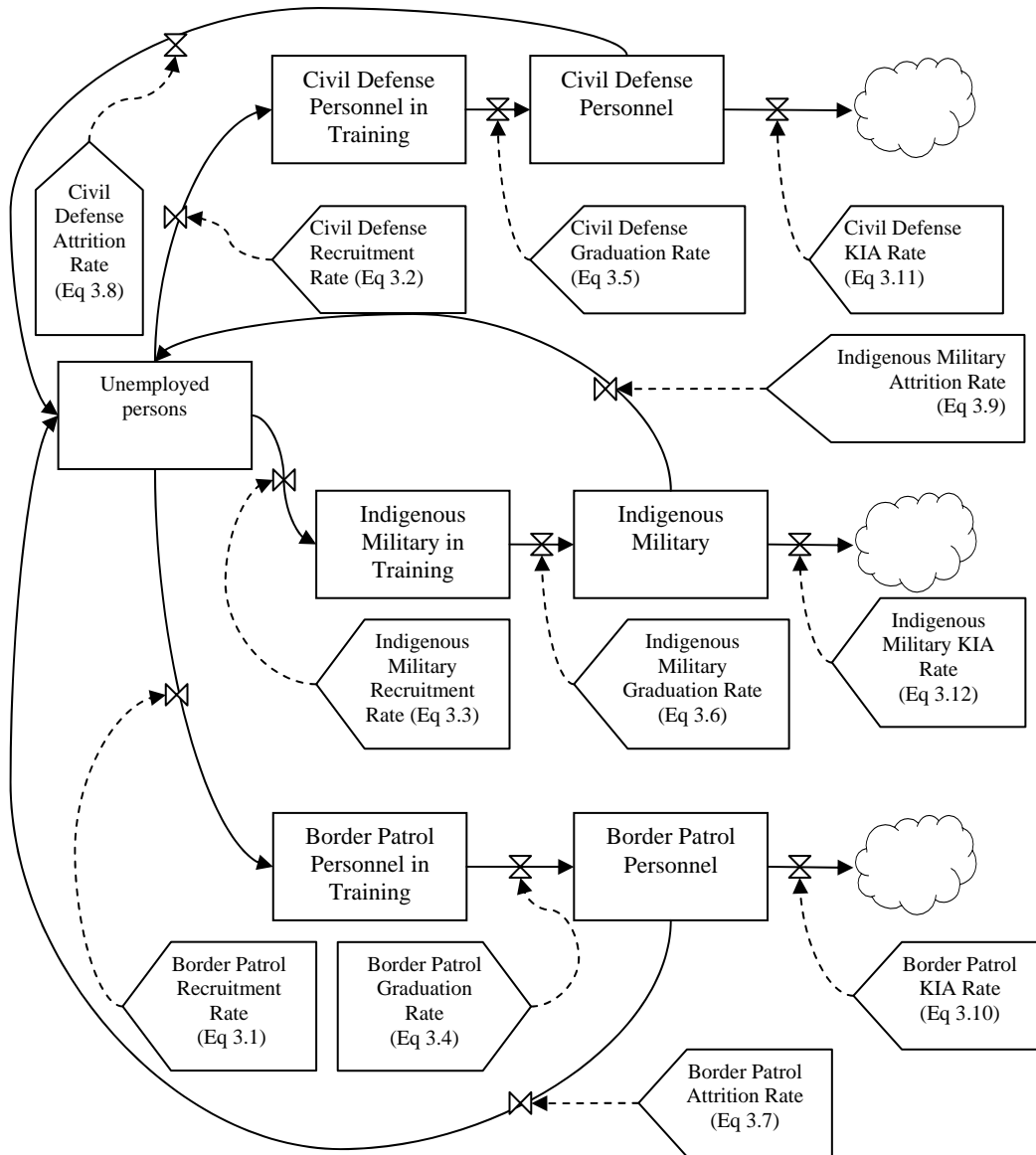
Figure 3.3: Indigenous Security Institutions Sub-model

The recruitment rates of the three security services are determined by factors exogenous to the model, such as the wages offered to members of each of the security services and the maximum capacities of the training facilities for each of the security services. The distributions of each of these three rates depend on the operational situation being modeled. If known distributions or rates exist, they would, of course, be

utilized. If they do not exist, research could be done to develop distributions or rates (a function has also been suggested). A potential distribution would be the Poisson distribution as it is a discrete distribution well suited for modeling an arrival process (Kulkarni, 1995:199). If a Poisson distribution is used, the recruitment rates of the three security services would be given by equations 3.1a, 3.2a, and 3.3a.

Eq. 3.1a *BPRecruitRate(t) ~ Poisson($\lambda_{BPRR}(t)$)*

Eq. 3.2a *CDRecruitRate(t) ~ Poisson($\lambda_{CDRR}(t)$)*

Eq. 3.3a *IMRecruitRate(t) ~ Poisson($\lambda_{IMRR}(t)$)*

Once trainees have entered the training programs for their security service they are batched into classes. Each class takes a predetermined number of training days before it is graduated and enters active duty. The maximum number and size of the training classes, as well as the lengths of the training programs, are determined by factors such as the skill requirements of each of the security services, the time it takes for trainees to reach the required skill level, the size of the training cadre, and the maximum capacities of the training facilities in the theater. These factors are exogenous to the model and would be based on specific operational requirements. The class size, maximum number of classes, and training length are potential policy factors that can be tested with this model.

Not every trainee who enters the training program of one of the security services graduates. A percentage of each of the training classes is assumed to return to unemployed status at the end of their training program. (It would be possible to have trainees washout throughout the program if such fidelity were desired. It has not been

provided in this model, however.) This percentage (*xxxTrainingAttrition*) is the training

program's attrition rate. It is represented by a random variable whose functional

distribution is determined by factors exogenous to the model. While the functional

distribution of each training program's attrition rate must be chosen to reflect the

specifics of each different scenario being modeled, a possible choice would be a Beta

distribution as it returns a number between two endpoints and can be parameterized to be

skewed as the scenario requires.

The graduation rates of each of the security services are discrete functions. For

the days when there is no class of trainees graduating, the graduation rate for each of the

security service training programs are zero. On the days that a class is graduating the

graduation rate for that security service is the class size multiplied by one minus the

training program's attrition rate. The graduation day for a particular class is the start date

of that class plus the class length. The graduation rates for the border patrol, the civil

defense force, and the indigenous military are given by equations 3.4, 3.5, and 3.6

respectively.

Eq. 3.4 *BPGradRate(t) =*

$$\begin{cases} BPGradClassSize(t) * \left(1 - BPTrainingAttrition(t)\right) & if \ \ StartDate + Classlength(t) = CurrentDate \\ 0 & otherwise \end{cases}$$

Eq. 3.5 *CDGradRate(t) =*

$$\begin{cases} CDGradClassSize(t) * \left(1 - CDTrainingAttrition(t)\right) & if \ \ StartDate + Classlength(t) = CurrentDate \\ 0 & otherwise \end{cases}$$

Eq. 3.6 *IMGradRate(t) =*

$$\begin{cases} IMGradClassSize(t) * \left(1 - IMTrainingAttrition(t)\right) & if \ \ StartDate + Classlength(t) = CurrentDate \\ 0 & otherwise \end{cases}$$

A possible expansion to the model would be to allow training programs of different lengths and intensities to graduate security personnel with different levels of effectiveness. This would allow policies concerning the trade-offs between the quality and quantity of security personnel to be tested, for example.

As the trainees of each of the security services graduate and transition to active duty status, the number of trainees in the affected security service training program decreases accordingly and the number of active duty personnel in the respective security service increases accordingly. The model assumes that the number of active duty personnel in each security services can only be increased by the graduation of classes of trainees. The number of active duty security personnel in each of the security services decreases as a result of that service's casualty rate and its active duty attrition rate.

The active duty attrition rate of each of the security services represents the rate at which active duty security personnel separate from their jobs. The model then returns these individuals to unemployed status where they remain until they enter some other employment category. These separations could be as a result of personnel quitting, being fired, or being incapacitated to an extent that they can no longer perform their job. The active duty attrition rate for each of the security services are random variables whose functional distributions depend on the particular scenario being simulated, and are determined by factors exogenous to the model. A possible distribution might be a discrete uniform distribution, for example. The active duty attrition rates for the three security services are given by equations 3.7, 3.8, and 3.9.

Eq. 3.7 $BPAttritionRate(t) \sim BPARDist\left(\mu_{BPAttritionRate}(t), \sigma_{BPAttritionRate}(t)\right)$

Eq. 3.8 $CDAttritionRate(t) \sim CDARDist\left(\mu_{CDAttritionRate}(t), \sigma_{CDAttritionRate}(t)\right)$

Eq. 3.9 $IMAttritionRate \sim IMARDist\left(\mu_{IMAttritionRate}(t), \sigma_{IMAttritionRate}(t)\right)$

A possible expansion to the model would be to make the attrition rates of the security

services dynamic by making the attrition rates of the security services functions of the

casualty rates of each security service, the public opinion, or perhaps other economic

opportunities.

The killed in action rate of each of the security services is the rate at which the

active duty security personnel of each of the services are killed. The security service

personnel who are killed leave active duty status and are eliminated from the model,

instead of returning to unemployed status as happens to the active duty security personnel

who have been attrited.

In this "first-cut" model, security forces that are wounded are not modeled, only

the killed in action rates for each of the security services are modeled. These killed in

action rates are functions of the daily number of insurgent attacks, the likelihood that

casualties occur, and the effectiveness of the security forces. The killed in action rates

for the border patrol, civil defense force, and indigenous military are given by equations

3.10, 3.11, and 3.12 respectively.

Eq 3.10 *BPKIARate(t) =*

  BPAttackEffectivenessParameter(t) * #OfInsurgentAttacks(t) * BPCasualtyRandomVariable(t)

Eq 3.11 *CDKIARate(t) =*

  CDAttackEffectivenessParameter(t) * #OfInsurgentAttacks(t) * CDCasualtyRandomVariable(t)

Eq 3.12 *IMKIARate(t) =*

  IMAttackEffectivenessParameter(t) * #OfInsurgentAttacks(t) * IMCasualtyRandomVariable(t)

Law Enforcement Sub-model

The law enforcement sub-model simulates the amount of violent crime in a country as a function of the number of police officers and criminals in the country. This is done with four level values and seven rates of change. Figure 3.4 shows the structure of the law enforcement sub-model. Equations 3.20 and 3.21, represented in figure 3.2 as ovals, are instantaneously computed functions.

In the law enforcement sub-model the recruitment, training, and deployment of police officers are modeled in the same manner as the security personnel recruitment, training, and deployment are modeled in the indigenous security institution sub-model. However, the specific parameter values in the various rate functions are different as the appropriate parameters for modeling police officer training and deployment are not necessarily the same parameters necessary for modeling the training and deployment of security services. The police recruitment rate is the rate at which police officer trainees are recruited out of the pool of unemployed people. This rate is given by equation 3.13.

$$\text{Eq. 3.13 } PORecruitRate(t) \sim PORRDist\left(\mu_{PO\,\text{Re}\,cruitRate}(t), \sigma_{PO\,\text{Re}\,cruitRate}(t)\right)$$

Once police officer trainees are recruited, they are batched into classes and are trained for the amount of time required. Once a class of police officer trainees has trained for the required amount of time, the class is graduated and the police officer trainees in the class become active duty police officers. Like the security forces, not every police officer trainee graduates. It is again assumed that on graduation day a percentage of the graduating class is returned to unemployed status according to the training attrition rate. This police officer trainee attrition rate is a random variable whose functional distribution

is determined by factors exogenous to the model. It would be fitted or selected according

to specific situational needs. The police officer graduation rate (*POGradRate*) is given

by equation 3.14.

Eq. 3.14 *POGradRate(t) =*

$$\begin{cases} POGradClassSize(t)*(1-POTrainingAttrition(t)) \ if & StartDate+Classlength(t)=CurrentDate \\ 0 & otherwise \end{cases}$$

As currently modeled, the number of active duty police officers can only be increased by classes

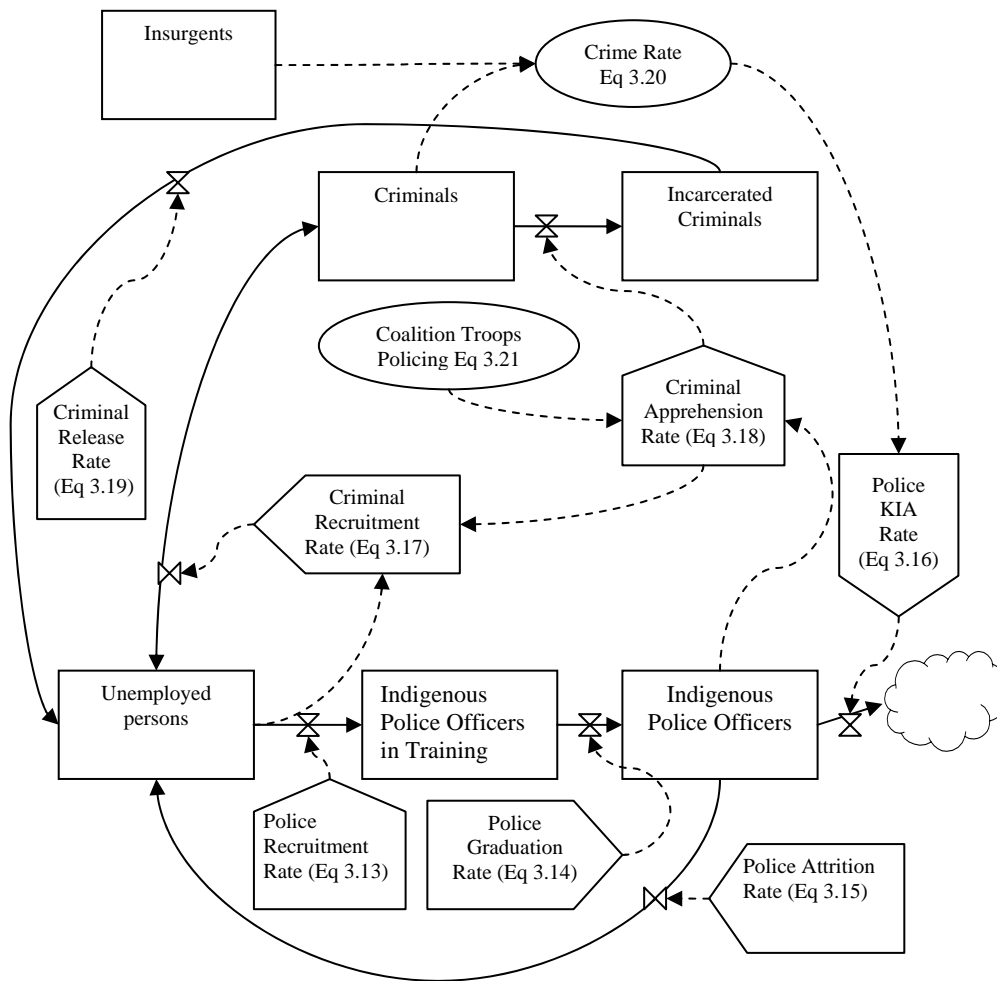of police officer trainees graduating from the police officer training program.

Figure 3.4: Law Enforcement Sub-model

The number of police officers on active duty is reduced by police officer attrition and police officer casualties. Police officers are lost as a result of officers quitting, being fired, or being severely wounded is accounted for by the police officer attrition rate. This rate is a random variable whose functional distribution must be chosen to reflect the particular idiosyncrasies of each scenario being simulated. The police officer attrition rate is the rate at which active duty police officers leave active duty police officer status and return to unemployed status. This rate is given by equation 3.15.

Eq. 3.15 $POAttritionRate(t) \sim POARDist\left(\mu_{BPAttritionRate}(t), \sigma_{BPAttritionRate}(t)\right)$

The number of active duty police officers lost due to death is accounted for by the police officer killed in action rate. The police officers who are killed leave active duty status and are eliminated from the model. They do not return to unemployed status as do the police officers who are attrited. The police officer casualty rate is a function of the crime rate and the number of insurgent attacks and is given by equation 3.16.

Eq. 3.16 $POKIARate(t) =$

$InsurgentAttackOnPoliceEffectParameter(t) * PoliceKIARandVar(t) * \#ofAttacks(t)$

$+ PoliceCrimeRateEffectParameter(t) * PoliceKIARandVar(t) * CrimeRate(t)$

In this baseline model each member of the country's labor force belongs to one of a number of different employment categories. Some of these employment categories have been discussed in previous sections, such as the employment categories related to the indigenous security forces, and some of these categories will be explained in the following sections. Three of these employment categories are the unemployed persons category, the criminals category, and the insurgent category. The unemployed category

will be discussed further in the labor market section, and the insurgent category will be further explored in the coalition military and insurgent activities section. However, for the purpose of explaining how the term criminal is defined in this model a few remarks are necessary here. Criminals are defined in the model as anyone who supports themselves through violent crime. Unemployed persons are defined as people who are either actively looking for a job or are discouraged workers. Insurgents are defined as anyone working for the violent overthrow of the occupation. While it is recognized that an insurgent may support themselves through a job, for example, at this level of fidelity, the model does not consider overlapping groupings. In this baseline model it is assumed employment categories are mutually exclusive and that a person cannot belong to two of these categories at once. People in the unemployed category are assumed to not commit crimes, people in the criminal category are assumed to not attack coalition troops, and people in the insurgents category both commit crime and attack coalition troops.

A recent study of cross-national panel data of homicide rates from 117 countries in the period 1980-1997 suggests that both economic growth and high income levels lower homicide rates (Neumayer, 2003:635). This is consistent with the rational choice theory of crime. The rational choice theory of crime assumes that an individual "weighs the benefits against the costs of committing violent crime and decides to commit the crime if the net present value of the benefit exceeds the net present value cost" (Neumayer, 2003:623). According to this rational choice theory of crime, policies that raise the costs of committing crime reduce the crime rate (Neumayer, 2003:623). Increasing the probability of apprehension for criminals lowers the crime rate by directly

increasing the costs of committing a crime, while improving the economic prospects of individuals lowers the crime rate by increasing the opportunity cost of committing crime.

This model assumes a rational choice theory of crime. The number of criminals in the country increases when unemployed persons to stop looking for a job and start supporting themselves through crime. The rate at which unemployed people turn to crime is the criminal recruitment rate. A positive criminal recruitment rate is associated with an increase in the number of criminals, while a negative criminal recruitment rate is associated with criminals choosing to stop supporting themselves through crime and start looking for jobs.

The criminal recruitment rate is a function of the number of unemployed people in the country and the criminal apprehension rate. Representing the criminal recruitment rate as a function of the number of unemployed people and the criminal apprehension rate is consistent with both empirical evidence and the rational choice theory of crime. Using data from a survey of over 16,000 high school students in the United States a paper published in by the National Bureau of Economic Research found that violent crime rates are directly correlated with unemployment (Mocan and Rees, 1999:Abstract). This is also consistent with the rational choice theory of crime, as an increase in employment options increases the opportunity cost of crime. The criminal recruitment rate used in this model is given in equation 3.17.

Eq 3.17 *CriminalRecruitRate(t) = CriminalRecruitRateInterceptParameter(t) +*

UnemploymentEffectParameter(t) * UnemploymentLevel(t) +

CriminalApprehensionRateEffectParameter(t) * CriminalApprehensionRate(t) +

$CriminalRecruitRateDist\left(\mu_{C\,\mathrm{Re}\,cruitRate}(t), \sigma_{C\,\mathrm{Re}\,cruitRate}(t)\right)$

The criminal apprehension rate is the daily number of criminals arrested. It represents the rate at which criminals transition from criminal status to incarcerated criminal status. The criminal apprehension rate is a function of the number of criminals in the country, the number of coalition military troops working to suppress crime, the number of civil defense troops, and the number of active duty indigenous police officers. The criminal apprehension rate is given by equation 3.18.

