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Prioritizing the Reconstruction of Critical Infrastructure within a Stability Operation Environment: A New Methodology

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> We knew it wasn't a matter of how many projects were completed. It was a matter of: Is the electricity flowing to Baghdad? Is there security on the streets? Is the oil flowing? Those were the things that mattered…Too often, though…it was all about the process – how many hundreds of millions of dollars you had put under contract – and not the product.[i]
>
> Geoff Witte, *Washington Post*

The Need to Transform

As of 31 March 2008, total funding for Iraq reconstruction stood at $112.52 billion, with the United States footing $46.3 billion of that amount in appropriated funds.[ii] Unfortunately, as decision-makers are well aware, there is no assurance that massive expenditures on critical infrastructure projects within a stability operations environment can ensure long-term stability in an affected country. Thomas Friedman, in his bestseller, *The World is Flat*, states repeatedly that the best way to ensure long-term stability is through economic integration with the modern world.[iii] However, the stability operations and counterinsurgency literature clearly states that before the desirable conditions of economic development and integration into the world economic system can sustain themselves, the host nation (HN) must be able to govern itself effectively and maintain a monopoly on the use of force within its own borders – neither of which is possible until the most fundamental "Maslow" needs of an affected population, such as physical security and essential services, are met.[iv]

With this in mind, Figure 1 seeks to provide a graphic depiction of a general assumption that the authors make about the traditional stability operations' lines of effort (LOEs). Namely, that primarily non-indigenous actors, such as coalition military forces and governmental and non-governmental aid agencies, must take the lead in satisfying the population's most fundamental "Maslow" needs during the "golden hour" of opportunity, before the host nation can provide effective, indigenous governance and security.[v]

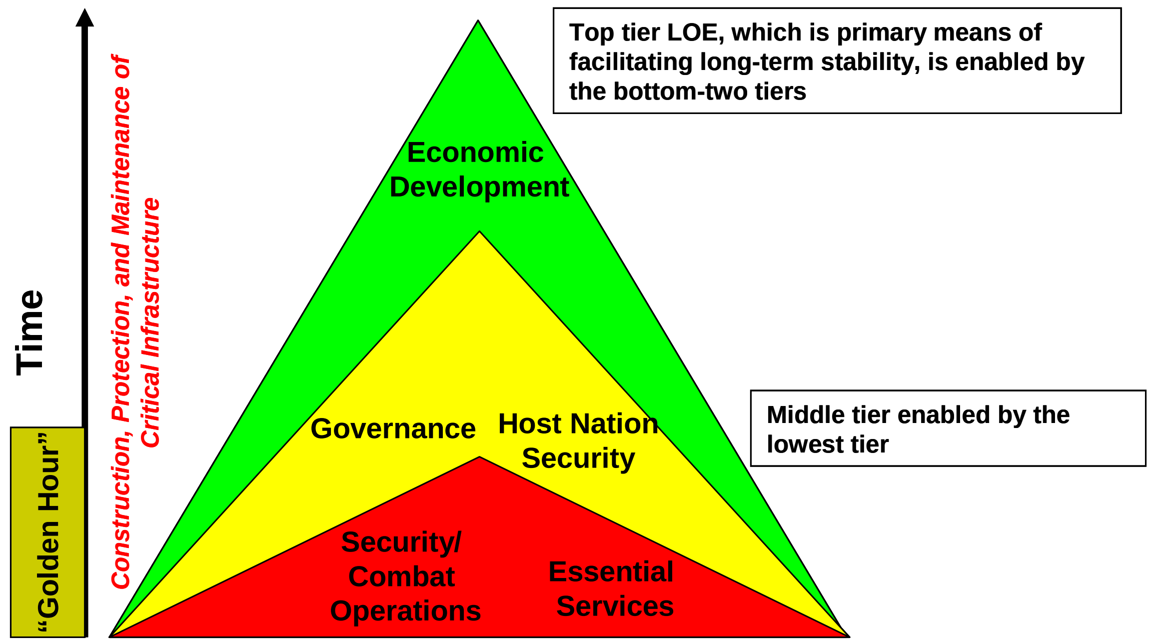

Figure 1.Success in a Counterinsurgency (COIN) and/ or Stability Operations Environment Rests Upon the Foundation of Being able to Secure and Provide Essential Services to the Affected Population.

This is not to suggest, however, that LOEs should be pursued sequentially; the diagram clearly shows that each of the LOEs has a fundamental role at the outset of stability operations. The diagram also acknowledges that the relative effectiveness of each successively higher tier of the "LOE hierarchy" (Figure 1) is dependent upon the lower tier which precedes it. Thus, an inherently unstable country can only achieve long-term stability once it achieves a higher state of economic development and interdependence with other national economies; yet, very little economic development and integration can occur until effective HN governance and security is established. None of this can occur without decision-makers accounting for the deliberate construction, protection, and maintenance of critical infrastructure[1], which spans the duration of the time continuum. That being said, the primary purpose of this paper is to introduce a methodology which will enable decision-makers and planners to better understand and exploit the fundamental relationships between critical infrastructure and each of the lines of effort within a stability operations environment in order to effectively and efficiently prioritize the reconstruction of critical infrastructure. The Critical Infrastructure Portfolio Selection Model (CIPSM) offers such a methodology.

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[1] The United States' National Infrastructure Protection Plan (NIPP) defines critical infrastructure in the following manner: *Physical or virtual assets, systems, and networks so vital to the United States that the incapacity or destruction of such assets, systems, or networks would have a debilitating impact on security, national economic security, public health or safety, or any combination of those matters.*

The Critical Infrastructure Portfolio Selection Model seeks to overcome previously identified shortcomings associated with reconstruction efforts in stability operations environments such as in Iraq and Afghanistan. [vi] This methodology works by doing a better job of identifying sets, or portfolios, of reconstruction projects that achieve effects across multiple lines of effort (LOEs) at costs commensurate with their benefits and risks. An additional benefit of this model is that, when implemented, it could be utilized as a decision support system (DSS) to support decision-makers across the inter-agency spectrum, and at every echelon of command, in order to facilitate the effective planning of reconstruction efforts in stability operations without imposing additional, onerous data collection requirements upon the lowest levels of command.

As stated at the outset, the primary motivation for introducing such a methodology is the staggering cost associated with engaging in stability operations in Iraq and Afghanistan. These unsustainable high costs, in light of a global economic downturn, and the competing interests of nations compel the prudent decision-maker to encourage greater inter-agency coordination and seek more efficient and effective ways to allocate our scarce resources as we seek to achieve national security objectives[vii]. Therefore, it should come as no surprise that two of the major organizations responsible for reconstruction in Iraq, the Iraq Transition Assistance Office (ITAO), formerly known as the Iraq Reconstruction Management Office (IRMO), and the U.S. Army Corps of Engineers' (USACE) Gulf Region Division (GRD), have put forth monumental efforts in attempting to manage this process. Both organizations have developed elaborate enterprise management systems to facilitate the collection, storage, and dissemination of critical infrastructure information[viii]. However, the Critical Infrastructure Portfolio Selection Model (CIPSM) provides a much-needed quantitative framework which enables decision-makers to evaluate a critical infrastructure project's ability to transform inputs (budget amounts) into meaningful outputs, which are directly linked to relevant measures of effectiveness (MOEs). Just as important, though, is that it is possible to implement this methodology simply by using the data available via the aforementioned enterprise management systems, so as not to impose additional data and intelligence collection burdens upon the lowest levels of command.

Before outlining a more "optimal" method for allocating resources, it is essential to understand the CIPSM's intended stakeholders. Figure 2, an extract from Kathleen Hicks' and Eric Ridge's, *Planning for Stability Operations: The Use of Capabilities-based Approaches,* represents a cross-walk of stability operations tasks and lines of effort (LOE) across multiple USG organizations.[ix]

State Department: Essential Tasks Matrix	Defense Department: StabOps Joint Operating Concept	U.S. Army: Stability Tasks Draft FM 3-0
Security	Safe & Secure Environment	Civil Security
Justice & Reconciliation		Civil Control
Governance & Participation	Representative, Effective Government	Support to Governance
Economic Stabilization & Infrastructure	Critical Infrastructure & Essential Services	Support Economic Infrastructure Development
	Economic Development	
Humanitarian Assistance & Social Well-being	Humanitarian Assistance	Provision of Essential Services

Figure 2. Different USG Perspectives on the Stability Operations Mission Set.
Source: Hicks, Kathleen and Eric Ridge, *Planning for Stability Operations: The Use of Capabilities-based Approaches* (Washington D.C.: Center for Strategic and International Studies (CSIS), December 2007).