Eq. 3.18 *CriminalApprehensionRate(t) = Criminals **

(PoliceEffectParameter(t) * PoliceOfficers(t) + CivilDefenseTroopEffectParameter(t) *

CivilDefenceTroops(t) + CMilitaryEffectParameter(t) * CMilitaryPolicing(t)) *

CriminalApprehensionRateRandVar(t)

Each police officer, civil defense troop, and coalition military troop working at crime suppression apprehends a certain number of criminals each day. This apprehension rate is determined in equation 3.18 by the police effectiveness parameter, the civil defense troop effectiveness parameter, and the coalition military effectiveness parameter. These effectiveness parameters can be constants to model the effectiveness of police and troops as a linear function of their numbers, or the effectiveness parameters can themselves be functions of the numbers of police and troops to model non-linearity associated with economies and diseconomies of scale with respect to law enforcement manning levels. The criminal apprehension rate is also a function of the total number of criminals in the

country; the more criminals there are in the country the likelier it is that a given number will be apprehend.

Currently the model assumes that all indigenous police officers are equally effective, and that all coalition troops working in police operations are equally effective. A possible expansion to the model would be to model the effectiveness of different types of troops to be different. For instance, in such an expansion an infantry unit working in police operations would not apprehend as many criminals as a military police unit of the same size. Another possible expansion would be to model translators who might improve the effectiveness of coalition military troops working at police operations.

Every day a percentage of the incarcerated criminals are released. These released criminals represent criminals who were investigated and released; tried, found not guilty, and released; and criminals who were convicted, served their prison sentence, and released. The percentage of incarcerated criminals released each day has been modeled as a random variable whose distribution must be selected to fit the particular scenario being simulated. The factors that influence the choice of what distribution to use are factors such as the length of typical sentences for various crimes and the percentage of trials that lead to convictions. The incarcerated criminal release rate is given by equation 3.19.

Eq. 3.19 *IncarceratedCriminalReleaseRate(t) =*

*IncarceratedCriminal(t) * IncarceratedCriminalsReleaseRandVar(t)*

In this model the crime rate has been expressed as a function of the number of insurgents and criminals in the country. The model assumes that each criminal and each insurgent in the country commits a certain number of crimes a day, and as a result the

crime rate is computed based on the number of criminals and insurgents in the country.
The crime rate is represented by equation 3.20.

Eq 3.20 *CrimeRate(t) = CrimeRateRandVar(t) * (Criminals(t) * CrimesPerCriminal(t) +*

Insurgents(t) * CrimesPerInsurgent(t))

The crime rate random variable introduces variability into the crime rate to account for

random influences on the crime rate that are not explicitly included in the model. The

choice of the distribution for the crime rate random variable is situation dependent.

The number of coalition troops conducting crime suppression operations is given

by equation 3.21. The allocation of coalition troops between border patrol activities,

crime suppression operations, and counter insurgency operations is directly impacted by

the modeler.

Eq. 3.21 *CoaltionTroopsPolicing(t) = TotalCoaltionTroops(t) * %CoalitionPolicing(t)*

Insurgent and Coalition Military Activities Sub-model

The insurgent and coalition military activities sub-model is comprised of three level

values and six rates of change. The level values are the number of coalition troops in the

country, the number of insurgents in the country, and the number of insurgents being

detained by the coalition. Figure 3.5 illustrates the nexus of these levels and rates. The

coalition troop level is influenced by two rates of change: (1) the coalition troop casualty

rate and (2) the coalition troops in country rate of change. The coalition troop rate of

change represents the net rate at which coalition troops are arriving or departing the country.

The modeler sets this rate and can set it at different levels to test the effect of various
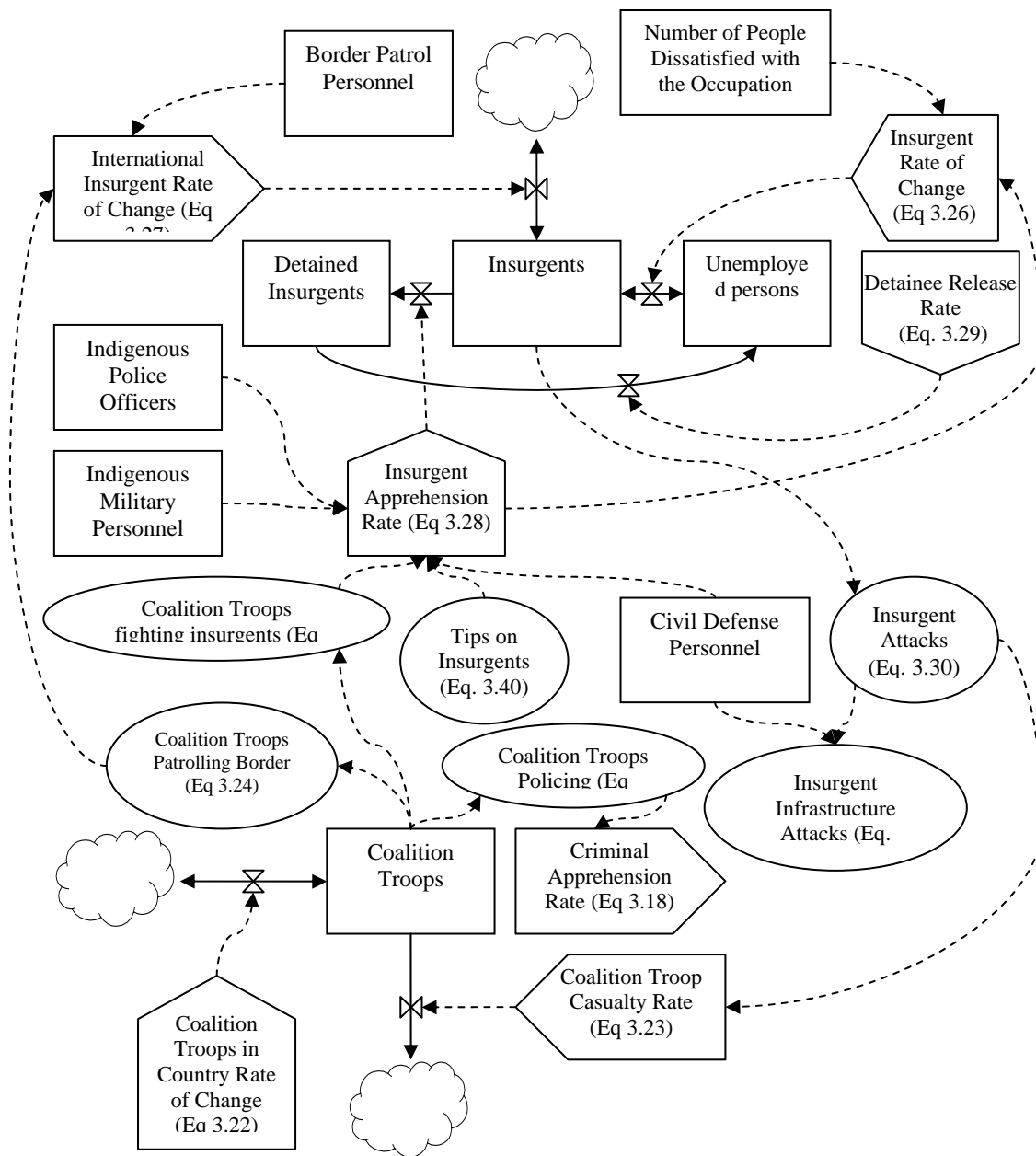
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Figure 3.5: Insurgent and Coalition Military Activities Sub-model

buildup and drawdown policies. Equation 3.22 gives the coalition troops in country rate of

change if the modeler wants to maintain constant a troop level throughout the simulation.

Eq. 3.22 *CoalitionTroopsInCountryRate(t) = CoalitionTroopCasualtyRate(t)*

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Formulating the coalition troops in country rate of change in this manner and holding the troop level constant means that the number of troops in country is only increased in order to compensate for casualties. The coalition troops in country rate could just as easily be set to some other approximate rate by the modeler to represent a specific situation or policy.

The coalition troop casualty rate is the rate at which coalition troops are killed or wounded to the extent that they cannot function as effective troops. The coalition troop casualty rate is a function of the number of daily insurgent attacks, the likelihood of casualties, and the effectiveness of the troops. The coalition troop casualty rate is given by equation 3.23.

Eq. 3.23 *CoalitionTroopCasualtyRate(t) =*

InsurgentAttackOnCoalitionEffectParameter(t) * #ofAttacks(t) * CTCasualtyRandVar(t)

The coalition troops in country level value is decreased by the number of troops that have been killed or wounded. Troops that are killed or wounded leave the model and are no longer available for operations. To maintain a specified level of effectiveness the troops would have to be replaced.

The allocation of the coalition troops in country between the different types of activities is a model parameter. Troops can be allocated into three different activities: crime suppression operations, border patrol operations, and counter insurgency operations. This troop allocation is represented by three functions that are instantaneously computed based on the troops in country level value and the allocation ratios set by the modeler. Troop allocation between crime suppression operations, border

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patrol operations, and counter insurgency operations are given by equations 3.21, 3.24, and 3.25 respectivly. The three parameters *%CoalitionPolicing*, *%CoalitionPatrollingBorders,* and *%CounterInsurgency* must always sum to one. (Equation 3.21 was discussed in the previous section and is included here for completeness.)

Eq. 3.21 *#CoaltionPolicing*(*t*) = *TotalCoaltionTroops*(*t*) * *%CoalitionPolicing*(*t*)

Eq. 3.24 *#CoalitionPatrolingBorders*(*t*) =

TotalCoaltionTroops(*t*) * *%CoalitionPatrollingBorders*(*t*)

Eq. 3.25 *#CoalitionCounterInsurgency*(*t*) =

TotalCoalitionTroops(*t*) * *%CounterInsurgency*(*t*)

As currently configured this model assumes that every coalition troop is equally effective at each activity. This is not the case in the real world. A possible expansion to the model would be to allow troops to be retrained over a period of time to increase their effectiveness at different activities. For instance, an infantry unit could spend six weeks training in crime suppression activities to improve its effectiveness at crime suppression.

In this model an insurgent is defined as anyone who is actively working to thwart the coalition through violence. This model assumes the insurgents attempt to thwart the coalition by attacking coalition targets and targets viewed as sympathetic to the coalition. In this model these are assumed to be coalition troops, indigenous security forces, indigenous police, the civilian population, and critical infrastructure. Insurgents actively working to thwart the coalition may also commit non-insurgency related crime, such as running a protection racket or a car theft ring. As a result the number of insurgents in the country affects the crime rate. However, people defined as criminals in this model do not

engage in anti-coalition violence *per se*, and the number of criminals in the country has no influence on the number of insurgent attacks.

In a working paper for the Center on Social and Economic Dynamics in 2001, Epstein, Steinbruner, and Parker present an agent based approach to modeling civil violence based on rational choice. In their model each member of the general population can either be "rebellious" or "quiescent" (Epstein *et al.*, 2001:2). The decision to rebel (or not) for each member of the population is made based on which action will maximize their expected utility (Epstein *et al.*, 2001:5). Each person's expected utility for revolting is dependent on their risk tolerance, their level of grievance against the government, and their assessment of the probability of being arrested (Epstein *et al.*, 2001:3-5). Each person's expected utility for not revolting is set at an arbitrary level *T* (Epstein *et al.*, 2001:6). If a person's expected utility for revolting exceeds their expected utility for not revolting they will join the rebellion; if a person's expected utility for not revolting exceeds their expected utility from revolting they become quiescent (Epstein *et al.*, 2001:5).

The model presented in this thesis uses a similar approach to simulating insurgency. It is assumed that based on a utility maximization calculation people make a rational choice between joining the insurgency and being unemployed. The rate at which people transition from unemployed status to insurgent status is the insurgent rate of change, which is a function of the rate at which insurgents are being killed or captured and the number of people who are dissatisfied with the occupation. The insurgent rate of change is given by equation 3.26.

Eq. 3.26 *InsurgentRateOfChange(t) =DissatisfiedPeople(t) **

   InsurgentKilledorDetainedEffectParameter(t) * InsurgentKilledOrDetainedRate(t) *

   InsurgentRateOfChangeRandVar(t)

The *InsurgentKilledorDetainedEffectParameter* and the distribution of the

InsurgentRateOfChangeRandVar depend on the specifics of the scenario being modeled,

and have to be set according to each individual situation. They could, however, be

parameters which vary according to other effects in an expression of the model.

   In addition to the domestic insurgents who join the insurgency from the ranks of

the unemployed, international sympathizers can travel to the country and join the

insurgency. Of the total number of insurgents that try to enter the country, some

percentage is turned back by the indigenous border guards and the coalition troops who

are patrolling the borders. The rate at which international insurgents enter the country is

give by equation 3.27.

Eq. 3.27 *InternationalInsurgentRate(t) = TotalInternationalInsurgentsRandVar(t) **

   (*BorderPatrolEffectParameter*(t) * *BorderPatrolTroops*(t) +

   CoalitionPatrollingBorderEffectParameter(t) * CoalitionPatrollingBorder(t))

The total number of international insurgents is a random variable whose distribution

depends on factors specific to the modeled environment, such as the international

perception of the legitimacy of the occupation, and the international perception of the

legitimacy of the insurgency. While the specifics of each situation dictate the appropriate

distribution for this random variable, a Poisson distribution would be a possible choice as

the number of international insurgents trying to enter the country is an arrival rate.

The insurgent killed or detained rate is the rate at which insurgents are either killed or detained. The level value for insurgents is decreased every day by this rate. Of the total daily number of insurgents apprehended some percentage are killed in the course of their apprehension and the rest are detained. The percentage of insurgents that are killed is a random variable whose distribution depends on the specifics of the individual scenario being modeled. The insurgents that are killed in the course of their apprehension are eliminated from the model. The insurgents that are detained transition to the detained insurgents category.

The rate at which insurgents are apprehended is a function of the total number of insurgents, the number of coalition military troops conducting counter insurgency operations, the size of indigenous military, the size of the civil defense force, the number of tips the coalition receives on insurgent activity. The insurgent killed or detained rate is given by equation 3.28, this rate is subtracted from the insurgents level value. The insurgent detention rate, the rate that is added to the detained insurgents level value is given by equation 3.28a.

Eq. 3.28 *InsurgentKilledOrDetainedRate(t) =*

Insurgents(t) * (CTroopsCounterInsurgEffectParameter(t) * CTroopsInCounterInsurg(t)

+ IMEffectParameter(t) * IndigenousMilitaryTroops(t) + CDEffectParameter(t) *

CivilDefenseTroops(t)) * TipsOnInsurgency(t) * InsurgentAppRandVar(t)

Eq. 3.28a *InsurgentDetentionRate(t) =*

(1-InsurgentKilledRate(t)) * InsurgentKilledOrDetainedRate(t)

Every day a percentage of the detained insurgents are released. This represents the fact that some insurgents that have been apprehended and detained are determined to

no longer be a threat and are released. This percentage is a random number whose

distribution depends on factors exogenous to the model such as the standard of proof

coalition forces use when deciding who should and should not be detained. When

formerly detained insurgents are released, they return to unemployed status from which

they may or may not rejoin the insurgency or the workforce. The insurgent release rate is

given by equation 3.29.

Eq. 3.29 *InsurgentReleaseRate(t) = DetainedInsurgents(t) * InsurgentReleaseRandVar(t)*

The amount of insurgent activity is represented in this model by the number of

attacks the insurgents make on coalition targets and targets perceived by the insurgency

as sympathetic to the coalition. The number of insurgent attacks is a direct function of

the number of insurgents in the country, the likelihood of attack, and their effectiveness

rate. The number of insurgent attacks is given by equation 3.30.

Eq. 3.30 *#OfInsurgentAttacks(t) =*

*Insurgents(t) * InsurgentEffectParameter(t) * InsurgentAttackRandVar(t)*

The insurgent effectiveness parameter is the average number of attacks each insurgent is

able to make each day. The insurgent attack is a random variable that introduces

variability into the number of attacks each insurgent can make per day. The distribution

of the insurgent attack random variable must be chosen by the modeler to fit the

particular scenario being modeled.

A percentage of the total number of insurgent attacks is attacks on critical

infrastructure targets. The number of insurgent attacks on critical infrastructure targets is

a function of the size of civil defense force, the total number of insurgent attacks, and the

percentage of the total number of attacks that are attacks on critical infrastructure targets.

This percentage is a random variable whose distribution is determined by factors exogenous to the model, such as the strategy of the insurgency. The number of insurgent attacks on infrastructure is given by equation 3.31.

Eq. 3.31 *#OfInfrastructureAttacks*(t) = *#OfInsurgentAttacks(t) * CDEffectParameter(t) *

*CivilDefenseTroops(t) * %OfAttacksOnInfrastructure(t)*

Labor Market Sub-model

In this baseline model every member of the country's labor force belongs to one of eight groups. Each person is either unemployed; employed in the private sector; employed as a trainee or active duty member of the police, the border patrol, the civil defense force, or the indigenous military; employed in a non-security related government job; a criminal; or an insurgent. For simplicity in the model, it has been assumed that each person in the labor market belongs to one and only one of these categories. As the model evolves over time, people move from one category to another as prescribed by the various rates of change.

The previous explanation of the indigenous security institutions sub-model detailed how people move back and forth between unemployed status and trainee and active duty status in the border patrol, the civil defense force, and the indigenous military. The discussion of the law enforcement sub-model explained how people transition between unemployed status and criminal status, as well as police officer trainee status and active duty police officer status. The presentation of the coalition military and insurgent activities sub-model explained how people transition between unemployed status and insurgent

status. The only aspects of the labor market that have not yet been discussed are the effects

of non-security related government jobs, private sector jobs, and the per capita gross

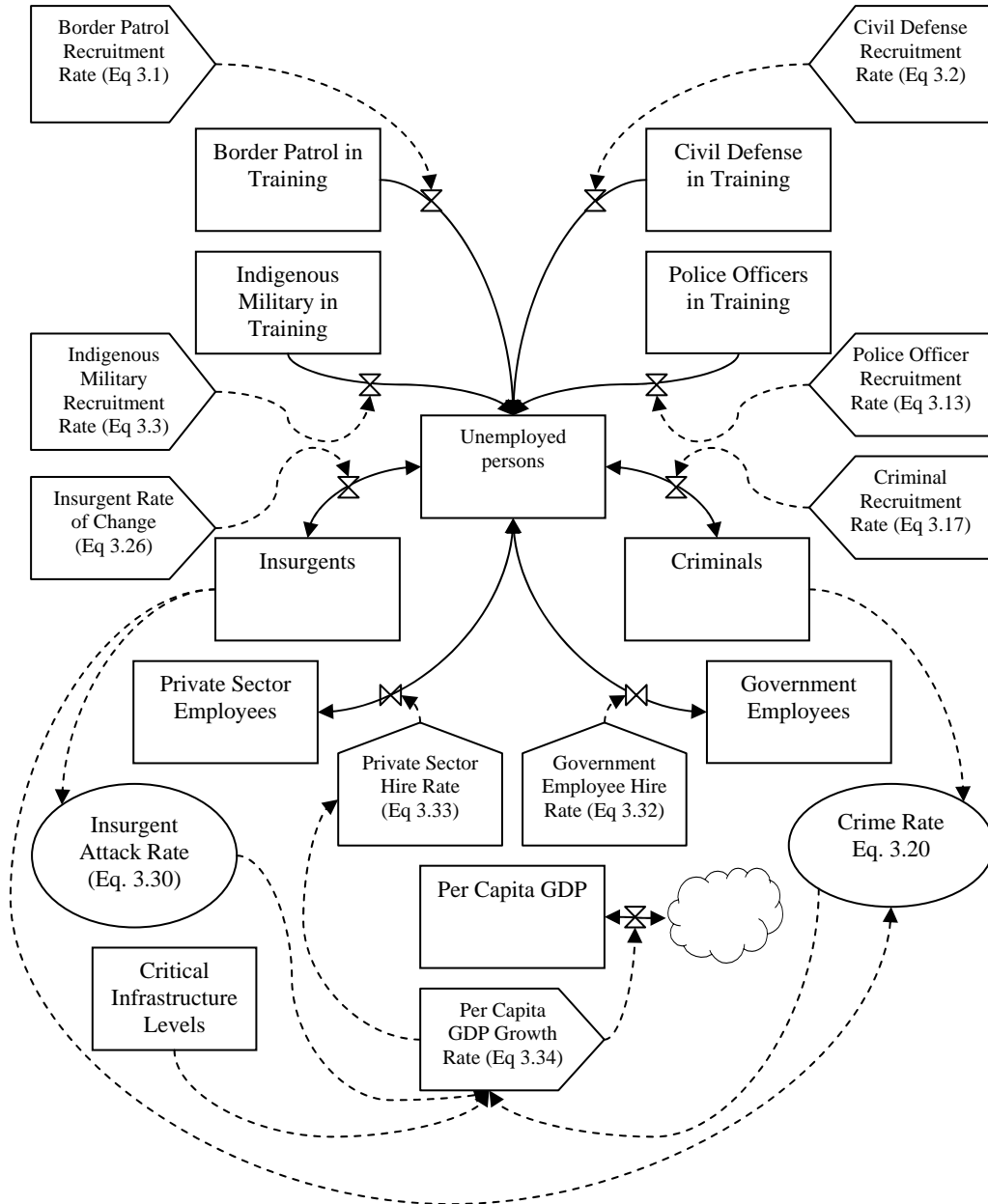domestic product. Figure 3.6 shows the structure of the labor market sub-model.