The significance of the near unanimity among the perspectives on stability operations is relevant from the point of the CIPSM, since this common operating picture makes the implementation of a data-intensive, inter-agency planning model much more viable and attractive to a broader set of stakeholders. Possible stakeholders and users of the system include: provincial reconstruction teams (PRTs), U.S. Agency for International Development (USAID), embassies in countries affected by stability operations, geographic combatant commands (to include subordinate commands down to the tactical level), and international financial institutions such as the World Bank. While this methodology may appear to be geared towards assisting decision-makers at the operational and strategic levels of command, the utility of this methodology is that it can, and should, be applied at all levels of command and influence in order to permit decision-makers to differentiate between those projects which are most important, and those projects which are less important. Once this prioritization occurs, decision-makers can then determine the sequence in which resources are assigned to the construction, protection, and maintenance of critical infrastructure projects.

As stated previously, none of the aforementioned LOEs can be pursued; nor can stability operations outcomes be achieved, unless the HN infrastructure can be constructed, protected, and maintained. Therefore, it is important to understand the relationship between infrastructures, essential services, and several of the key concepts that will be used throughout this paper. Figure 3 attempts to graphically depict the relationships between these critical terms by using a concept map.

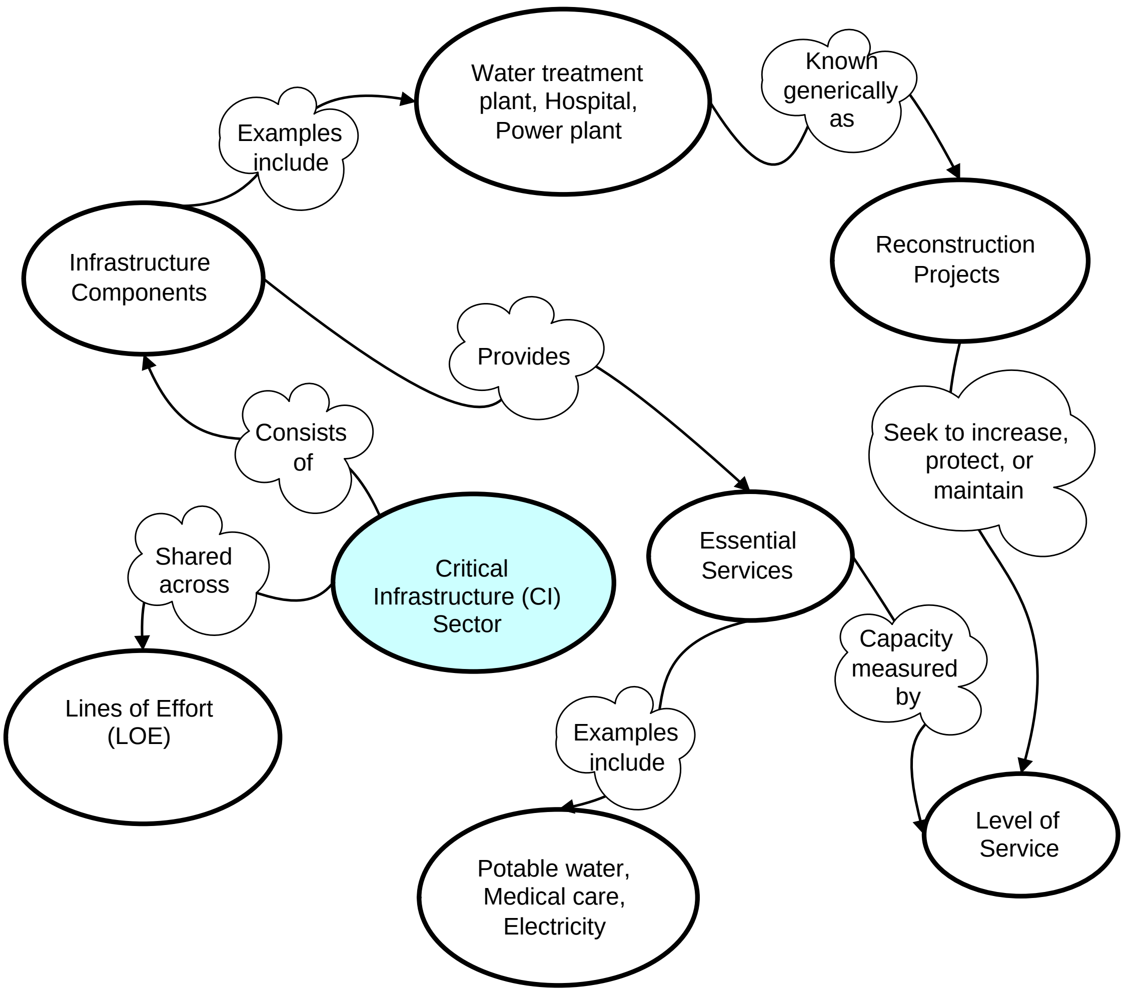

Figure 3. Mapping of Relationships Between Important Terms and Concepts.

Figure 4 attempts to enhance the conceptual framework laid out in Figure 3 by depicting the interdependent relationships that exist among the standard infrastructure sectors as defined by the Department of Homeland Security infrastructure protection literature.[2] For ease of classification for decision-makers, Dr. Ted Lewis, an expert on developing mathematical algorithms in support of domestic infrastructure protection, has arranged each of these critical infrastructure sectors into one of three distinct levels.

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[2] The standard Department of Homeland Security CI sectors are: Information and Telecommunications, Power and Energy, Water and Sewage, Banking/ Finance, Transportation, the Chemical Industry, the Defense Industry, Postal and Shipping, Food and Agriculture, Public Health, and Emergency Services.

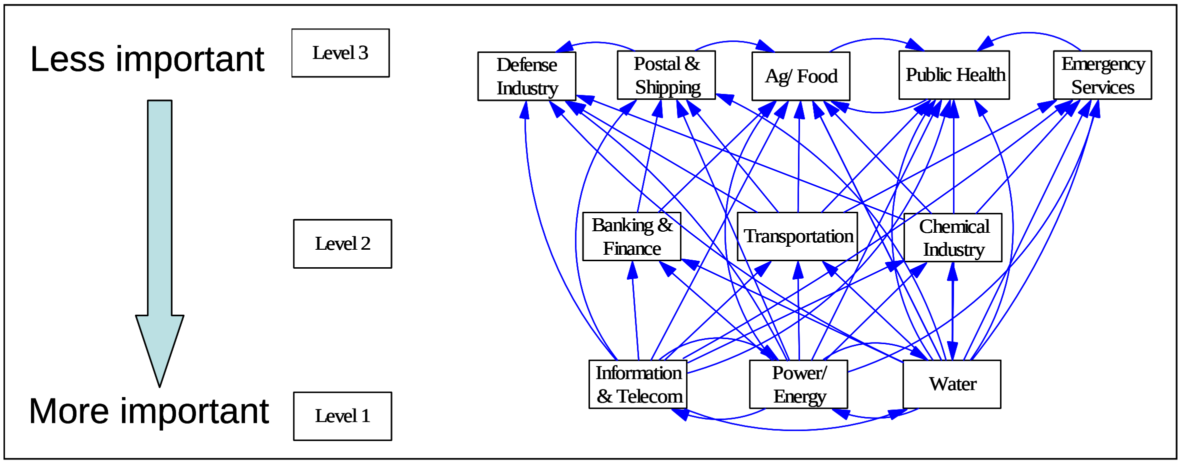

Figure 4. The Authors' Depiction of Dr. Ted Lewis' Hierarchy of Critical Infrastructure Sectors as Depicted on the Cover of Dr. Ted Lewis' Textbook, *Critical Infrastructure Protection in Homeland Security: Defending a Networked Nation*.[x]

The CIPSM operates largely on the assumption that interdependent relationships between standard infrastructure sectors in a domestic environment also apply to interdependencies that exist between infrastructure sectors in stability operations environments; despite obvious differences in the levels of modernization of infrastructure sectors that exist between developing countries and the United States. This assumption has enabled the authors to transform methodologies, originally intended to facilitate the protection of domestic infrastructure, to help prioritize the restoration of infrastructure in developing countries. The Critical Infrastructure Portfolio Selection Model is simply an example of a methodology that was taken from a domestic infrastructure protection application and modified to support a decision-maker's needs within a stability operations environment.

Having addressed the concept map and defined the standard critical infrastructure sectors, it appears that, throughout the majority of Operation Iraqi Freedom, the strategic and operational-level reconstruction effort, with respect to the construction, protection, and maintenance of CI, has not been truly "effects-based." That is not to say that measures of performance (MOP) have not been collected on the status of critical infrastructure within the theater of operations. One need only read USACE's Gulf Region Division (GRD) Reports,[xi] or other similar progress report, to know that data collection and availability is not the problem. Nor is it to say that leaders do not understand the relationship between critical infrastructure status and desired effects among the populace. Leaders at every level of command have clearly identified and documented that a relationship exists between the level of basic services available to the HN populace, and the HN response.[xii] What is missing, though, is a more robust, quantitative model that utilizes the given data in order to generate "value" for an affected population vis-à-vis the prioritization of critical infrastructure construction, protection, and maintenance efforts.