Figure 3.6: Labor Market Sub-model

The model provides that besides getting a job in the government as a police officer, a member of the border patrol, the civil defense force, or the indigenous military, people can be employed in non-security related government jobs. The rate at which people transition from unemployed status to government employee status is the government employee hire rate. The upper bound of the government employee hire rate is parameter controlled by the modeler, as in an occupation the occupying authority has direct control over how many government employees it hires. At the level of fidelity of the baseline model non-security related government employee attrition is not modeled. Of course, this could be added if it is of interest in the operational environment being modeled. The government employee hire rate is given by equation 3.32.

Eq. 3.32 $GovernmentHireRate(t) \sim GHRDist\left(\mu_{GovtHireRate}(t), \sigma_{GovtHireRate}(t)\right)$

The distribution of the government employee hire rate depends on the situation being modeled. A potential distribution would be the Poisson distribution as it is a discrete distribution well suited for modeling an arrival process. If a Poisson distribution is used the government employee hire rate would be given by equation 3.32a.

Eq. 3.32a $GovernmentHireRate \sim Poisson(\lambda_{GovtHireRate}(t))$

If required, a training delay similar to that seen for the security forces could be incorporated into the hiring of non-security government employees.

The private sector hire rate represents the rate at which people transition between unemployed status and private sector employee status. Private sector employees are defined in this model as anyone employed by the private sector. This includes people employed by a company that has been hired by the government to fulfill a contract, but

does not include anyone employed directly by the government. This rate can be positive

or negative to represent an increase or decrease in the number of private sector jobs.

This initial model assumes the private sector hire rate is a function of the growth

rate of the country's per capita gross domestic product. The relationship between the

unemployment rate and the growth rate of a country's gross domestic product has been

well documented and is often referred to as the statistical relationship known as "Okun's

Law" after the economist Arthur Okun who postulated the relationship in 1962

(Blanchard, 2000:25). In the paper "Potential GNP: Its Measurement and Significance"

Okun found that:

> in the postwar period, on the average, each percentage point in the unemployment
> rate above four percent has been associated with about a three percent decrement
> in the real gross national product (1962:2).

Okun supported these findings with a regression of the unemployment rate data onto

postwar real GNP data (Okun, 1962:2).

The private sector hire rate is given by equation 3.33. This equation presents the

private sector hire rate as a function of the growth rate of the real per capita gross

domestic product, the real per capita GDP effect parameter, and the private sector hire

rate random variable.

Eq. 3.33 *PrivateSectorHireRate(t) = RPerCapGDPGrowth(t) * RPerCapGDPEffectParameter(t)*

* PrivateSectorHireRateRandVar(t)

The private sector hire rate random variable introduces variability into the relationship as

the real per capita GDP effect parameter is not known with certainty and fluctuates with

changes to the overall economy.   The distribution of the private sector hire rate random

variable is scenario dependent and must be chosen on the particulars of the economy being modeled.

In their paper "On Aid, Growth and Good Policies" Carl-Johan Dalgaard and Henrik Hansen build an econometric model of economic growth in developing countries. In their model they represent real per capita GDP growth as a function of six factors: (1) the country's previous GDP, (2) the amount of civil unrest in the country, (3) the degree to which the country is ethnically fractionalized, (4) the quality of the countries institutions, the level of development of their financial markets, (5) the quality of the country's economic policy, and (6) the amount of international aid the country has received (Dalgaard and Hansen, 2002:35). In the model developed in this thesis the country's real per capita GDP growth rate is represented as a function of civil unrest, captured through the number of insurgent attacks and the crime rate, and the critical infrastructure levels. In this first cut model, the amount of ethnic fractionalization, the quality of institutions, financial market development, economic policy, and international aid are all assumed to be constant throughout the course of the simulation, and as a result are not modeled dynamically. The real per capita GDP growth rate is given by equation 3.34.

Eq. 3.34 *PerCapRGDPGrowthRate(t) = RGDPRandVar(t) * (InsurgentAttacksEffectParameter(t)*

* #OfInsurgentAttacks(t) + CrimeEffectParameter(t) * CrimeRate(t) +

WaterEffectParameter(t) * WaterShortage(t) + FoodEffectParameter(t) *

FoodShortage(t) + FuelEffectParameter(t)* FuelShortage(t) +

ElectricityEffectParameter(t) * ElectricityShortage(t) +

PreviousPerCapRGDPEffectParameter(t) * PreviousPerCapRGDP(t))

In this equation the distribution of the real per capita GDP growth rate random variable is determined by the particulars of the country being modeled and it is influenced by the factors of ethnic fractionalization, quality of institutions, financial market development, economic policy, and international aid. Again, greater fidelity can be added if desired in specific applications.

Critical Infrastructure Sub-model

Critical infrastructures are important. They affect local population's opinion of the occupation, and the growth rate of the economy. Which infrastructures are critical depends on the exact scenario being modeled. In order to model a particular situation more or less critical infrastructures may need to be added or deleted from the general model presented here.

In the generic model developed in this thesis four infrastructures are included in the critical infrastructure sub-model: (1) potable water, (2) food, (3) fuel, and (4) electricity. The critical infrastructures were selected based on the assumption that in general they are essential for preventing humanitarian crisis or social unrest within the population. The level value of each of these infrastructures is measured in units delivered. It is this quantity of the critical resource ultimately delivered as compared to the quantity demanded that is assumed to be important in this model. No distinction is made in this baseline model between a shortage of a critical resource due to insufficient production or insufficient distribution. For instance, no distinction is made between a shortage of potable water do to an insufficient water treatment infrastructure or a shortage of potable water do to an insufficient water distribution infrastructure. In both cases the critical

resource is ultimately not delivered and the effects on public opinion and economic activity are the same.

The model assumes the demands for the critical resources are exogenous and set by the modeler to levels appropriate for modeling the scenario in question. The critical resource shortage/surplus amounts are functions of the quantity delivered of the critical resource and the quantity demanded. The shortage/surplus amounts for water, food, fuel, and electricity are given by equations 3.35, 3.36, 3.37, and 3.38 respectively.

Eq. 3.35 *WaterShortage/Surplus(t) =*

GallonsOfWaterDelivered(t) – GallonsOfWaterDemanded(t)

Eq. 3.36 *FoodShortage/Surplus(t) =*

TonsOfFoodDelivered(t) - TonsOfFoodDemanded(t)

Eq. 3.37 *FuelShortage/Surplus(t) =*

GallonsOfFuelDelivered(t) - GallonsOfFuelDemanded(t)

Eq 3.38 *ElectricityShortage/Surplus(t) =*

MegaWattDelivered(t) – MegaWattDemanded(t)

A possible expansion to the model would be to make the demand for resources a function of the per capita GDP so that as the economy grows and the standard of living rises demand for resources such as electricity and fuel also grow. Another possible expansion would be to include the transportation infrastructure and communications infrastructure among the critical infrastructures. These were not included in this version of the model as they are not as critical for preventing humanitarian crises as water, food, fuel, and electricity. However, they are important for generating sustained economic growth, and should be included in a more comprehensive model.

The development rates for the four critical infrastructures are modeled as functions of the baseline development rate, the number of insurgent infrastructure attacks, and the levels of other relevant critical infrastructures. The baseline development rate is an input. It represents an assumed potential development rate under peaceful conditions. The number of insurgent infrastructure attacks represents the daily number of insurgent attacks on the critical infrastructure and has been discussed in greater detail in the explanation of the insurgent and coalition military actions sub-model. The development rates of each of the critical infrastructures are also influenced by the levels of some of the other related critical infrastructures. These interrelations are dependent on the exact scenario being modeled, and have to be tailored to fit the particular country of interest. For the purpose of explaining the general model some potential relationships are identified.

The water development rate is the rate of change of the gallons of water distributed daily. It is a function of the baseline water development rate, the number of insurgent infrastructure attacks, and the electricity shortage/surplus level as water pumps and purification facilities often need electricity to function. The water development rate is given by Equation 3.39.

Eq. 3.39 *WaterDevelopmentRate(t) = BaseWaterDevelopmentRate(t) ***
*(InfrastructureAttackWaterEffectParameter(t) * #OfInfrastructureAttacks(t) +*
*ElectricShortageEffectParameter(t) * ElectricShortage(t))*

The food development rate is the rate of change of the tons of food delivered daily. It is a function of the baseline food development rate, the number of insurgent infrastructure attacks, and the fuel shortage/surplus level. The food development rate is a

function of the fuel shortage/surplus level because the food distribution networks in many countries rely of fuel powered truck transportation and a significant shortage of fuel could negatively impact the food delivery infrastructure. The food development rate is given by equation 3.40.

Eq. 3.40 *FoodDevelopmentRate(t) = BaseFoodDevelopmentRate(t) **

(InfrastructureAttackFoodEffectParameter(t) * #OfInfrastructureAttacks(t) +

FuelShortageEffectParameter(t) * FuelShortage(t))

The fuel development rate is the rate of change of the gallons of fuel delivered daily. It is a function of the baseline fuel development rate, the number of insurgent infrastructure attacks, and the electric shortage/surplus, as oil refineries and fuel distribution infrastructures often cannot function at full capacity without electricity. The fuel development rate is given by equation 3.41.

Eq. 3.41 *FuelDevelopmentRate(t) = BaseFuelDevelopmentRate(t) **

(InfrastructureAttackFuelEffectParameter(t) * #OfInfrastructureAttacks(t) +

ElectricShortageEffectParameter(t) * ElectricShortage(t))

The electric development rate is the rate of change of the number of mega watt hours delivered daily. It is a function of the baseline electric development rate and the number of insurgent infrastructure attacks. The electric development rate is given by equation 3.42.

Eq. 3.42 *ElectricDevelopmentRate = BaseElectricDevelopmentRate(t) **

InfrastructureAttackElectricEffectParameter(t) * #OfInfrastructureAttacks(t)

The overall structure of the critical infrastructure sub-model is given in figure 3.7. Clearly, other key infrastructures could be modeled, such as fire protection, education, and health services, for example. While they have not been included in the initial model,

they could be incorporated into the model as required by the situation being investigated and the fidelity needed to meet the analysis requirements.
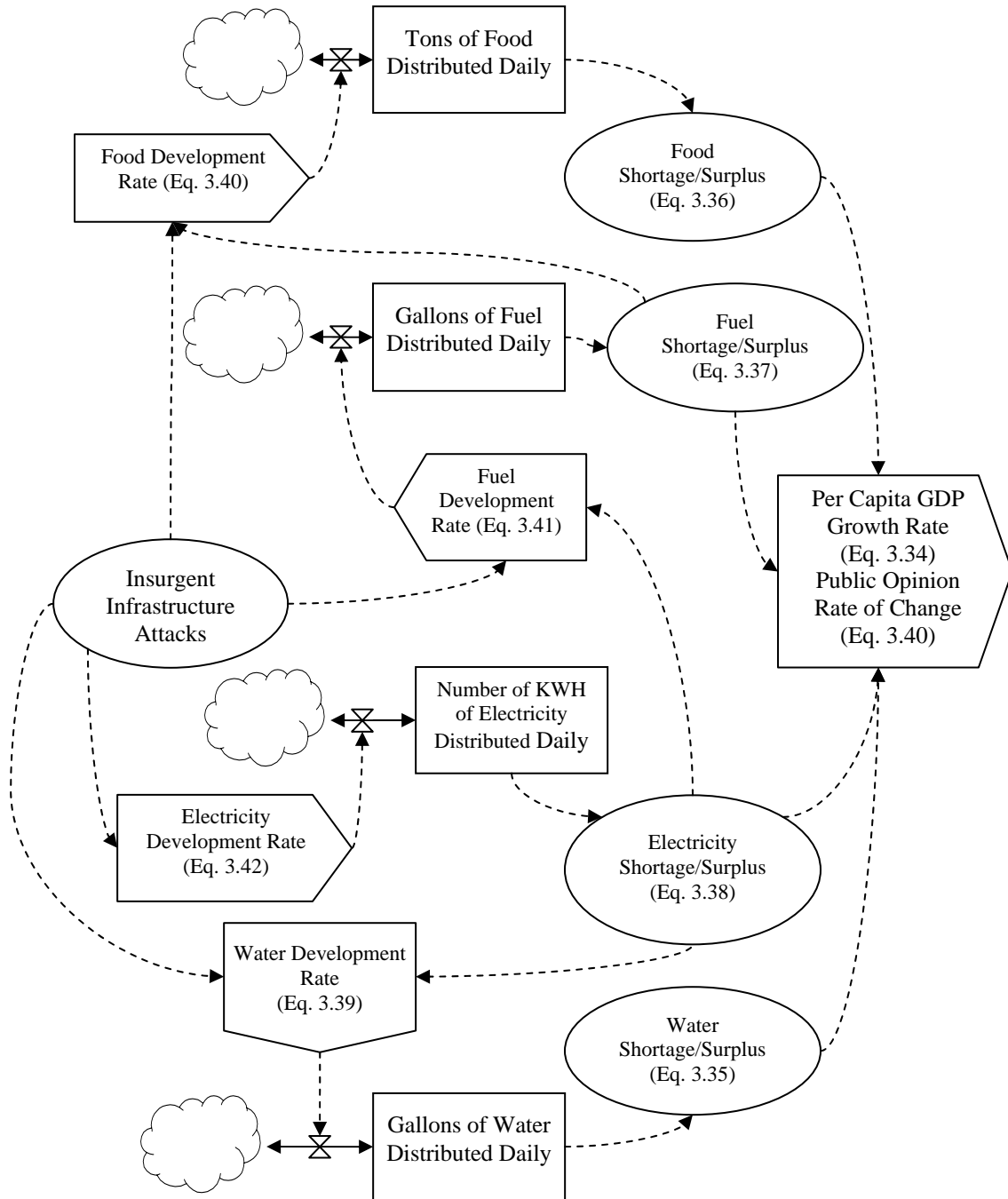
Figure 3.7: Critical Infrastructure Sub-model

Public Opinion Sub-model

The public opinion sub-model influences the rest of the model in two ways. The number of people who are dissatisfied with the occupation influences the insurgent rate of change, and the number of people who are neutral to or satisfied with the occupation influences the number of tips the indigenous population gives on insurgent activities. Figure 3.8 gives the overall structure of the public opinion sub-model.

Figure 3.8: Public Opinion Sub-model

The public opinion rate of change is a function of seven variables: (1) the number of unemployed people, (2) the number of daily insurgent attacks, (3) the crime rate, and

the shortage/surpluses of the critical resources of (4) water, (5) food, (6) fuel, and (7)

electricity. The Public opinion rate of change is given by equation 3.43.

Eq. 3.43 *PublicOpinionRateOfChange(t) = UnemploymentEffectParameter(t)**

UnemploymentLevel(t) + InsurgentAttacksEffectParameter(t) * InsurgentAttacks(t) +

CrimeRateEffectParameter(t) * CrimeRate(t) +

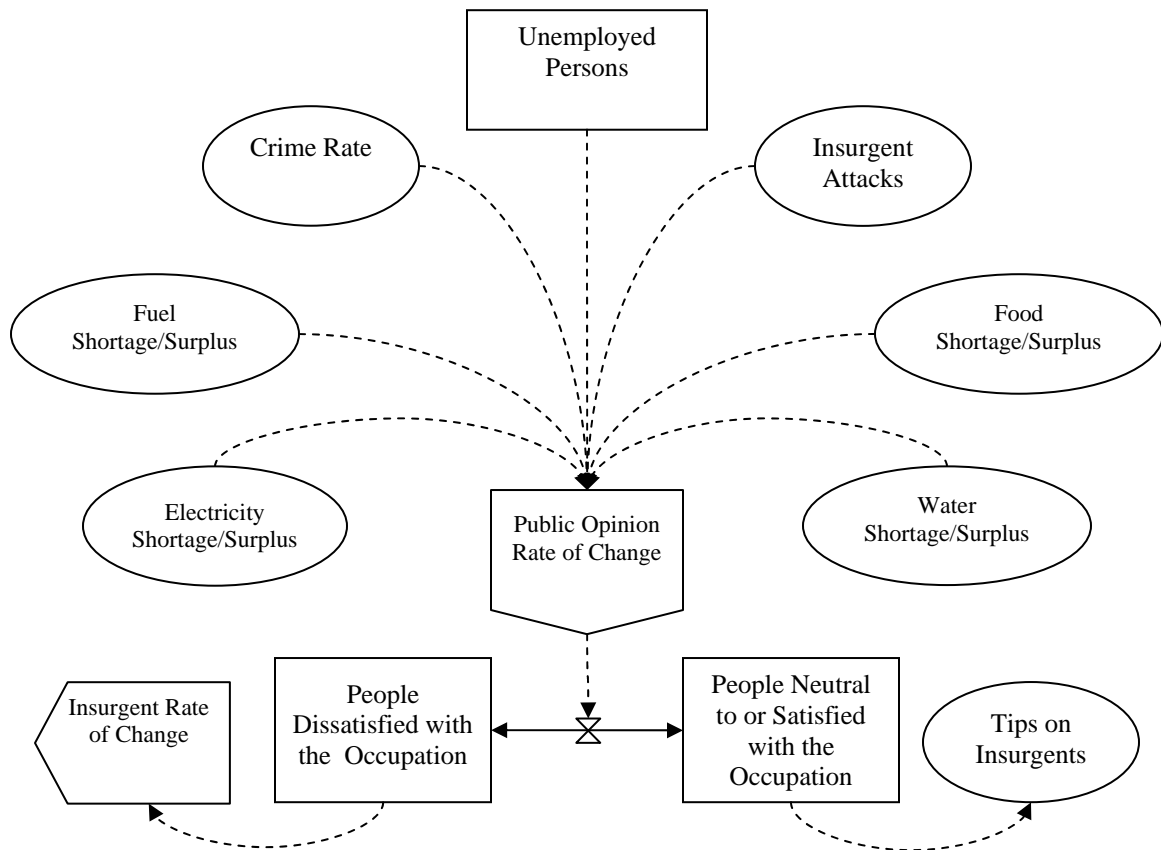*WaterShortage/SurplusEffectParameter(t) * WaterShortage/Surplus(t) +*

FoodShortage/SurplusEffectParameter(t) * FoodShortage/Surplus(t) +

FuelShortage/SurplusEffectParameter(t) * FuelShortage/Surplus(t) +

ElectricShortage/SurplusEffectParameter(t) * ElectricShortage/Surplus(t)

The number of tips on insurgent activity is the daily number of useful tips the

coalition receives on insurgent activity. This number is a function of the number of

people who are neutral to or satisfied with the occupation. The more tips the coalition

troops receive on insurgent activity the more effective they are at apprehending members

of the insurgency. The number of tips on insurgent activity is given by equation 3.44.

Eq. 3.44 *TipsOnInsurgents(t) = #OfPeopleSatisfiedWithOccupation(t) * TipsRandomVariable(t)*

The tips random variable is a number between zero and one that represents how many

tips each satisfied or neutral person makes on insurgent activity each day. The

distribution of this random variable depends on the specifics of the scenario being

modeled and an appropriate distribution must be chosen to fit the situation of interest. An

obvious extension would be the inclusion of a local and international media effect and

coalition psychological operations, for example. Each of these effects is an area for

further research.

Summary

The general form of the proposed systems dynamics based model for simulating the establishment of security in a post conflict reconstruction is proposed. The model is divided into six sub-models: indigenous security forces, law enforcement, insurgent and coalition military activity, labor market, critical infrastructures, and public opinion. The interactions and time dependent functional forms of the rates of change associated with each of the 23 level variables in the general model are identified.

While any number of different variables and levels of fidelity could be added to this initial model, it should be recalled that the goal of the thesis is to show the viability of this approach. The base model is populated with scenario specific data and analyzed in chapter four as a demonstration of the viability of this approach.

IV. Illustration

Notional Scenario: Regime Change

Chapter III discussed a general form of the post-conflict stability operations model developed in this work. This chapter demonstrates how the general model can be applied to investigate a specific scenario. This is done by first sketching a notional example of a post-conflict stability operation. The general form of the post-conflict stability operations model was then applied to model this notional scenario, and the results of the simulation are presented and analyzed.

This notional regime change scenario, based on the 2003 overthrow of the Baathist regime in Iraq, investigates key factors to the establishment of stability. In this notional scenario, a coalition, including the United States, has determined that the government of Iraq posed a threat to security in the world, and that a regime change in Iraq was of vital interest. As a result of this vital interest, an international coalition force was formed to enforce a regime change in Iraq. After a rapid air campaign and land invasion, the Iraqi government collapsed.

Day zero for this notional analysis is assumed to be the day the coalition forces captured Baghdad. The objective of the analysis was to identify influential factors that can be used to investigate policy alternatives with respect to the length of time required to establish security in the aftermath of the Baathist regime collapse. This was accomplished through first initializing the parameters of the basic stability operations

model described in Chapter III, inputting appropriate distributions and parameters, and then performing a screening experiment that identifies influential factors.

Variables

As in the general post-conflict stability operations model, the variables are used to measure the state of the stability operation in six critical areas: (1) Iraqi security institutions, (2) law enforcement, (3) the Iraqi labor market, (4) insurgent and coalition military activity, (5) critical infrastructures, and (6) Iraqi public opinion. These variables are summarized in table 4.1.

Table 4.1: Summary of Variables in the Notional Regime Change Scenario

Sub-model	State Variable
Iraqi Security Forces	# of Iraqi Border Police
	# of Iraqi Civil Defense Personnel
	# of Iraqi Military Personnel
	# of Facility Protection Service Personnel
	# of Iraqi Border Police in Training
	# of Iraqi Civil Defense Personnel in Training
	# of Iraqi Military Personnel in Training
	# of Facility Protection Service Personnel in Training
Law Enforcement	# of Iraqi Police Officers
	# of Iraqi Police Officers in Training
	# of Coalition Troops Working in Law Enforcement
	# of Criminals in Iraq
	# of Incarcerated Criminals in Iraq
Iraqi Labor Market	# of Unemployed Iraqis
	# of Non-Security Related Government Employees
	# of Private Sector Employees
	Iraq's Per Capita Gross Domestic Product
Insurgent and Coalition Military Activities	# of Insurgents
	# of Detained Insurgents
	Total Number of Coalition Troops in Iraq
	# of Coalition Troops Securing Iraq's Borders
	# of Coalition Troops Conducting Counter Insurgency Operations
Critical Infrastructures	Daily Gallons of Potable Water Distributed
	Daily number of Megawatts of Electricity Delivered
	Barrels of Oil Produced Per Day
Iraqi Public Opinion	Iraqis Dissatisfied With the Coalition
	Iraqis Neutral to or Satisfied With the Coalition

The capacity of the Iraqi security institutions are measured by eight variables: (1) the number of Iraqi border patrol personnel, (2) the number of Iraqi civil defense force personnel, (3) the number of Iraqi military personnel, (4) the number of facility protection service personnel, (5) the number of Iraqi border patrol personnel in training, (6) the number of Iraqi civil defense personnel in training, (7) the number of Iraqi military personnel in training, and (8) the number of facility protection service personnel in training.

The state of law enforcement in Iraq is measured by five variables: (1) the number of Iraqi police officers, (2) the number of Iraqi police officers in training, (3) the number of coalition troops working in a law enforcement capacity, (4) the number of criminals in Iraq, and (5) the number of incarcerated criminals in Iraq.

The state of the Iraqi labor market is measured by four variables: (1) unemployed Iraqis, (2) non-military non-police government employees, (3) private sector employees, and (4) Iraq's per capita gross domestic product.

Insurgent activity in Iraq is measured by two variables: (1) the number of insurgents in Iraq and (2) the number of detained insurgents. Regardless of their motivation, anyone in Iraq working to thwart the coalition through violent means is considered an insurgent. Coalition troop activity is measured by three variables: (1) the total number of coalition troops in Iraq, (2) the number of coalition troops patrolling Iraq's borders, and (3) the number of coalition troops conducting counter-insurgency operations.

Iraq's critical infrastructures included in this scenario are water distribution, electricity, and fuel production and distribution. While there are other important infrastructures in Iraq, Pollack suggests these three are critical (Pollak, 2004:2). Iraq's critical infrastructure will be measured by three variables: (1) the daily gallons of potable water distributed, (2) the daily number of megawatt hours of electricity being delivered in Iraq, and (3) the number of barrels of crude oil per day produced in Iraq.

Public opinion in Iraq is measured by two variables: (1) the number of Iraqis dissatisfied with the coalition's occupation and (2) the number of Iraqis neutral to or satisfied with the coalition's occupation.

The Rates of Change

Taken together the 27 level values identified in the preceding section describe the state of the stability operation and its environment. However, by themselves these level values do not develop dynamically. Each level value has one or more rates of change associated with it. These rates of change determine how the level values evolve over time. The level values, coupled with the rates of change, capture how the entire system evolves through time. The overall model of the stability operation in Iraq is divided into the six sub-models in the general model: (1) Iraqi security institutions, (2) law enforcement, (3) the Iraqi labor market, (4) insurgent and coalition military activity, (5) critical infrastructures, and (6) Iraqi public opinion. The specific equations that determine the rates of change in these six sub-models are explained in the following sections.

Iraqi Security Institutions

In post-conflict Iraq the coalition has worked to increase the capacity of the Iraqi security institutions (Swannack,2003:3). It has done this through the standing up of four security services: (1) the Iraqi Civil Defense Corps, (2) the Facility Protection Service, (3) the Iraqi Border Police, and (4) the Iraqi Army.

The Iraqi Civil Defense Corps (ICDC) soldiers are Iraqis who are integrated into coalition military units "to gather intelligence, run combat patrols in the city, establish fixed-site security positions, and conduct raids and cordon search operations" (Miles, 2003:1). Recruits for the ICDC enter an intensive three week combat training program where they learn troop-leading procedures, crowd and riot control, and how to operate an AK-47 assault rifle (Miles, 2003:2). As of the end of January 2004 the ICDC had 19,800 troops, with an eventual goal of 40,000 troops (Brookings Institution, 2004:11).

In this model the training capacity for the ICDC is assumed to be a maximum of three classes of 1,000 trainees each. This training rate is consistent with standing up 20,000 troops in six months, with a three week training program, and a 25% attrition rate. The daily recruiting rate for the ICDC is about 143 troops for a weekly rate of 1000. The Daily recruit rate for the ICDC is given by equation 4.1a and 4.1b. In this notional example the *ICDCRecruitRate* is a function of time, the ICDC class size, the number of classes that can be trained concurrently, and the class length.

Eq. 4.1a *ICDCRecruitRate*(*t*) =

$(ICDCClassSize(t) * \#OfICDCClasses(t)) /ClassLength(t)$

where *ICDCClassSize*(*t*) is computed based on the end goal of 20000 in six months for

this example such that

$(ICDCClassSize(t) * \#OfICDCClasses(t)) /ClassLength(t)*(\#Days / Week)$

$* \#Weeks * (1\text{-}E(ICDCTrainingAttrition(t))) = \#OfDesired\ ICDC\ Personnel$

$((ICDCClassSize(t) * 3) / 21)*(7 / Week)* 26 * (0.75) = 20000$

$ICDCClassSize(t) \approx 1000$

Eq. 4.1b *ICDCRecruitRate*(*t*) = (1000 * 3) / 21 = 143

The attrition rate for the ICDC training program is assumed to be similar to the

attrition rate for the Iraqi Army training program and is given by the variable

ICDCTrainingAttrition which is assumed to be a triangularly distributed random variable

with a minimum of 0, a mean of 0.25, and a maximum of 0.5. The attrition rate of the

Iraqi Army training program and the selection of this distribution is discussed later in this

section. The ICDC trainees who do not graduate the program return to unemployed

status at the end of the training program. The generic graduation rate for the ICDC is

given by equation 4.2a while the expression used in the scenario is given by 4.2b. The

ICDC training graduation rate is a function of the time period, the *ICDCTrainingAttrition*,

and the training class length.

Eq. 4.2a *ICDCGraduationRate*(*t*) =

$$\begin{cases} ClassSize(t)*(1-ICDCTrainingAttrition(t)) \ if \ \ StartDate+ClassLength(t)=CurrentDate \\ 0 \hspace{8em} otherwise \end{cases}$$

Eq. 4.2b *ICDCGraduationRate*(*t*) =

$$\begin{cases} 1000*(1-ICDCTrainingAttrition(t)) \ if \ \ StartDate+21=CurrentDate \\ 0 \hspace{8em} otherwise \end{cases}$$

Garamone has stated that active duty attrition has not been a problem with the security services in Iraq (Garamone, 2003:1). For this reason the active duty attrition rate parameter for the ICDC in this notional analysis, given by equation 4.3, is assumed to be a Poisson distributed random variable with a mean and variance of zero.

Eq. 4.3 *ICDCAttritionRate*(t) ~ Poisson(*ICDCAttritionRateParameter*(t))

Where

ICDCAttritionRateParameter(t) = 0

The *ICDCAttritionRate* is a function of the time period. In this notional example the *ICDCAttritionRate* has been effectively set at 0 for all time periods. However, another distribution could be used to fit the scenario being investigated.

The Iraqi Army undergoes a similar training program to the ICDC. The Army is trained at the battalion level. About 1000 recruits enter each class to produce an active battalion of 757 troops (Eaton, 2004:2). Officers, non-commissioned officers, and enlisted men are first trained separately. They are then all integrated and train together for three additional weeks before they graduate and enter active duty (Eaton, 2004:3). The coalition has the capacity to train three battalions simultaneously (Eaton, 2004:3). As of the end of January three battalions had graduated and three more were being trained (Eaton, 2004:3). The coalition plans to use these first battalions as a cadre that will eventually train more units until the goal of nine infantry brigades of three battalions each is reached (Eaton, 2004:2;Combined Joint Task Force 7, 2003:2). Attrition for the Iraqi Army training program has been as high as 50%, but generally has averaged about between 20% and 25%, which the Army has said is a typical attrition rate based on the type of recruiting and training involved (Eaton, 2004:13). The attrition rate for the Iraqi

Army training program in this notional scenario is given by the variable

IMilTrainingAttrition and has been modeled as a triangularly distributed random variable

with a minimum of 0, a mean of 0.25, and a maximum of 0.5, to reflect the attrition rates

observed in the Iraqi Army training program.

This model assumes that the coalition is able to induce as many Iraqis to join the

Army as can be trained. In order to keep a 60 day training program with three classes of

1000 recruits each full, 50 trainees need to be recruited each day. The Iraqi Army

recruitment rate is given by equation 4.4a and 4.4b.

Eq. 4.4a *IraqiArmyRecruitRate(t)=*

(*IMilClassSize(t) * #OfIMilClasses*(t))/*ClassLength(t)*

Eq. 4.4b *IraqiArmyRecruitRate(t)* = (1000 * 3) / 60 = 50

The graduation rate for the Iraqi Army is given by equations 4.5a and 4.5b.

Eq. 4.5a *IraqiArmyGraduationRate(t)* =

$$\begin{cases} ClassSize(t)*\left(1-IMilTrainingAttrition(t)\right) & if \;\; StartDate + ClassLength(t) = CurrentDate \\ 0 & otherwise \end{cases}$$

Eq. 4.5b *IraqiArmyGraduationRate(t)* =

$$\begin{cases} 1000*\left(1-IMilTrainingAttrition(t)\right) if \;\; StartDate + 60 = CurrentDate \\ 0 \hspace{5.5cm} otherwise \end{cases}$$

News reports have suggested that active duty attrition has not been a problem

with the security services in Iraq (Garamone, 2003:1). As a result the attrition rate

parameter for the Iraqi Army in this scenario, given by equation 4.6, is assumed to be

zero.

Eq. 4.6   *IraqiArmyAttritionRate(t)* ~ Poisson(*IraqiArmyAttritionRateParameter*(*t*))

Where

      IraqiArmyAttritionRateParameter(*t*) = 0

The Facility Protection Service (FPS) personnel go through a three day training course before they are used to guard government buildings and facilities (Ministry of Interior, 2004:5). The training course includes "instruction in hand-to-hand combat, weapons familiarization, professional conduct, and personal interaction" (DoD, 2003:4). This very short training course has enabled the coalition to quickly train a large number of FPS troops. By the beginning of February 2004 there were 97,800 FPS personnel working throughout Iraq (Brookings Institution, 2004:11).

This notional analysis assumes that the coalition can train three classes of 1000 FPS recruits simultaneously, and that it can induce enough Iraqis to enroll in the training program to keep all the classes full. The FPS recruitment rate required to keep these classes full is given generally by equation 4.7a and specifically for this scenario by 4.7b and is 1000 new recruits per day.

Eq. 4.7a *FPSRecruitRate(t) =(ClassSize(t) * #OfClasses*(*t*))*/ClassLength(t)*

Eq. 4.7b *FPSRecruitRate(t)*= (1000*3) / 3 = 1000

The attrition rate for the FPS training program is given by the variable *FPSTrainingAttrition* and is assumed to be a triangularly distributed random variable with a minimum of 0, a mean of 0.25, and a maximum of 0.5. The graduation rate for the FPS is stated in general by equation 4.8a and is reexpressed for this specific excersice in 4.8b.

Eq. 4.8a *FPSGraduationRate(t) =*

$$\begin{cases} ClassSize(t)*(1-FPSTrainingAttrition(t)) \ if \ \ StartDate+ClassLength(t)=CurrentDate \\ 0 \hspace{11cm} otherwise \end{cases}$$

Eq. 4.8b *FPSGraduationRate(t) =*

$$\begin{cases} 1000*(1-FPSTrainingAttrition(t)) \ if \ \ StartDate+3=CurrentDate \\ 0 \hspace{8cm} otherwise \end{cases}$$

Continuing with the assumption that active duty attrition has not been a problem

for the security services in Iraq, the active duty attrition rate for the FPS in this model,

given by equation 4.9, is also set to be zero (Garamone,2003:1).

Eq. 4.9 *FPSAttritionRate(t)* ~ Poisson(*FPSAttritionRateParameter(t)*)

Where

$FPSAttritionRateParameter(t) = 0$

The Iraqi Border Police initially go through the standard eight week police

training program followed by "an additional two weeks of post academy training

specifically tailored for border police officers" (Ministry of Interior, 2004:4). By the

beginning of February 2004 there were 21,000 Iraqi Border Police working to secure

Iraq's borders (Brookings Institution, 2004:11). The eventual goal is a force of 25,000

border police (Brookings Institution, 2004:11).

For this notional example it is assumed that ten classes of 1,000 Iraqi Border

Police trainees can be trained simultaneously, and that there are enough recruits to fill

these classes. This assumption is based on the open source data available on the training

rates of Iraqi Border Police (Brookings Institution, 2004:11). Of course, these parameters

can be modified to fit the scenario being modeled. For this scenario the Iraqi Border

Police recruit rate is given in general by equation 4.10a and tailored for this analysis in

4.10b.

Eq. 4.10a *IBPRecruitRate(t) = (ClassSize(t) * #OfClasses(t))/ClassLength(t)*

Eq. 4.10b *IBPRecruitRate(t) = (1000 * 10) / 70 = 143*

The attrition rate for the Iraqi Border Police training program is given by the

variable *IBPTrainingAttrition* and is assumed to be a triangularly distributed random

variable with a minimum of 0, a mean of 0.25, and a maximum of 0.5. The graduation

rate for the Iraqi Border Police is given by equation 4.11.

Eq. 4.11a *IBPGraduationRate(t) =*

$$\begin{cases} ClassSize(t)*\bigl(1-IBPTrainingAttrition(t)\bigr) \; if \;\; StartDate+ClassLength(t)=CurrentDate \\ 0 \hspace{18em} otherwise \end{cases}$$

Eq. 4.11b *IBPGraduationRate(t) =*

$$\begin{cases} 1000*\bigl(1-IBPTrainingAttrition(t)\bigr) \; if \;\; StartDate+70=CurrentDate \\ 0 \hspace{13em} otherwise \end{cases}$$

The active duty attrition rate parameter for the Iraqi Border Police in this notional

example is given by equation 4.12 and is assumed to be zero, based on news reports of

the active duty attrition rates of the Iraqi security forces (Garamone, 2003:1).

Eq. 4.12 *IBPAttritionRate(t)* ~ Poisson(*IBPAttritionRateParameter*(t))

Where

$\quad$ *IBPAttritionRateParameter*(t) = 0

Open source data is not available for the number of casualties of each Iraqi

security service, but the Brookings Institution gives a rough estimate that about 200 Iraqi

security service personnel were killed in the months of December 2003 and January 2004

(2004:4). In the same months Iraq's security services were typically attacked two to four

times per day nationwide (Brookings Institution, 2004:7). If over a two month period the

Iraqi security services were attacked three times per day and there was, on average, one

casualty per attack there would be close to 200 casualties over that time period. This is

consistent with the limited open source data available on the number of Iraqi security

force casualties. In this scenario the daily number of casualties in the Iraqi security

forces is assumed to be a Poisson distributed random variable with a mean of one times

that day's number of insurgent attacks against Iraqi security forces. The daily Iraqi

security force casualties are then randomly applied to one of the four security forces or

the Iraqi Police. The Iraqi Police are discussed in the following section, and the number

of insurgent attacks on Iraqi security forces are discussed in the insurgent and coalition

military section. The daily casualty rate for the Iraqi security forces is given by Equation

4.13.

Eq. 4.13 *IraqiSecurityForceCasualties(t)* ~ Poisson(*InsurgentAttacksOnIraqiSF(t)*)

Law Enforcement

Establishing law and order is critical in Iraq. "The fear Iraqis have of crime and

lawlessness is, without question, the single greatest impediment to social, political, and

economic reconstruction in Iraq today" (Pollak, 2004:12). If the coalition is unable to

solve Iraq's crime problems then ordinary Iraqis may "seek protection behind local

militias of one sort or another—which would spell the end of reconstruction and be the

first step on the road to civil war" (Pollak, 2004:12).