Methodology and Approach

In the most general terms, the Critical Infrastructure Portfolio Selection Model is an operations-research systems analyst (ORSA)-based, portfolio selection method that seeks to provide a list of the most "economical" critical infrastructure projects for both the host nation populace, and the rest of the international community. The term "portfolio" in this context, refers to a collection of investments. In the case of reconstruction efforts, investments refer to distinct sets, or portfolios, containing one or more critical infrastructure (CI) projects (see Figure 5).

Project #	1	2	3	4	5	6
Portfolio #	Airport: Runway (rehab)	Airport: Utility building (electricity), co-generation, and rehab distribution system (construct)	Hospital (rehab)	Railroad junction/ segment of rail (rehab)	Shrine (rehab)	Rehabilitation of water distribution network
1	1	0	0	0	0	0
2	1	1	0	0	0	0
3	1	1	1	0	0	0
4	1	1	1	1	0	0
5	1	1	1	1	1	0
6	1	1	1	1	1	1
7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

A "1" indicates that a project is contained in a portfolio
A "0" indicates that a project is not contained in a portfolio

Figure 5. The First Ten Portfolios of Projects Evaluated as Part of Major Lindberg's Masters in Military Arts and Sciences (MMAS) Thesis are Shown as they Appear in MS Excel©.[xiii]

Furthermore, the term "economical" refers to a critical infrastructure (CI) component's ability to accomplish objectives, or generate value, at a cost commensurate with the risk.[xiv] The CIPSM operates on the premise that there is at least one portfolio, and possibly more, that can optimize benefits to an affected population across lines of effort (LOE) at costs that are commensurate with risk.

To illustrate this point, a practical example of this methodology is provided. Figure 6 provides a map of a city in Iraq, with relevant critical infrastructure projects identified by the numbered circles, while Figures 7 and 8 provide a more detailed description of the twenty five projects under consideration.