The cornerstone of the coalition's strategy to enforce law and order in Iraq is the

Iraqi Police Service. The Iraqi Police Service recruits new police officers and

experienced police officers. New police officers undergo an eight week training program (Interior Ministry, 2004:1). It is assumed in this illustrative example that the new police officer training course can train three classes of 1,500 recruits each simultaneously, and that there is a four day lag between the end of training and when new police officers enter active duty. Experienced police officers undergo a three week training program to educate recruits on "international standards of human rights, modern policing techniques, and Iraqi criminal law and procedure" (Interior Ministry, 2004:1). The three week training program can train 3,000 recruits simultaneously (Interior Ministry, 2004:1). In this scenario it is assumed that the 3,000 recruits are trained in concurrent classes of 1,000 recruits each.

This analysis assumes that the coalition can recruit enough trainees to keep both of these training programs full. That translates to 75 new trainees and 143 experienced trainees recruited each day. The new and experienced Iraqi police officer trainee recruitment rates are given by equations 4.14 and 4.15 respectively.

Eq. 4.14a *NewIPORecruitRate(t) = (ClassSize(t) * #OfClasses(t))/ClassLength(t)*

Eq. 4.14b *NewIPORecruitRate(t) = (1500 * 3) / 60 = 75*

Eq. 4.15a *ExperiencedIPORecruitRate(t) = (ClassSize(t) * #OfClasses(t))/ClassLength(t)*

Eq. 4.15b *ExperiencedIPORecruitRate(t) = (1000 * 3) / 21 = 143*

The attrition rates for both of these programs are *NewIPOTrainingAttritionRate* and *EIPOTrainingAttritionRate*, respectively. It has been assumed that these values are triangularly distributed random variables with minimum values of 0, means of 0.25, and maximum values of 0.5. The Iraqi police officer graduation rate is the sum of the new police officer training program graduation rate and the experienced police officer training

program graduation rate. It is given in general by equation 4.16a and specifically for this

scenario in 4.16b.

Eq. 4.16a *IPOGradRate(t) = NewIPOGradRate(t) + ExperiencedIPOGradRate(t)*

Where

NewIPOGradRate(t)=

$$\begin{cases} ClassSize(t)*(1-NewIPOTrainingAttrition(t)) \; if \; StartDate+ClassLength(t)=CurrentDate \\ 0 \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad otherwise \end{cases}$$

ExperiencedIPOGradRate(t)=

$$\begin{cases} ClassSize(t)*(1-EIPOTrainingAttrition(t)) \; if \; StartDate+ClassLength(t)=CurrentDate \\ 0 \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad otherwise \end{cases}$$

Eq. 4.16b *IPOGradRate(t) = NewIPOGradRate(t) + ExperiencedIPOGradRate(t)*

Where

$$NewIPOGradRate(t)= \begin{cases} 1500*(1-NewIPOTrainingAttrition(t)) \; if \; StartDate+60=CurrentDate \\ 0 \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad otherwise \end{cases}$$

ExperiencedIPOGradRate(t)=

$$\begin{cases} 1000*(1-EIPOTrainingAttrition(t)) \; if \; StartDate+21=CurrentDate \\ 0 \qquad\qquad\qquad\qquad\qquad\qquad\qquad otherwise \end{cases}$$

In this model active duty attrition is assumed to not be a problem. An interesting addition

to the model would be to make the active duty attrition rate a dynamic function of the

police officer casualty rate, the salary paid police officers, and the police officer work

load.

Eq. 4.17 IPO*AttritionRate(t)* ~ Poisson(*IPOAttritionRateParameter*(t))

Where

IPOAttritionRateParameter(t) = 0

The criminal recruitment rate is the rate at which unemployed people stop looking

for jobs and start supporting themselves through crime. In this notional scenario it has

been assumed that every day between two and three unemployed people per thousand

become criminals. Of those people who become criminals or who already are criminals,

two criminals per criminal apprehended the previous day leave criminal status and return

to unemployed status. The criminal recruitment rate assumed by this model is given by

equation 4.18.

Eq. 4.18 *CriminalRecruitRate(t)* = (U_1 * *UnemploymentLevel* – *CAppEffectParameter**

CriminalApprehensionRate $_{CurrentDay-1}$) * T_1

Where

U_1 ~ Uniform(0.002,0.003)

CAppEffectParameter = 2

T_1 ~ Triangular(.5,1,1.5)

While there is evidence that suggests that the rate at which people choose to become

criminals is affected by their economic situation and their probability of apprehension,

the exact relationship given above is notional (Neumayer, 2003:635). Further research

needs to be done to investigate the validity of this notional relationship. As a result of

this uncertainty the criminal recruitment rate varies by plus or minus 50%.

The criminal apprehension rate is assumed to be the rate at which criminals are

arrested by Iraqi police, the Iraqi Civil Defense Corps, and coalition military forces

conducting crime suppression operations. According to FBI data on reported crimes and

arrests in 59 large U.S. cities, about 20% of reported violent crimes result in an arrest

(Levitt, 1995:32). The stated goal of the coalition is to ultimately train a force of about

110,000 police and Iraqi Civil Defense Corps personnel to maintain law and order in Iraq

(Brookings Institution, 2004:11). This scenario assumes that 110,000 police and ICDC

personnel will be able to achieve a similar ratio of arrests per criminals. This similar

ratio of arrests can be approximately attained if each group of 11,000 police and ICDC

personnel in this scenario can apprehend between one and three percent of the criminals

in Iraq each day, never exceeding one arrest per ten police and ICDC personnel. The

criminal apprehension rate is then given by equation 4.19.

Eq. 4.19 *CriminalApprehensionRate(t) = Criminals(t) **

$$(\frac{IPOLevel(t) + ICDCLevel(t) + CoalitionMilitaryPolicing(t)}{PoliceForceEffectParameter(t)}) * U_1$$

Such that

CriminalApprehensionRate(t) $\leq$

$$(\frac{IPOLevel(t) + ICDCLevel(t) + CoalitionMilitaryPolicing(t)}{MinPoliceToCaptureACri \min al(t)})$$

PoliceForceEffectParameter(t) = 1

U_1 ~ Uniform(0.01,0.03)

MinPoliceToCaptureACriminal(t) = 10

The criminal apprehension rate given in equation 4.19 is notional. Further research is

needed to determine the actual apprehension rate.

The criminal release rate gives the rate at which criminals who have been arrested

are released back into the general population. This rate includes people who were

arrested and released because they were found to be innocent, people who were arrested

stood trial and were acquitted, and people who were arrested convicted and have finished

their sentences. This scenario assumes that every day between zero and five percent of

the incarcerated criminals are released into the pool of unemployed persons. Equation

4.20 gives the criminal release rate.

Eq. 4.20   *CriminalReleaseRate(t) = (IncarceratedCriminalsLevel(t)) $\cdot$ U_1*

Where

U_1 ~ Uniform(0,0.05)

This release rate is notional and can be adjusted to various levels to simulate alternative levels of prosecutorial effectiveness and punishment severity.

A lack of reliable open source data exists on the crime rate in post-conflict Iraq. The Brookings Institute reports that one of the few open source statistics that was available between May 2003 and January 2004 is a rough estimate of the number of crime related deaths in Baghdad (Brookings Institute, 2004:12). This number was calculated based on the number of bodies with fatal gunshot wounds brought to morgues in the Baghdad area, recognizing that not all bodies brought to morgues are victims and not all victims are brought to morgues (Brookings institution, 2004:12). The scenario analyzed here uses the number of crime related deaths as a proxy for the violent crime rate. It is assumed that each criminal and insurgent is responsible for an average of between 0.25 and one crime related deaths each year. Included in this rate is also the casualty rate of Iraqi security forces, and deaths as a result of insurgent attacks on the civilian population. In this notional example it is assumed that on average 20 civilians are killed as a result of each insurgent attack on the civilian population. The crime related death rate is given by equation 4.21 and is calculated as a proxy for the amount of crime in Iraq. The ISF casualty rate is applied to the Iraqi security force levels in the Iraqi security forces sub model.

Eq. 4.21 *CrimeRelatedDeathRate(t) =*

$$(\frac{1}{365}) * (Criminals(t) + Insurgents(t)) * U_1 + ISFCasualtyRate(t) + P_1$$

Where

$U_1 \sim$ Uniform(0.25,1)

$P_1 \sim$ Poisson(*InsurgentAttackCivEffectParameter*(t)**InsurgentAttacksCivilians*(t))

InsurgentAttackCivEffectParameter(t) = 20

The last equation in the law enforcement sub-model describes the number of

coalition troops that are being used to conduct crime suppression operations. Pollack

reports that in Iraq from May 2003 to January 2004 few coalition forces were employed

in crime suppression operations (Pollak, 2004:13). It is assumed in this notional scenario

that 5% of coalition troops are employed in crime suppression operations as shown in

equation 4.22.

Eq. 4.22 *CoalitionTroopsPolicing(t) =*

%OfCoalitionTroopsSupressingCrime(t)*TotalCoalitionTroops(t)

Where

%OfCoalitionTroopsSupressingCrime(t) = .05

Insurgent and Coalition Military Activities

Insurgent and coalition military activities are represented in this scenario by three

level values and six rates of change. The level values are the number of coalition troops

in Iraq, the assumed number of insurgents in Iraq, and the number of insurgents being

detained by the coalition. The rates of change are: (1) the coalition troop rate of change,

(2) the coalition troop casualty rate, (3) the insurgent recruitment rate, (4) the

international insurgent rate of change, (5) the insurgent apprehension rate, and (6) the detained insurgent release rate.

The coalition troop level is influenced by two rates of change: (1) the coalition troops in country rate of change and (2) the coalition troop casualty rate. The coalition troop rate of change represents the rate at which coalition troops are arriving or departing the country, and the coalition casualty rate is the rate at which coalition troops are being killed or wounded. These two rates can be set at different levels to investigate the effects of a troop build-up or a troop draw-down. For this scenario run the number of coalition troops in Iraq was be held constant by setting the coalition troop rate of change equal to the coalition troop casualty rate. The coalition troop rate of change is given by equation 4.23.

Eq. 4.23 *CoalitionTroopRateOfChange(t) = CoalitionTroopCasualtyRate(t)*

This formulation of the *CoalitionTroopRateOfChange* effectively maintains the coalition troop manning level.

The coalition troop casualty rate is a function of the number of insurgent attacks that are made on coalition troops. According to the Brookings Institute, in the months of August 2003 through January 2004 an average of five fatalities resulted from each 100 attacks on U.S. troops, with an average of eight troops wounded for each fatality (Brookings Institution, 2004:3-6). Therefore, on the average there were 0.4 casualties per attack on U.S. troops. In this example it has been assumed that all coalition troops have a similar average casualties per attack, and that the coalition troop casualties per attack is a Poisson distributed random variable with a mean of 0.4 times the daily number of

insurgent attacks against coalition troops. For this scenario the coalition troop casualty rate is given by equation 4.24.

Eq. 4.24 *CoalitionTroopCasualtyRate*(*t*) ~

Poisson(*AvgCasualtiesPerAttack*(*t*) * *#OfInsurgentAttacksOnCoalitionTroops*(*t*))

Where

AvgCasualtiesPerAttack(*t*) = 0.4

The insurgent recruitment rate is the rate at which people transition from unemployed status to insurgent status. For this analysis insurgents are defined as anyone, regardless of their motivation, attempting to thwart the coalition through violent means. In the case of Iraq some of the people attempting to thwart the coalition through violence are motivated by political beliefs, some by religious beliefs, some by the potential for financial gain, and some by a combination of these three.   In this analysis all of these people are included in the insurgent category.

Similar to how the criminal recruitment rate was modeled in the law enforcement sub-model, in this notional example every day between two and three people per 10,000 who have become dissatisfied with the occupation consider joining the insurgency. There is no open source data on the rate at which people join the insurgency so this number has been approximated based on monthly estimates of insurgent strength reported by the Brookings Institution (2004:10). Of the people who either are considering becoming insurgents or already are insurgents, a percentage of them reconsider their decision and decide not to participate in the insurgency. The total number of insurgents who reconsider is a function of the number of insurgents captured the previous day. As a result the insurgent recruitment rate can be negative. A negative insurgent recruitment

rate would represent people choosing to leave the insurgency and transition to unemployed status. The insurgent recruitment rate is given by equation 4.25.

Eq. 4.25 *InsurgentRecruitmentRate(t)* = (U_1 * *DissatisfiedPeople(t)* -

U_2 *InsurgentKilledOrDetainedRate* $_{CurrentDay-1}$) * T_1

Where

U_1 ~ Uniform(0.0002,0.0003)

U_2 ~ Uniform(0,1)

T_1 ~ Triangular(0.5,1,1.5)

Formulating the insurgent recruitment rate as a function of the number of dissatisfied people and the insurgent apprehension rate is consistent with the research done by Epstein, Steinbruner, and Parker (2001:3-5). Epstein, Steinbruner, and Parker, in an agent based simulation on civil violence, made the choice of whether each agent revolted or not based on, among other things, that agent's level of grievance and their perceived chance of being arrested for revolting (2001:3-5). Because of the uncertainty of the insurgent recruitment rate, it has been allowed to vary by plus or minus 50%.

The international insurgent rate of change depicts the rate at which people are coming to Iraq to join the insurgency. The number of international insurgent that try to enter Iraq is assumed to be determined by social and political dynamics that are exogenous to the model. In a statement made on 19 December 2003, the U.S. military said that of the almost 9,000 suspected insurgents it has detained, about 200 to 300 of them were foreign nationals (Kimmitt, 2003:9). In addition, it has been estimated that about 90% of the insurgents in Iraq are former regime loyalists (Brookings Institution,

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2004:10). In this analysis it has been assumed that every day between zero and ten

international insurgents try to enter Iraq, and that the number that succeed in entering the

country is a function of the number of Iraqi border police and coalition troops patrolling

the borders. The international insurgent rate of change is given by equation 4.26.

Eq. 4.26 *InternationalInsurgentRateOfChange(t) =* $D_1 *$

$$\frac{\text{BPEffectParameter(t)}}{(\text{BPEffectParameter(t)} + CoalitionTroopsPatrollingBorders(t) + IraqiBP(t))}$$

Where

$D_1 \sim$ DiscreteUniform(0,10)

BPEffectParameter(t) = 10,000

This scenario notionally assumes that 10,000 troops patrolling Iraq's borders will be able

to stop 50% of the international insurgents trying to enter Iraq, that 20,000 troops will be

able to stop 66% of the insurgents trying to enter Iraq, and that 30,000 troops will be able

to stop 75% of the insurgents trying to enter Iraq.

The insurgent detained or killed rate is the rate that insurgents are detained or

killed by the coalition and the Iraqi security forces. This rate is a function of the number

of insurgents in the country, the number of coalition troops and Iraqi security forces

conducting counter insurgency operations, and the number of tips the coalition receives

on insurgent activity. For each month between May 2003 and January 2004 the coalition

detained or killed between 750 and 2,000 suspected insurgents, averaging just over 1000

per month (Brookings Institution, 2004:10). It has been assumed in this scenario that

without any tips on insurgent activity each group of 30,000 troops conducting counter

insurgency operations can apprehend between 0.05% and 0.15% of the insurgents in Iraq

each day. As there is no open source data on the effectiveness of troops at apprehending

insurgents, this number has been approximated based on assumed insurgent levels and

reported insurgent apprehensions. The insurgent apprehension rate is given by equation

4.27.

Eq. 4.27 *InsurgentKilledOrDetainedRate(t) =Insurgents(t)* *

CounterInsurgencyEffectParameter(t) * (*CoalitionTroopsCounterInsurgency(t)* +

IraqiArmyTroops(t) + *ICDCTroopEffectParameter(t)* * *ICDCTroops*) * U_1 + P_1

Where

CounterInsurgencyEffectParameter(t) = 10,000

ICDCTroopEffectParameter(t) = 0.5

U_1 ~ Uniform(0.0005,0.0015)

P_1 ~ Poisson(*AvgApprehensionsPerTip*(t) * *TipsOnInsurgentActivity*(t))

AvgApprehensionsPerTip(t) = 0.3

It has also been assumed that, on average, three tips in ten leads to the successful

apprehension of an insurgent. The Brookings Institution has reported that in late spring

and early summer about half of all intelligence leads were productive (2004:7). The tip

effectiveness parameter in this scenario has been chosen as a conservative estimate, as it

has been assumed that not all tips are actionable intelligence leads.

In this notional example it is assumed that of the total number of insurgents that

are killed or detained each day, zero to two percent of them are killed. The number of

insurgents killed in operations each day is given by equation 4.28.

Eq. 4.28 *InsurgentKilledRate(t) = U_1 * InsurgentKilledOrDetainedRate(t)*

Where

U_1 ~ Uniform(0,0.02)

The detained insurgent release rate gives the rate the detained insurgents are released back into the pool of unemployed persons. This rate is determined directly by the coalition, as it can decide how many detainees it will release each day. In this scenario it is assumed that on average one out of three detainees is released each day. The detained insurgent release rate is given by equation 4.29.

Eq. 4.29 *DetainedInsurgentReleaseRate(t)* ~ Poisson(*DetainedInsurgentReleaseRateParameter*(*t*) *

DetainedInsurgents(*t*))

Where

DetainedInsurgentReleaseRateParameter(*t*) = 0.33

In January 2004 U.S. troops were attacked an average of 18 times per day, Iraqi security forces were attacked an average of 4 times per day, Iraqi civilians were attacked an average of 1 time per day, and Iraq's oil infrastructure was attacked twice in the whole month (Brookings Institution, 2004:6-7). That is an average of about 23 attacks per day, with roughly 78% of attacks being directed at U.S. troops, 17% of attacks being directed at Iraqi security forces, 4% of attacks being directed at Iraqi civilians, and 1% of attacks being directed at critical infrastructure. In January 2004, 14 cells, each consisting of between 20 and 100 insurgents were believed to be operating in Baghdad, and between 3,000 and 5,000 insurgents were thought to be operating nationwide (Brookings Institution, 2004:10). If these numbers are accurate and there were 4,000 insurgents

operating nationwide in 100 cells of 40 insurgents each, and each cell was able to launch

an attack every 4 days there would be about 25 attacks per day in Iraq.

It is assumed in this example that insurgents organize themselves into cells of 40,

that each cell can launch an attack on average every 4 days, and that on average 78% of

attacks are directed at coalition troops, 17% of attacks are directed at Iraqi security forces,

4% of attacks are directed at Iraqi civilians, and 1% of attacks are directed at critical

infrastructure. Based on these assumptions the daily insurgent attack rates on coalition

troops, Iraqi security forces, Iraqi civilians, and critical infrastructure are given by

equations 4.30, 4.31, 4.32, and 4.33 respectively.

Eq. 4.30 *InsurgentAttacksOnCoaltion(t)* ~ Poisson(*%OfAttacksOnCoalition(t)*

$$* \frac{Insurgents(t)}{InsurgentsPerCell(t)} * AttacksPerDayPerCell(t))$$

Where

%OfAttacksOnCoalition(t) = 0.78

InsurgentsPerCell(t) = 40

AttacksPerCellPerDay(t) = 0.25

Eq. 4.31 *InsurgentAttacksOnIraqiSF(t)* ~ Poisson(*%OfAttacksOnIraqiSF(t)*

$$* \frac{Insurgents(t)}{InsurgentsPerCell(t)} * AttacksPerDayPerCell(t))$$

Where

%OfAttacksOnIraqiSF(t) = 0.17

InsurgentsPerCell(t) = 40

AttacksPerCellPerDay(t) = 0.25

Eq. 4.32 *InsurgentAttacksCivilians(t)* ~ Poisson(*%OfAttacksOnCiv(t)*

$$* \frac{Insurgents(t)}{InsurgentsPerCell(t)} * AttacksPerDayPerCell(t))$$

Where

   %OfAttacksOnCiv(t) = 0.04

   InsurgentsPerCell(t) = 40

   AttacksPerCellPerDay(t) = 0.25

Eq. 4.33 *InsurgentAttacksInfrastructure(t)* =

$$P_1 * \frac{FPSEffectParameter(t)}{FPSEffectParameter(t) + FPSLevel(t)}$$

Where

$$P_1 \sim \text{Poisson}(\textit{%OfAttacksOnInf(t)} * \frac{Insurgents(t)}{InsurgentsPerCell(t)} * AttacksPerDayPerCell(t))$$

   %OfAttacksOnInf(t) = 0.01

   InsurgentsPerCell(t) = 40

   AttacksPerCellPerDay(t) = 0.25

   FPSEffectParameter(t) = 20,000

The additional term in equation 4.33 represents the effect the Facility Protection Service

troops have on foiling attacks on infrastructure targets. This equation assumes that

20,000 FPS troops could foil about 50% of infrastructure attacks and the coalition's goal

of 50,000 FPS troops could foil almost 75% of all infrastructure attacks (Brookings

Institution, 2004:11).

Iraqi Labor Market

In this example it has been assumed that every member of Iraq's labor force

belongs to one of ten groups. Each person is either (1) unemployed; (2) employed in the

private sector; employed as a trainee or active duty member of the (3) Iraqi police, (4)

border police, (5) civil defense corps, (6) facility protection service, or (7) Iraqi Army; employed in a (8) non-security related government job; (9) a criminal; or an (10) insurgent. Each person in the labor market is assumed to belong to one and only one of these categories. However, as the scenario evolves over time, people move from one category to another as prescribed by the various rates of change.

The previous explanation of the Iraqi security institutions sub-model detailed how people move back and forth between unemployed status and trainee and active duty status in the Iraqi Border Police, the Iraqi Civil Defense Corps, the Facility Protection Service, and the Iraqi Army. The discussion of the law enforcement sub-model explained how people transition between unemployed status and criminal status, as well as Iraqi police officer trainee status and active duty Iraqi police officer status. The presentation of the coalition military and insurgent activities sub-model outlined how people transition between unemployed status and insurgent status. The only aspects of the labor market that have not yet been discussed are the effects of non-security related government jobs, private sector jobs, and the per capita gross domestic product.

The detailed dynamics of the standing up the new Iraqi government is beyond the scope of this model, and is left as an area for further research. However, its direct effect with respect to the establishment of security is accounted for as a source of jobs. The rate at which unemployed Iraqis are hired into government jobs is considered exogenous to the model and set directly by the modeler as the coalition can decide how many jobs it wishes to offer. This example assumes that the initial Iraqi government has about as many non-security related personnel as it has security related personnel. The coalition's

stated goal is to train about 225,000 personnel in Iraqi security forces (Brookings Institution, 2004:10). If the non-security related civil service is to be of about the same size and stood up over the course of 18 months, then the government will hire on average about 410 workers a day. This example assumes that on average 410 qualified workers can be enticed to take a government job each day. The hiring rate of the non-security related civil service is given by equation 4.34.

Eq. 4.34 *Non-SecurityGovernmentRate(t) ~ Poisson(AvgGovtHireRate(t))*

Where

$AvgGovtHireRate(t) = 410$

In this analysis the growth in the number of private sector jobs is a function of the growth rate of the Iraqi gross domestic product. The relationship between the rate of change of unemployment in a country and its growth rate of gross domestic product is often referred to as Okun's law (Blanchard, 2000:25). In the United States since 1960 a drop in the unemployment rate of about one percentage point has been associated with each 2.5 percent increase in the annualized GDP growth rate (Blanchard, 2000:26). Despite being termed a "law," this relationship is an empirical rule, more a "rule of thumb," than a binding fact of economics. However, it makes sense that such a relationship should exist; "High output growth leads to high employment growth, as firms hire more workers to produce more, and high employment growth leads to a decrease in unemployment" (Blanchard, 2000:25). For this scenario it is assumed that every day for each increase of 1% in the GDP growth rate the number of private sector jobs will increase by one tenth of one percent, and for each decrease of 1% in the GDP growth rate the number of private sector jobs will decrease by one tenth of one percent.

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The daily rate of change of the number of private sector jobs in the economy is given by equation 4.35.

Eq. 4.35 *PrivateSectorHireRate(t) = (GDPGrowthEffectParameter(t) * PerCapGDPGrowth(t) ***

PrivateSectorJobs(t)) * T_1

Where

GDPGrowthEffectParameter(t) = 0.001

T_1 ~ Triangular(0.5,1,1.5)

In the scenario developed in this thesis, Iraq's real per capita GDP growth rate is represented as a function of civil unrest, captured through the number of insurgent attacks and the crime rate, and the critical infrastructure levels. According to Dalgaard and Hansen in their paper "On Aid, Growth and Good Policies" other influential factors that contribute to a country's post-conflict economic growth rate include the country's amount of ethnic fractionalization, the quality of its institutions, the level of its financial market development, its economic policy, and the amount of international aid it receives. These factors are all assumed to be constant throughout the course of this example simulation, and as a result are not modeled dynamically. Clearly, an area for further research would be to expand the economic portion of this model by allowing these factors to evolve dynamically. The International Monetary Fund (IMF) has forecasted a per capita GDP growth rate of 26% for Iraq in 2004, although qualifies this proposed growth rate as conditional on the security situation in Iraq improving and meeting its assumptions about oil and power production (International Monetary Fund, 2003:22).

For this analysis the International Monetary Fund's estimate of a 26% GDP growth rate has been used as a baseline estimate for Iraq's economic growth rate. This

baseline growth rate is then adjusted according to the number of crime related deaths that

take place and by the amount that Iraq's oil production differs from the IMF's estimate.

The daily per capita GDP growth rate is given by equation 4.36.

Eq. 4.36 $PerCapGDPRate(t) = \dfrac{BaselineGDPGrowthRate(t)}{365} * PerCapGDPLevel(t) -$

$CrimeRelatedDeathEffectParameter(t)* (CrimeRelatedDeaths(t)) -$

$(PriceOfABarrelOfOil(t)*(AssumedBPDOilProduced(t) -$

$DailyOilDelivered(t)))/IraqiPopulation(t)$

Where

$CrimeRelatedDeathEffectParameter(t) = 0.000228$

$PriceOfABarrelOfOil(t) = 20.50$

$AssumedBPDOilProduced(t) = 2,000,000$

$IraqiPopulation(t)=25,000,000$

Equation 4.36 calculates the daily growth rate of per capita GDP as the IMF's baseline

estimate minus 0.0228% of GDP growth for every related death and $20.50 per barrel of

oil short of the IMF's assumed level of 2,000,000 barrels of oil produced per day. These

parameters are notional and further research needs to be done to investigate their validity.

Critical Infrastructure

The three critical infrastructures in Iraq that are included in this scenario are: (1)

the water distribution infrastructure, (2) the electricity distribution infrastructure and (3)

the oil production infrastructure. While there are other important infrastructures in Iraq,

these three are considered most critical (Pollak, 2004:2). This analysis represents the

levels of these infrastructures with three variables: (1) the daily gallons of potable water

distributed, (2) the daily number of megawatt hours of electricity being delivered in Iraq,

and (3) the number of barrels of crude oil per day produced in Iraq. For each of these three critical infrastructures an estimate for how rapidly these infrastructures can be developed under peaceful circumstances is used as a baseline and the number of successful infrastructure attacks reduces and possibly reverses the development rate of each infrastructure.

The goal of the Civilian Provisional Authority in Iraq is to increase electric generation and distribution to 6,000 mega watts (MW) per day by the summer of 2004 (Brookings Institution, 2004:15). Achieving that level would mean a 100% increase from the July 2003 electricity production and distribution level of just over 3,000 MW per day. Such an increase requires an average increase of 8.2 MW per day. For this notional analysis it is assumed that one in three insurgent attacks on infrastructure is an attack on the electrical infrastructure, and that each successful attack reduces the daily electricity production and distribution level between zero and ten percent. The electricity development rate is given by equation 4.37.

Eq. 4.37 $ElectricityDevelopmentRate(t) = T_1 - P_1 * U_1 * DailyElectricDelivered(t)$

Where

T_1 ~Triangular($MinElectricDev(t)$, $MedElectricDev(t)$, $MaxElectricDev(t)$)

$MinElectricDev(t) = 4.1$

$MedElectricDev(t) = 8.2$

$MaxElectricDev(t) = 12.3$

P_1 ~Poisson($InsurgentInfAttackEffectParameter(t) * InsurgentInfrastructureAttacks(t)$)

$InsurgentInfAttackEffectParameter(t) = 0.33$

U_1 ~ Uniform(0,0.1)

The electricity shortage in Iraq is given by equation 4.38 where 4,400 MW was the estimated electricity demand per day based on pre-war levels (Brookins Institution, 2004:15). The pre-war level of 4,400MW per day of electric production is used in this equation rather than the CPA's goal of 6,000MW per day. The electric shortage rate is used to approximate how much electricity production is short of its typical level.

Eq. 4.38 *ElectricShortage(t) = ElectricDemand(t) – DailyElectricDelivered(t)*

Where

$\quad$ *ElectricDemand(t) = 4,400*

The Civilian Provisional Authority's goal for crude oil production in Iraq is three million barrels per day by the end of 2004 (Brookings Institution, 2004:15). Achieving this goal would require increasing crude oil production by on average about 5,000 barrels per day from the June 2003 level of 300,000 barrels per day. This scenario assumes that one in three infrastructure attacks is made on Iraq's oil infrastructure and that each attack on the oil infrastructure reduces oil production by between zero and ten percent. The daily oil production development rate is given by equation 4.38.

Eq. 4.39 $\quad$ *OilDevelopmentRate(t) = T_1 - P_1 *U_1*DailyOilDelivered(t)*

Where

$\quad$ T_1 ~Triangular(*MinOilDev(t), MedOilDev(t), MaxOilDev(t)*)

$\quad$ *MinOilDev(t)* =2500

$\quad$ *MedOilDev(t)* = 5000

$\quad$ *MaxOilDev(t)* = 7500

$\quad$ P_1 ~Poisson(*InsurgentInfAttackEffectParameter(t) * InsurgentInfrastructureAttacks(t)*)

$\quad$ *InsurgentInfAttackEffectParameter(t)* = 0.33

$\quad$ U_1 ~ Uniform(0, 0.1)

The shortage of oil is given by equation 4.40, where 450,000 is the daily domestic demand for barrels of crude oil in Iraq (Brookings Institution, 2004:15). 450,000 barrels of oil per day has been used as it is the amount of crude oil consumed on average every day in Iraq. The CPA's goal of producing three million barrels of oil per day includes not only oil earmarked for domestic consumption but also oil that will be sold abroad.

Eq. 4.40 *OilShortage(t) = OilDemand(t) – DailyOilDelivered(t)*

Where

$OilDemand(t) = 450{,}000$

As refining crude oil into various types of usable fuel requires electricity, a shortage in electricity produces a proportional shortage in the daily amount of oil produced.

The estimated pre-war potable water supply in Iraq was 12.9 million liters per day (Brookings Institution, 2004:16). Immediately after the war in May 2003 it was reported that the potable water supply was four million liters per day. By the end of June it was estimated that 13.2 million liters were available per day, and by the end of November 21.4 million liters were available per day. The improvement in potable water availability between May and June represents an average daily gain of 300,000 liters. If it is assumed that one third of infrastructure attacks are directed at water infrastructure, and that each water infrastructure attack reduces water availability between zero and five percent then the water development rate is given by equation 4.41.

Eq. 4.41 $WaterDevelopmentRate(t) = T_1 - P_1 * U_1 * DailyWaterDelivered(t)$

Where

> $T_1 \sim$ Triangular($MinWaterDev(t)$, $MedWaterDev(t)$, $MaxWaterDev(t)$)
>
> $MinWaterDev(t) = 150,000$
>
> $MedWaterDev(t) = 300,000$
>
> $MaxWaterDev(t) = 450,000$
>
> $P_1 \sim$ Poisson($InsurgentInfAttackEffectParameter(t)$ * $InsurgentInfrastructureAttacks(t)$)
>
> $InsurgentInfAttackEffectParameter(t) = 0.33$
>
> $U_1 \sim$ Uniform(0, 0.05)

This scenario assumes that the quantity of water demanded equals the pre-war level of 12.9 million liters of water per day. Since some water pumps are electric, a shortage of electricity causes a proportional decrease in the level of water delivered per day. The water shortage rate is given by equation 4.41.

Eq. 4.42 WaterS*hortage(t) = WaterDemand(t) – DailyWaterDelivered(t)*

Where

> $WaterDemand(t) = 12,900,000$

Iraqi Public Opinion

The public opinion sub-model influences the rest of the model in two ways. The number of people who are dissatisfied with the occupation influences the insurgent rate of change and the number of people who are neutral to, or satisfied with, the occupation influences the number of tips the indigenous population gives on insurgent activities.

The public opinion rate of change has been modeled in this example as a function of nine variables: (1) the number of unemployed people, (2) the number of employed people,

(3) the number of crime related deaths, the shortage/surpluses of the critical resources of (4)

water, (5) oil, and (6) electricity, and the delivered amounts of (7) water, (8) oil, and (9)

electricity. The public opinion rate of change is given by equations 4.43a through 4.43c.

Eq. 4.43a *DissatisfactionPoints*(*t*) = *UnemploymentEffectParameter*(*t*)**UnemployedPersons*(*t*) +

CrimeRelatedDeathRateEffectParameter(*t*)**CrimeRelatedDeathRate*(*t*)+

WaterDeliveredEffectParameter(*t*)**WaterShortageRate*(*t*) +

ElectricityDeliveredEffectParameter(*t*)**ElectricShortageRate*(*t*) +

OilDeliveredEffectParameter(*t*)*OilShortageRate(*t*)

Eq. 4.43b *SatisfactionPoints*(*t*) = *EmploymentEffectParameter*(*t*)*EmployedPersons(*t*) +

WaterDeliveredEffectParameter(*t*)**DailyWaterDelivered*(*t*) +

ElectricityDeliveredEffectParameter(*t*)**DailyElectricityDelivered*(*t*) +

OilDeliveredEffectParameter(*t*)**DailyOilDelivered*(*t*)

Eq. 4.43c If *DissatisfactionPoints(t)* > *SatisfactionPoints(t)* Then

PublicOpinionRateOfChange(t) = (((*SatisfactionPoints*(*t*) /*DissatisfactionPoints(t)*) -1)

* SatisfiedPeople(t)) / *PublicOpinionResponsivenessParameter*(*t*)

 Else If *SatisfactionPoints*(*t*)≥*DissatisfactionPoints*(*t*) Then

PublicOpinionRateOfChange(t) = - (((*DissatisfactionPoints(t)* / *SatisfactionPoints*(*t*)) -1)

* DissatisfiedPeople(t)) / *PublicOpinionResponsivenessParameter*(*t*)

Where

UnemploymentEffectParameter(t) = 1

EmploymentEffectParameter(t) = 1

CrimeRelatedDeathRateEffectParameter(*t*) = 30,000

WaterDeliveredEffectParameter(*t*) = 0.5

ElectricityDeliveredEffectParameter(*t*) = 1445

OilDeliveredEffectParameter(*t*) = 14.44

PublicOpinionResponsivenessParameter(*t*) = 90

The dissatisfaction points approximates the gross number of people who have cause to be dissatisfied and the satisfaction points approximate the gross number of people who have cause to be satisfied. The daily rate of change of public opinion is a function of the ratio of these two numbers and the number of people who are currently satisfied and dissatisfied.

This example assumes that every day on average one in every 50,000 Iraqis who are neutral to or satisfied with the occupation per 10,000 insurgents will give the coalition a useful tip on insurgent activity, and that the average number of tips on insurgent activity will not exceed 1,000 per day. The number of tips given by Iraqis on insurgent activity is given by equation 4.44.

Eq. 4.44 *TipsOnInsurgentActivities*(t) ~

Poisson(*Insurgents*(t) * *SatisfiedIraqis*(t) * *TipRateParameter*(t))

Where

TipRateParameter(t) = 1 / 500,000,000

Insurgents(t) * *SatisfiedIraqis*(t) * *TipRateParameter*(t) $\leq 1,000$

Other possible expansions, while not included in this "first-cut" model include the effects of the media, availability of schools, and other such factors. While the example provided is limited, it can be used to conduct analysis and illustrate the potential strength of this approach. The following screening experiment provides that illustration.

Screening Experiment

A system dynamics model like the one presented in this chapter could be employed to provide insight to a decision maker about the principle drivers to the

establishment of security in post-conflict reconstruction. Such information would help decision makers effectively allocate their limited resources of money and manpower.

In order to identify the principle drivers of security in the notional scenario detailed in this chapter, a screening experiment was designed to test the effects of various parameters in the model. In this experiment, seven parameters were selected as factors of interest. While others could have been selected, these were chosen to illustrate how key drivers can be identified with a screening experiment. These parameters are: (1) the initial percentage of the population who is dissatisfied with the occupation, (2) the initial number of police officers, (3) the initial number of criminals, (4) the initial number of insurgents, (5) the baseline gross domestic product growth rate, (6) the training class sizes of the Iraqi security forces, and (7) the baseline infrastructure development rate.

The number of days from the start of the post-conflict reconstruction until security was established was selected as the criteria for measuring the effects of these factors of interest. For this experiment, security was said to have been established when the average number of deaths as a result of criminal and insurgent activity fell below a specified level for 30 days. Washington DC has an annual murder rate of 43 per 100,000 citizens which was used as a stopping criterion for this model (Brookings Institution, 2004:12). When the 30 day moving average of deaths as a result of criminal and insurgent activity falls below this rate, security is said to be established and the simulation is stopped.

Three replications of a seven factor one-half fractional factorial design (2^{7-1}) were chosen for the screening experiment. This experiment varied each of the seven factors of

interest between a low value and a high value, and recorded the output value. This is a resolution VII design which enables one, two, and three factor interactions to be tested without the complications of lower order aliasing (Meyers and Montgomery, 2002:157).

In the experiment the low value of the initial percentage of the population that was dissatisfied with the occupation was set at 30%. This number was chosen to reflect the results of a State Department survey of Iraqis in November 2003. In that survey 71% of respondents are reported to have said that they would feel less safe if the coalition left Iraq immediately (Brookings Institution, 2004:18). The high value was arbitrarily set at a dissatisfaction level of 60%, so that the effects of a high dissatisfaction level could be explored.

The low value of initial police officers was set at 10,000 to reflect the initial amount of police officers there were in Iraq in May 2003, at the beginning of the occupation. The Brookings Institution reports that in May 2003 there were between 7,000 and 9,000 police officers in Iraq (2004:11). The high value was set at 30,000 so that the effect of an additional 20,000 police officers could be evaluated.

The initial number of criminals was set at a low value of 50,000 and a high value of 100,000. There is little data on the number of criminals there were in Iraq in May 2003, so in this notional example the high value was set at twice the level of the low value enabling the effect of the initial number of criminals on the number of days until security is established to be tested.

The low value of the baseline GDP growth rate was set at 26%. This value reflects the International Monetary Fund's forecast of the growth rate of Iraq's economy

in 2004 (International Monetary Fund, 2003:22). The high value was set at twice the low value to reflect an even more optimistic economic growth rate.

The low value of the training class sizes for the Iraqi security forces were set at the levels previously identified in this chapter. The high values were set at twice the low values to enable the effects that faster training has on establishing security to be tested.

The low value of the baseline infrastructure development rate was set at the levels previously identified in the Critical Infrastructure section of this chapter. The high levels were set at twice that to enable the effects that faster infrastructure development has on establishing security to be tested. The high and low factor levels are summarized in table 4.2.

Table 4.2: Screening Experiment High and Low Factor Settings

Factor	Low	High
Initial Dissatisfied People	30%	60%
Initial Police Officers	10,000	30,000
Initial Criminals	50,000	100,000
Initial Insurgents	10,000	20,000
Baseline GDP Growth	26%	52%
Baseline Iraqi Security Forces Class Size	1x	2x
Baseline Critical Infrastructure Development Rate	1x	2x

Results

Three repetitions of each of the 64 design points were run for a total of 192 simulation runs. The output data is presented in figure 4.1.
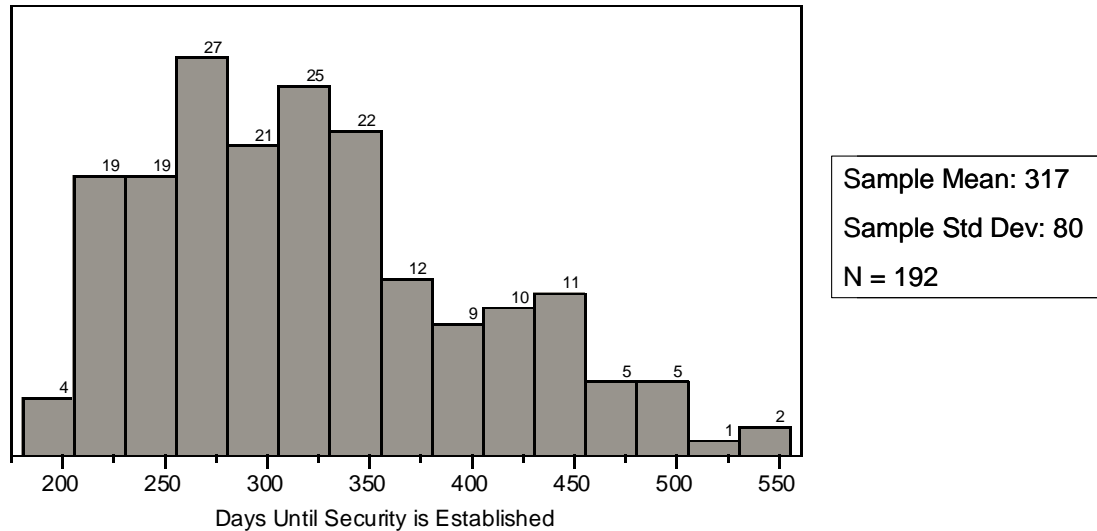

Figure 4.1: Screening Experiment Output Histogram

The mean number of days until security was established for all of the simulations was 317 days with a standard deviation of 80 days given the ranges of the factors set in this design and the functional relationships defined in this notional model.

This output data was fitted to the log-linear model expressed in equation 4.45 to identify the one, two, and three factor effects (Neter *et al.*, 1996:308). A is the initial number of dissatisfied people, B is the initial number of police officers, C is the initial number of criminals, D is the initial number of insurgents, E is the baseline GDP growth rate, F is the class size of the Iraqi security forces, and G is the baseline infrastructure development rate.

$$\text{Eq 4.45 Ln Y} = \beta_0 + \sum_{i \in I} \beta_i X_i + \sum_{\substack{i,j \in I \\ i \neq j}} \beta_{ij} X_i X_j + \sum_{\substack{i,j,k \in I \\ i \neq j, j \neq k \\ k \neq i}} \beta_{ijk} X_i X_j X_k + \varepsilon$$

Where

$$I = \{A,B,C,D,E,F,G\}$$

$$X_i \equiv \text{The level of factor } i \; \forall i \in I$$

It is assumed with this model that the four, five, six, and seven factor interactions are

negligible and captured within the ε term.

The model had an R squared value of 0.98 with an F ratio of 110 indicating that it

had significantly more explanatory power than the model $\text{Ln Y} = \beta_0 + \varepsilon$. Table 4.2 lists

the estimates for the one, two, and three factor terms that were found to be significant at

the 95% level of confidence. All of the estimates for the one, two, and three factor terms

are listed in Appendix C.

Table 4.2: Significant Factor Parameter Estimates

Term	Estimate	p-value
Intercept	5.727733	<.0001
A: Initial Dissatisfied People	0.185359	<.0001
B: Initial Police Officers	-0.02877	<.0001
C: Initial Criminals	0.012877	<.0001
D: Initial Insurgents	0.029326	<.0001
E: GDP Growth Rate	-0.05763	<.0001
F: ISF Training Rates	-0.04549	<.0001
G: Infrastructure Development Rate	-0.12592	<.0001
A: Initial Dissatisfied People*E: GDP Growth Rate	0.016179	<.0001
A: Initial Dissatisfied People*G: Infrastructure Development Rate	-0.02001	<.0001
C: Initial Criminals*F: ISF Training Rates	0.006223	0.0345
D: Initial Insurgents*G: Infrastructure Development Rate	-0.01114	0.0002
E: GDP Growth Rate*F: ISF Training Rates	0.010438	0.0005
E: GDP Growth Rate*G: Infrastructure Development Rate	0.007491	0.0112
A: Initial Dissatisfied People*E: GDP Growth Rate*F: ISF Training Rates	-0.01065	0.0004
A: Initial Dissatisfied People*E: GDP Growth Rate*G: Infrastructure Development Rate	0.00648	0.0278
D: Initial Insurgents*E: GDP Growth Rate*F: ISF Training Rates	-0.00841	0.0046

The factor with the largest impact on how long it takes to establish security in the screening experiment, as seen in table 4.2, is the initial percent of the population that is dissatisfied with the occupation. The next largest impact factor was the baseline infrastructure development rate. The least influential factor was the initial number of criminals.

In this notional scenario, the number of people who are initially dissatisfied with the occupation has a significant impact on how long it takes to establish security in the post-conflict reconstruction. While this value cannot be directly manipulated by coalition forces once the reconstruction has begun, it may be possible to influence these conditions by how the coalition troops conduct themselves prior to phase IV, and how rapidly they bring civilian support programs into effect for phase IV operations. This result suggests that efforts to win over the populace during phase I, II, and III operations, coupled with the rapid establishment of reconstruction support, has a demonstrable effect on how much time establishing security is likely to take.

In this notional scenario, the critical infrastructure development rate after hostilities also had a significant impact on how quickly security was established. This suggests that having an actionable plan in place to rapidly restore civilian utilities as soon as the hostilities are over could reduce the amount of time it takes to establish security and potentially save lives. While a notional example, the model does show the power of this approach.

Summary

In this chapter the general model developed in Chapter III is applied to a notional scenario based on Operation Iraqi Freedom. A screening experiment is designed and seven factors to the establishment of security are tested. Of 16 significant individual and interaction effects, the initial amount of people who are dissatisfied with the occupation and the rate that critical infrastructures are restored are found to have the highest impact on how long it takes to establish security in a post-conflict reconstruction operation.

V. Conclusions

Conclusions about the General Model and Its Application

This thesis effort developed a general model for simulating the establishment of security in a post-conflict reconstruction. The relevant literature on post-conflict reconstruction was reviewed and a set of level values and rates of change were identified to begin to describe the dynamics of a post-conflict reconstruction. This general model was then applied to a notional scenario to illustrate how such a model could be employed to provide insight about potential policy alternatives to a decision maker. A screening experiment was designed to identify key factors that influence how long it takes to establish security in the notional post-conflict reconstruction scenario. The statistical significance of these factors was tested and notional policy implications were inferred. The runs of this notional scenario demonstrated the dynamic interactions that such a model can simulate.

The model developed allows an analyst to take a very complex problem and gain insight into it by dividing it into manageable component parts. This enables an analyst to aggregate assumptions about simpler questions such as the effectiveness of troops, the growth rate of an economy, and construction of infrastructure into an estimate for answering more complex questions, such as, "How long will it take to establish security in Iraq?"

The model developed in this thesis requires data on a wide range of subjects. Data is needed on the effectiveness of troops, police officers, and other types of security

forces. Economic data is required to model the growth of a country's economy dynamically. Data on the construction of infrastructure is needed, as is public opinion data. Not all of this data is available, but the development of the general model and the application of this model to the notional scenario highlight what data is needed. It also identifies information needs for future post-conflict operations.

If the general model developed by this thesis were applied to a scenario using operational data, a wide variety of potential policy alternatives could be identified and tested. Bounds could be set on how long establishing security is likely to take, the amount of resources needed to produce an outcome could be estimated, and assumptions about various aspects of stability operations could be tested. The application of such a model could help decision makers employ forces more effectively, saving money and, more importantly, lives.

Areas for Further Research

This thesis effort is a first step at developing a comprehensive post-conflict reconstruction model. Its greatest contribution is as a jumping off point for further research into how to simulate post-conflict reconstruction. Besides applying the model to operational data, one of the most promising areas for follow on research is in expanding the general model. The general model developed in this thesis can be expanded in two general directions: it can be expanded by increasing the model's resolution and it can be expanded by increasing the model's scope.

The general model proposed here is a high level model. It can be applied to a scenario to infer macro level policy implications, such as how quickly police officers need to be trained, but its resolution is insufficient to provide insight on more micro level decisions, such as where those police officers should be deployed throughout the country. One way to increase the resolution of this model is to include different regions of the country as separate but interconnected parts of the whole. Different ethnic groups in different parts of the country could be modeled individually, allowing security to be established in the model in one or two regions of a country while other regions are still volatile.

Another way that the resolution of this model could be increased would be by modeling the effectiveness of different types of troops differently. For instance, a military police officer could be modeled to be more effective in a crime suppression role than an artillery officer in a crime suppression role. Different training programs could also be modeled to create troops with different skill sets. An indigenous border guard trainee who has undergone a three month training program could be modeled as being more effective than an indigenous border guard trainee who has only undergone a week long training program. Other effects such as equipment, experience, and the number of translators could all be included to increase the model's capabilities.

In addition to expanding the model's resolution, the model's scope could be expanded. The model proposed by this thesis is primarily focused at simulating only one of the four pillars of post-conflict reconstruction. The other three pillars could be included. For instance, governance and participation could be included in the model by

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simulating the standing up of various parts of a government prior to holding elections. The mood of the populace could be simulated dynamically and could be used to simulate the outcome of an election. The economic aspects of the model could be expanded to simulate the longer term recovery of a country's economy. A larger set of infrastructures could be included, such as communications, the media, transportation, education, agriculture, and manufacturing.

This thesis has demonstrated the potential of this approach. History has shown that effective post-conflict reconstruction is critical not only in the nations where conflict has occurred, but also for long term global stability. Modeling efforts that can help decision makers more effectively execute the re-establishment of stable nations should be perused.

Appendix A: General Model State Variables

BorderPatrolPersonnel – The number of active duty troops in the indigenous border

patrol.

CivilDefensePersonnel – The number of active duty troops in the indigenous civil

defense force.

IndigenousMilitaryPersonnel – The number of active duty troops in the indigenous

military.

BorderPatrolPersonnelInTraining – The number of potential indigenous border patrol

troops training to become active duty border patrol troops.

CivilDefensePersonnelInTraining – The number of potential indigenous civil defense

troops training to become active duty civil defense troops.

IndigenousMilitaryPersonnelInTraining – The number of potential indigenous military

troops training to become active duty military troops.

PoliceOfficers – The number of active duty indigenous police officers.

PoliceOfficersInTraining – The number of indigenous police officers in training.

Criminals – The number of people supporting themselves through crime.

IncarceratedCriminals – The number of criminals and suspected criminals who are being

detained awaiting trial or being jailed as part of a prison sentence.

Unemployed Persons – The number of people who want jobs who do not have them,

including people who are actively looking for a job and people who have given up

looking for a job, but still want one.

GovernmentEmployees – The number of non-security related government employees.

PrivateSectorEmployees – The number of people employed by the private sector. Includes people who are employed by a firm that is fulfilling a government contract.

Insurgents – The number of people who are actively working to thwart the coalition through violence, regardless of their motivation.

DetainedInsurgents – The number of insurgents and suspected insurgents that are being held by the coalition.

PerCapitaGDP – The total dollar value of goods and services produced within the country's borders divided by the country's population.

CoalitionMilitaryForces – The total number of coalition troops in the country.

DailyWaterDelivered – The number of gallons of potable water distributed every day in the country.

DailyFoodDelivered – The number of tons of food distributed every day in the country.

DailyFuelDelivered – The number of gallons of fuel distributed every day in the countery.

DailyElectricityDelivered – The number of megawatts of electricity distributed every day in the country.

DissatisfiedPeople – The number of people who are dissatisfied with the coalition.

SatisfiedPeople – The number of people who are neutral to, or satisfied with, the coalition.

Appendix B: General Model Equations

Indigenous Security Institutions Sub-model Equations

Eq. 3.1 $BPRecruitRate(t) \sim BPRRDist\left(\mu_{BP\,Re\,cruitRate}(t), \sigma_{BP\,Re\,cruitRate}(t)\right)$

Eq. 3.1a $BPRecruitRate(t) \sim Poisson(\lambda_{BPRR}(t))$

Eq. 3.2 $CDRecruitRate(t) \sim CDRRDist\left(\mu_{CD\,Re\,cruitRate}(t), \sigma_{CD\,Re\,cruitRate}(t)\right)$

Eq. 3.2a $CDRecruitRate(t) \sim Poisson(\lambda_{CDRR}(t))$

Eq. 3.3 $IMRecruit\ Rate(t) \sim IMRRDist\left(\mu_{IM\,Re\,cruitRate}(t), \sigma_{IM\,Re\,cruitRate}(t)\right)$

Eq. 3.3a $IMRecruitRate(t) \sim Poisson(\lambda_{IMRR}(t))$

Eq. 3.4 $BPGradRate(t) =$
$$\begin{cases} BPGradClassSize(t)*\left(1 - BPTrainingAttrition(t)\right) if & StartDate + Classlength(t) = CurrentDate \\ 0 & otherwise \end{cases}$$

Eq. 3.5 $CDGradRate(t) =$
$$\begin{cases} CDGradClassSize(t)*\left(1 - CDTrainingAttrition(t)\right) if & StartDate + Classlength(t) = CurrentDate \\ 0 & otherwise \end{cases}$$

Eq. 3.6 $IMGradRate(t) =$
$$\begin{cases} IMGradClassSize(t)*\left(1 - IMTrainingAttrition(t)\right) if & StartDate + Classlength(t) = CurrentDate \\ 0 & otherwise \end{cases}$$

Eq. 3.7 $BPAttritionRate(t) \sim BPARDist\left(\mu_{BPAttritionRate}(t), \sigma_{BPAttritionRate}(t)\right)$

Eq. 3.8 $CDAttritionRate(t) \sim CDARDist\left(\mu_{CDAttritionRate}(t), \sigma_{CDAttritionRate}(t)\right)$

Eq. 3.9 $IMAttritionRate \sim IMARDist\left(\mu_{IMAttritionRate}(t), \sigma_{IMAttritionRate}(t)\right)$

Eq. 3.10 $BPKIARate(t) = BPAttackEffectivenessParameter(t) * \#OfInsurgentAttacks(t) *$
$BPCasualtyRandomVariable(t)$

Eq. 3.11 $CDKIARate(t) =$
$CDAttackEffectivenessParameter(t) * \#OfInsurgentAttacks(t) * CDCasualtyRandomVariable(t)$

Eq. 3.12 $IMKIARate(t) =$
$IMAttackEffectivenessParameter(t) * \#OfInsurgentAttacks(t) * IMCasualtyRandomVariable(t)$

Law Enforcement Sub-model Equations

Eq. 3.13 $PORecruitRate(t) \sim PORRDist\left(\mu_{PO\,Re\,cruitRate}(t), \sigma_{PO\,Re\,cruitRate}(t)\right)$

Eq. 3.14 $POGradRate(t) =$
$$\begin{cases} POGradClassSize(t) * \left(1 - POTrainingAttrition(t)\right) & if \quad StartDate + Classlength(t) = CurrentDate \\ 0 & otherwise \end{cases}$$

Eq. 3.15 $POAttritionRate(t) \sim POARDist\left(\mu_{BPAttritionRate}(t), \sigma_{BPAttritionRate}(t)\right)$

Eq. 3.16 *POCasualtyRate(t) =*
*InsurgentAttackOnPoliceEffectParameter(t) * PoliceCasualtyRandVar*(t) * #ofAttacks(t) +
*PoliceCrimeRateEffectParameter(t) * PoliceCasualtyRandVar*(t) * CrimeRate(t)

Eq. 3.17 *CriminalRecruitRate(t) = CriminalRecruitRateInterceptParameter(t) +*
*UnemploymentEffectParameter(t) * UnemploymentLevel(t) +*
*CriminalApprehensionRateEffectParameter(t) * CriminalApprehensionRate*(t) +
$CriminalRecruitRateDist\left(\mu_{C\,Re\,cruitRate}(t), \sigma_{C\,Re\,cruitRate}(t)\right)$

Eq. 3.18 *CriminalApprehensionRate(t) = Criminals * (PoliceEffectParameter(t) * PoliceOfficers(t) +*
*CivilDefenseTroopEffectParameter(t) * CivilDefenceTroops(t) + CMilitaryEffectParameter*(t) *
CMilitaryPolicing(t)) * *CriminalApprehensionRateRandVar*(t)

Eq. 3.19 *IncarceratedCriminalReleaseRate(t) = IncarceratedCriminal(t) **
IncarceratedCriminalsReleaseRandVar(t)

Eq. 3.20 *CrimeRate(t) = CrimeRateRandVar(t) * (Criminals(t) * CrimesPerCriminal(t) +*
*Insurgents(t) * CrimesPerInsurgent*(t))

Eq. 3.21 *CoaltionTroopsPolicing(t) = TotalCoaltionTroops(t) * %CoalitionPolicing(t)*

Insurgent and Coalition Military Activities Equations

Eq. 3.22 *CoalitionTroopsInCountryRate(t) = CoalitionTroopCasualtyRate(t)*

Eq. 3.23 *CoalitionTroopCasualtyRate(t) = InsurgentAttackOnCoalitionEffectParameter(t) * #ofAttacks(t) **
CTCasualtyRandVar(t)

Eq. 3.24 *#CoalitionPatrolingBorders(t) = TotalCoaltionTroops(t) * %CoalitionPatrollingBord*ers(t)

Eq. 3.25 *#CoalitionCounterInsurgency(t) = TotalCoalitionTroops(t) * %CounterInsurgency(t)*

Eq. 3.26 *InsurgentRateOfChange(t) =DissatisfiedPeople(t) **
*InsurgentKilledorDetainedEffectParameter(t) * InsurgentKilledOrDetainedRate(t) **
InsurgentRateOfChangeRandVar(t)

Eq. 3.27 *InternationalInsurgentRate(t) = TotalInternationalInsurgentsRandVar(t) **
(*BorderPatrolEffectParameter*(t) * *BorderPatrolTroops*(t) +
*CoalitionPatrollingBorderEffectParameter(t) * CoalitionPatrollingBorder*(t))

Eq. 3.28 *InsurgentKilledOrDetainedRate(t)* =
Insurgents(t) * (CTroopsCounterInsurgEffectParameter(t) * CTroopsInCounterInsurg(t) +
IMEffectParameter(t) * IndigenousMilitaryTroops(t) + CDEffectParameter(t) *
CivilDefenseTroops(t)) * TipsOnInsurgency(t) * InsurgentAppRandVar(t)

Eq. 3.28a *InsurgentDetentionRate(t) = (1-InsurgentKilledRate(t)) * InsurgentKilledOrDetainedRate(t)*

Eq. 3.29 *InsurgentReleaseRate(t) = DetainedInsurgents(t) * InsurgentReleaseRandVar(t)*

Eq. 3.30 *#OfInsurgentAttacks(t) = Insurgents(t) * InsurgentEffectParameter(t) **
InsurgentAttackRandVar(t)

Eq. 3.31 *#OfInfrastructureAttacks*(t) = *#OfInsurgentAttacks(t) * CDEffectParameter(t)*
* %OfAttacksOnInfrastructure(t)

Labor Market Sub-model Equations

Eq. 3.32 *GovernmentHireRate(t) ~ GHRDist$\left(\mu_{GovtHireRate}(t), \sigma_{GovtHireRate}(t)\right)$*

Eq. 3.32a   *GovernmentHireRate ~ Poisson($\lambda_{GovtHireRate}(t)$)*

Eq. 3.33 *PrivateSectorHireRate(t) = RPerCapGDPGrowth(t) * RPerCapGDPEffectParameter(t)*
* PrivateSectorHireRateRandVar(t)

Eq. 3.34 *PerCapRGDPGrowthRate(t) = RGDPRandVar(t) * (InsurgentAttacksEffectParameter(t) **
#OfInsurgentAttacks(t) + CrimeEffectParameter(t) * CrimeRate(t) + WaterEffectParameter(t) *
WaterShortage(t) + FoodEffectParameter(t) * FoodShortage(t) + FuelEffectParameter(t)*
FuelShortage(t) + ElectricityEffectParameter(t) * ElectricityShortage(t) +
PreviousPerCapRGDPEffectParameter(t) * PreviousPerCapRGDP(t))

Critical Infrastructure Sub-model Equations

Eq. 3.35 *WaterShortage/Surplus(t) = GallonsOfWaterDelivered(t) – GallonsOfWaterDemanded(t)*

Eq. 3.36 *FoodShortage/Surplus(t) = TonsOfFoodDelivered(t) - TonsOfFoodDemanded(t)*

Eq. 3.37 *FuelShortage/Surplus(t) = GallonsOfFuelDelivered(t) - GallonsOfFuelDemanded(t)*

Eq. 3.38 *ElectricityShortage/Surplus(t) = MegaWattDelivered(t) – MegaWattDemanded(t)*

Eq. 3.39 *WaterDevelopmentRate(t) = BaseWaterDevelopmentRate(t) **
(InfrastructureAttackWaterEffectParameter(t) * #OfInfrastructureAttacks(t) +
ElectricShortageEffectParameter(t) * ElectricShortage(t))

Eq. 3.40 *FoodDevelopmentRate(t) = BaseFoodDevelopmentRate(t) **
(InfrastructureAttackFoodEffectParameter(t) * #OfInfrastructureAttacks(t) +
FuelShortageEffectParameter(t) * FuelShortage(t))

Eq. 3.41 *FuelDevelopmentRate(t) = BaseFuelDevelopmentRate(t) **
(InfrastructureAttackFuelEffectParameter(t) * #OfInfrastructureAttacks(t) +
ElectricShortageEffectParameter(t) * ElectricShortage(t))

Eq. 3.42 *ElectricDevelopmentRate = BaseElectricDevelopmentRate(t) **
InfrastructureAttackElectricEffectParameter(t) * #OfInfrastructureAttacks(t)

Public Opinion Sub-model Equations

Eq. 3.43 *PublicOpinionRateOfChange(t) = UnemploymentEffectParameter(t)**
UnemploymentLevel(t) + InsurgentAttacksEffectParameter(t) * InsurgentAttacks(t) +
CrimeRateEffectParameter(t) * CrimeRate(t) +
WaterShortage/SurplusEffectParameter(t) * WaterShortage/Surplus(t) +
FoodShortage/SurplusEffectParameter(t) * FoodShortage/Surplus(t) +
FuelShortage/SurplusEffectParameter(t) * FuelShortage/Surplus(t) +
ElectricShortage/SurplusEffectParameter(t) * ElectricShortage/Surplus(t)

Eq. 3.44 *TipsOnInsurgents(t) = #OfPeopleSatisfiedWithOccupation(t) * TipsRandomVariable(t)*

Appendix C: Two and Three Factor Parameter Estimates

Table C.1: Single Factor Parameter Estimates and Significance

Term	Estimate	p-value
Intercept	5.727733	<.0001
A: Initial Dissatisfied People	0.185359	<.0001
B: Initial Police Officers	-0.02877	<.0001
C: Initial Criminals	0.012877	<.0001
D: Initial Insurgents	0.029326	<.0001
E: GDP Growth Rate	-0.05763	<.0001
F: ISF Training Rates	-0.04549	<.0001
G: Infrastructure Development Rate	-0.12592	<.0001

Shaded factors are significant at the 95% level of confidence.

Table C.2: Two Factor Parameter Estimates and Significance

Term	Estimate	p-value
A: Initial Dissatisfied People*B: Initial Police Officers	0.003908	0.182
A: Initial Dissatisfied People*C: Initial Criminals	-0.00541	0.0655
A: Initial Dissatisfied People*D: Initial Insurgents	0.002469	0.3981
A: Initial Dissatisfied People*E: GDP Growth Rate	0.016179	<.0001
A: Initial Dissatisfied People*F: ISF Training Rates	0.000251	0.9315
A: Initial Dissatisfied People*G: Infrastructure Development Rate	-0.02001	<.0001
B: Initial Police Officers*C: Initial Criminals	-0.00201	0.4913
B: Initial Police Officers*D: Initial Insurgents	-0.00047	0.8733
B: Initial Police Officers*E: GDP Growth Rate	0.003946	0.1779
B: Initial Police Officers*F: ISF Training Rates	0.005155	0.0791
B: Initial Police Officers*G: Infrastructure Development Rate	0.001259	0.6661
C: Initial Criminals*D: Initial Insurgents	-0.00314	0.2823
C: Initial Criminals*E: GDP Growth Rate	-0.00256	0.3804
C: Initial Criminals*F: ISF Training Rates	0.006223	0.0345
C: Initial Criminals*G: Infrastructure Development Rate	0.00263	0.3682
D: Initial Insurgents*E: GDP Growth Rate	-0.00428	0.1439
D: Initial Insurgents*F: ISF Training Rates	-0.0001	0.9722
D: Initial Insurgents*G: Infrastructure Development Rate	-0.01114	0.0002
E: GDP Growth Rate*F: ISF Training Rates	0.010438	0.0005
E: GDP Growth Rate*G: Infrastructure Development Rate	0.007491	0.0112
F: ISF Training Rates*G: Infrastructure Development Rate	0.004346	0.138

Shaded factors are significant at the 95% level of confidence.

Table C.3: Three Factor Parameter Estimates and Significance

Term	Estimate	p-value
A: Initial Dissatisfied People*B: Initial Police Officers*C: Initial Criminals	-0.00144	0.6229
A: Initial Dissatisfied People*B: Initial Police Officers*D: Initial Insurgents	0.000594	0.8386
A: Initial Dissatisfied People*B: Initial Police Officers*E: GDP Growth Rate	-0.00301	0.3032
A: Initial Dissatisfied People*B: Initial Police Officers*F: ISF Training Rates	-0.00216	0.4597
A: Initial Dissatisfied People*B: Initial Police Officers*G: Infrastructure Development Rate	-0.00155	0.5961
A: Initial Dissatisfied People*C: Initial Criminals*D: Initial Insurgents	0.001971	0.4998
A: Initial Dissatisfied People*C: Initial Criminals*E: GDP Growth Rate	0.000397	0.8918
A: Initial Dissatisfied People*C: Initial Criminals*F: ISF Training Rates	-0.001	0.7315
A: Initial Dissatisfied People*C: Initial Criminals*G: Infrastructure Development Rate	0.002418	0.408
A: Initial Dissatisfied People*D: Initial Insurgents*E: GDP Growth Rate	-0.00188	0.5209
A: Initial Dissatisfied People*D: Initial Insurgents*F: ISF Training Rates	-0.00151	0.6054
A: Initial Dissatisfied People*D: Initial Insurgents*G: Infrastructure Development Rate	0.002064	0.4797
A: Initial Dissatisfied People*E: GDP Growth Rate*F: ISF Training Rates	-0.01065	0.0004
A: Initial Dissatisfied People*E: GDP Growth Rate*G: Infrastructure Development Rate	0.00648	0.0278
A: Initial Dissatisfied People*F: ISF Training Rates*G: Infrastructure Development Rate	0.005181	0.0776
B: Initial Police Officers*C: Initial Criminals*D: Initial Insurgents	0.001102	0.7059
B: Initial Police Officers*C: Initial Criminals*E: GDP Growth Rate	-0.00397	0.1755
B: Initial Police Officers*C: Initial Criminals*F: ISF Training Rates	0.001538	0.5983
B: Initial Police Officers*C: Initial Criminals*G: Infrastructure Development Rate	0.001823	0.5323
B: Initial Police Officers*D: Initial Insurgents*E: GDP Growth Rate	-0.00075	0.7985
B: Initial Police Officers*D: Initial Insurgents*F: ISF Training Rates	-0.0016	0.5845
B: Initial Police Officers*D: Initial Insurgents*G: Infrastructure Development Rate	0.002461	0.3997
B: Initial Police Officers*E: GDP Growth Rate*F: ISF Training Rates	0.001812	0.5349
B: Initial Police Officers*E: GDP Growth Rate*G: Infrastructure Development Rate	0.000838	0.774
B: Initial Police Officers*F: ISF Training Rates*G: Infrastructure Development Rate	-0.00048	0.8703
C: Initial Criminals*D: Initial Insurgents*E: GDP Growth Rate	0.000381	0.8962
C: Initial Criminals*D: Initial Insurgents*F: ISF Training Rates	-0.00445	0.129
C: Initial Criminals*D: Initial Insurgents*G: Infrastructure Development Rate	0.001971	0.4997
C: Initial Criminals*E: GDP Growth Rate*F: ISF Training Rates	0.001768	0.5449
C: Initial Criminals*E: GDP Growth Rate*G: Infrastructure Development Rate	0.005516	0.0605
C: Initial Criminals*F: ISF Training Rates*G: Infrastructure Development Rate	-0.00073	0.8032
D: Initial Insurgents*E: GDP Growth Rate*F: ISF Training Rates	-0.00841	0.0046
D: Initial Insurgents*E: GDP Growth Rate*G: Infrastructure Development Rate	0.005431	0.0645
D: Initial Insurgents*F: ISF Training Rates*G: Infrastructure Development Rate	-0.00054	0.8533
E: GDP Growth Rate*F: ISF Training Rates*G: Infrastructure Development Rate	0.00354	0.2264

Shaded factors are significant at the 95% level of confidence.

Bibliography

Blanchard, Olivier. *Macroeconomics* (2nd edition). Upper Saddle River NJ: Prentice Hall, 2000.

Brookings Institution. "Iraq Index: Tracking Variables of Reconstruction and Security in Post-Saddam Iraq," (Updated Feb 13, 2004). Washington DC: 2004.

Challenges Project. *Challenges of Peace Operations: Into the 21st Century-Concluding Report 1997-2002*. Elanders Gotab, Stockholm, 2002.

Christensson, S Anders. A.E.R. Woodcock. "Advanced Command and Control Facilities for Distributed Decision-Making." MilitaryScience.org 2002. Online at (as of 4 March 2004): http://www.militaryscience.org/public/media/publications/Advanced%20Command%20and%20Control.pdf

Collier, Paul, Lani Elliott, Håvard Hegre, Anke Hoeffler, Marta Reynal-Querol, and Nicholas Sambanis. *Breaking the Conflict Trap: Civil War and Development Policy*. Washington DC: The World Bank and Oxford University Press, 2003.

Combined Joint Task Force 7. "Iraqi Military Reconstruction Plan," Website, Online at (as of 4 March 2004): http://www.cjtf7.army.mil/irag-faqs/iraq-information/reconstruction-plan.htm

Dalgaard, Carl-Johan and Henrick Hansen. "On Aid, Growth and Good Policies," *Journal of Development Studies*. 2001 Vol 37 Issue 6 pp 17-41.

Dobbins, James, John G. McGinn, Keith Crane, Seth G. Jones, Rollie Lal, Andrew Rathmell, Rachel Swanger, and Anga Timilsina. *America's Role in Nation-Building From Germany to Iraq.* Santa Monica CA: Rand, 2003.

Eaton, Paul. "Coalition Provisional Authority Briefing with Rebuilding Iraq Armed Forces," US Department of Defense Transcript, 21 Jan 2004. Online at (as of 4 March 2004): http://www.defenselink.mil/transcripts/2004/tr20040121-1181.html

Epstein, Joshua M., John D. Steinbruner, Miles T. Parker. "Modeling Civil Violence: An Agent-Based Computational Approach," Center on Social and Economic Dynamics Working Paper No 20. January 2001.

Feil, Scott. "Building Better Foundations: Security and Postconflict Reconstruction," *Washington Quarterly*, Autumn 2002, vol. 25 iss. 4 pp 97-109.

Forrester, Jay W. *Industrial Dynamics*. New York: MIT Press and John Wiley and Sons, 1961.

Forrester, Jay W. *Urban Dynamics*. Cambridge MA: MIT Press, 1969.

Forrester, Jay W. *World Dynamics.* Cambridge MA: Wright-Allen Press, 1971.

Garamone, Jim. "DoD, Coalition to Look into Iraqi Army Resignations," *American Forces Press Service*, 11 Dec 2003. Online at (as of 4 March 2004): http://www.defenselink.mil/news/Dec2003/n12112003_200312114.html

Grymes, Robbert D. "Establishing Security and Stability in Afghanastan," USAWC Strategy Research Project. 7 April 2003. US Army War College: Carlisle Barracks PA.

Hamre, John J, Frederick Barton, Bathsheba Crocker, Johanna Mendelson-Forman, and Robert Orr. *Iraq's Post-Conflict Reconstruction: A Field Review and Recommendations.* Washington DC: Center for Strategic and International Studies, 17 July 2003.

Harme, John J and Gordon R Sullivan. "Toward Postconflict Reconstruction," *Washington Quarterly*, Autumn 2002, vol. 25 iss. 4 pp 85-96.

International Monetary Fund. "Iraq: Macroeconomic Assessment." 21 October 2003.

Kimmitt, Mark. "Coalition Provisional Authority Briefing," US Department of Defense Transcript, 19 Dec 2003. Online at (as of 4 March 2004): http://www.defenselink.mil/transcripts/2003/tr20031219-1041.html

Kulkarni, Vidyadhar G. *Modeling and Analysis of Stochastic Systems*. London: Chapman and Hall, 1995.

Lane, DC. "Invited Review and Reappraisal: Industrial Dynamics," *Journal of the Operational Research Society.* 1997 vol 48 no 10 pp 1037-1042.

Lane, DC. "Invited Reviews on System Dynamics," *Journal of the Operational Research Society.* 1997 vol 48 no12 pp1254-1259.

Levitt, Steven D. "Why Do Increased Arrest Rates Appear to Reduce Crime: Deterrence, Incapacitation, or Measurement Error," National Bureau of Economic Research Working Paper 5268. Cambridge MA: 1995.

Meyers, Raymond H and Douglas C Montgomery. *Response Surface Methodology* (2nd Edition). New York: John Wiley and Sons, 2002.

Miles, Donna. "Iraqi Civil Defense Corps Grows in Numbers and Role," *American Forces Press Service*, 29 Oct 2003. Online at (as of 4 March 2004): http://www.defenselink.mil/news/Oct2003/n10292003_200310293.html

Ministry of Interior. "Security Forces Information Packet," Coalition Provisional Authority Website. Online at (as of 4 March 2004): http://www.cpa-iraq.org/security/interior.html

Mocan, Naci and Rees, Daniel. "Economic Conditions, Deterrence and Juvenile Crime: Evidence from Micro Data", National Bureau of Economic Research Working Paper 7405. Cambridge MA: 1999.

National Strategy for Combating Terrorism. Febuary 2003. Online at (as of 4 March 2004):http://www.whitehouse.gov/news/releases/2003/02/counter_terrorism/counter_terrorism_strategy.pdf

Neumayer, Eric. "Good Policy Can Lower Violent Crime: Evidence from a Cross-National Panel of Homicide Rates, 1980-97." *Journal of Peace Research* Vol 40 no 6, 2003, pp 619-640.

Neter, John, Michael H. Kunter, Christopher J. Nachtsheim, and William Wasserman. *Applied Linear Statistical Models* (4th edition). Boston: McGraw-Hill, 1996.

Okun, Arthur M. "Potential GNP Its Measurement and Significance." *1962 Proceedings of the Business and Economic Statistics Section of the American Statistical Association*.

Perito, Robert. "Special Report: Establishing the Rule of Law in Iraq," United States Institute of Peace, 2003.

Play to Win: Final Report of the Bi-Partisan Commission on Post-Conflict Reconstruction, January 2003. Online at http://www.pcrproject.org/PCRFinalReport.pdf (as of June 3, 2003).

Pollak, Kenneth M. "After Saddam: Assessing the Reconstruction of Iraq," *Foreign Affairs,* 12 January 2004. Online at (as of 4 March 2004): http://www.foreignaffairs.org/20040109faupdate83175/kenneth-m-pollack/after-saddam-assessing-the-reconstruction-of-iraq.html

Swannack, Charles H. "Army Maj. Gen. Swannack Jr., Live Video Tele-conference from Baghdad," US Department of Defense Transcript, 18 November 2003. Online at (as of 4 March 2004): http://www.defenselink.mil/transcripts/2003/tr20031118-0887.html

United Nations. A/RES/53/92. "The Causes of Conflict and the Promotion of Durable Peace and Sustainable Development in Africa," 16 December 1998.

United Nations and the World Bank. "Joint Iraqi Needs Assessment," October 2003. Online at (as of 4 March 2004): http://lnweb18.worldbank.org/mna/mena.nsf/Attachments/Iraq+Joint+Needs+Assessment/$File/Joint+Needs+Assessment.pdf

US Department of Defense. "Defend America," Website July 2003. Online at (as of 4 March 2004): http://www.defendamerica.mil/iraq/update/jul2003/iu073003.html

US Department of Defense. "Joint Doctrine For Military Operations Other Than War," JP3-07. 16 June 1995.

US Department of Defense. "Joint Tactics, Techniques, and Procedures For Peace Operations," JP3-07.3. 12 Feb 1999.

von Hippel, Karin. "Democracy by Force: A Renewed Commitment to Nation Building," *Washington Quarterly,* Winter 2000 Vol 23 Issue 1 p 95-113.

Warner, Mac, Mike Dziedzic, Tyler Randolph, Peter Garcia, Susan Remis Silver, and Sandy Levinson. "SFOR Lessons Learned In Creating a Secure Environment With Respect for the Rule of Law." May 2000.

Woodcock, Alexandar E.R. "Perceptual and Societal Dynamical Models for Compliance and Peace Building" *The Cornwallis Group VII: Analysis for Compliance and Peace Building* pp 111-136. The Canadian Peacekeeping Press, Clementsport NS: 2003.

REPORT DOCUMENTATION PAGE

1. REPORT DATE *(DD-MM-YYYY)* 03-2004	2. REPORT TYPE **Master's Thesis**	3. DATES COVERED *(From – To)* Jun 2003 – Mar 2004

4. TITLE AND SUBTITLE MODELING AND ANALYSIS OF POST-CONFLICT RECONSTRUCTION	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Richardson, Damon B., 2nd Lt., USAF	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(S) Air Force Institute of Technology Graduate School of Engineering and Management (AFIT/EN) 2950 Hobson Way, Building 641 WPAFB OH 45433-7765	8. PERFORMING ORGANIZATION REPORT NUMBER AFIT/GOR/ENS/04-10

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) LTC Thomas Kastner Chief, Assessments Branch, CCJB-AR, CENTCOM 7115 South Boundary Blvd MacDill AFB, FL 33621	10. SPONSOR/MONITOR'S ACRONYM(S) USCENTCOM
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

    APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

    The forces at play in reconstruction operations are a complex system of time phased interlocking cause and effect relationships that are not thoroughly understood. A model capable of capturing the general dynamics involved in post-conflict reconstruction would provide insight to decision makers regarding potential policy alternatives. This research effort demonstrates the viability of using systems dynamics modeling techniques to simulate the establishment of public order and safety in a post-conflict reconstruction operation (Phase IV operations). A high level generic framework is developed that can be used as a general template for modeling post-conflict reconstruction. It is then demonstrated with a notional test case based on the OIF AOR.

15. SUBJECT TERMS
Post-Conflict Reconstruction, Simulation, Peace-building, Democratization, Nation Building, Systems Dynamics

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Richard F. Deckro, AFIT/ENS
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER *(Include area code)* (937) 255-6565, ext 4325; e-mail: Richard.Deckro @afit.edu
U	U	U	UU	130	