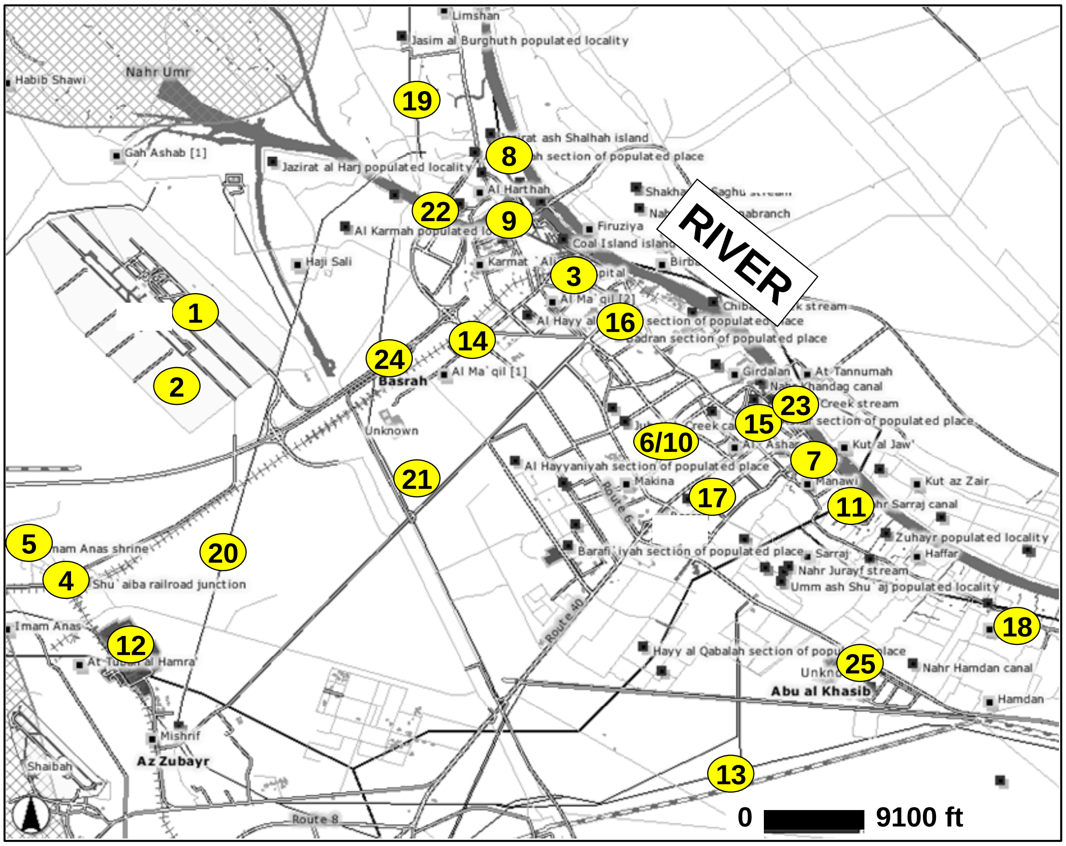

Figure 6. Physical Locations of the Twenty Five Critical Infrastructure Components Under Consideration.

	Infrastructure Project	Design life (yrs)	Primary Effects and Benefits
1	Airport: Runway *(rehab)*	20	Runway that is capable of servicing large commercial and military aircraft for extended periods of time without requiring extensive repairs after each use
2	Airport: Utility building (electricity), co-generation, and rehab distribution system *(construct)*	20	Improve reliability of utilities (electricity) at airport
3	Hospital *(rehab)*	60	Modernized emergency room, operating room, and specialty clinics
4	Railroad junction/ segment of rail *(rehab)*	40	Modernize rail network -- facilitate ease of transport of goods
5	Shrine (rehab)	50	Religious/ community services
6	Rehabilitation of water distribution network	20	Reduce leakage, fix breaks, improve water pressure, and reduce non-revenue water (NRW) through effective metering/ billing
7	Rehabilitation of WTP	20	Maintain potable water production capacity and improve quality (esp. turbidity and color)
8	Construction of Transmission System	40	Enable bulk (water) distribution management and provide stable water input for distribution system via ring main, reservoir, and pumping facility
9	Construction of Water Treatment Plant	30	Increase potable water production capacity
10	Construction of Distribution System/ Facilities	40	Series of transfer pumps, elevated tanks, pipes, etc. in order to enable higher, and more stable, distribution management
11	Construction of Reverse Osmosis (RO) Plant	30	Maintain potable water production capacity and improve quality (esp. total dissolved solids (TDS))
12	Oil storage facility (rehab)	25	Modernized warehouse, material handling equipment, loading/ unloading docks, storage and transfer systems
13	Oil pipeline section (rehab)	25	Increase reliability of flow through structural improvements and improved monitoring and control systems
14	Road intersection/ interchange A (rehab)	20	Reduce congestion/ improve level of service (LOS) and throughput
15	Road intersection/ interchange B (rehab)	20	Reduce congestion/ improve level of service (LOS) and throughput

Figure 7. Description of the First Fifteen Critical Infrastructure Components Under Consideration.

	Infrastructure Project	Design life (yrs)	Primary Effects and Benefits
16	Bank (estab. Modern transaction features)	40	Banking services more readily available (ATM) and interfaced with remainder of bank/ financial infrastructure via modernized IT/ IS
17	Rehab of Sewage and industrial waste collection/ transmission system	25	Clean/ build/ repair network of collectors and interceptors to reduce levels of filth and disease
18	Wastewater treatment plant (construct)	25	Dispose of domestic and industrial wastewater in an environmentally sensitive manner
19	Electrical power distribution line segment A (rehab)	20	Reliable distributtion of electricity to customers
20	Electrical power distribution line segment B (rehab)	20	Reliable distributtion of electricity to customers
21	Electrical power distribution line segment C (rehab)	20	Reliable distributtion of electricity to customers
22	Road (surfaced) segment/ vehicle bridge A (rehab)	60	Significant repair of bridge wearing surface, superstructure, substructure to improve LOS/ throughput
23	Road (surfaced) segment/ vehicle bridge B (rehab)	60	Significant repair of bridge wearing surface, superstructure, substructure to improve LOS/ throughput
24	Road (surfaced) segment/ vehicle bridge C (rehab)	20	Repair road to improve LOS/ throughput
25	Communications tower (construct)	40	Improved cellular and wireless communications

Figure 8. Description of the Final Ten Critical Infrastructure Components Under Consideration.

For the sake of brevity, the mathematical details underlying the Critical Infrastructure Portfolio Selection Model are omitted. The model utilizes two separate ORSA methodologies that were not originally designed for use in stability operations applications. The first ORSA methodology that was utilized within the CIPSM was developed by a team of Israeli engineers and scientists consisting of Harel Eilat, Boaz Golany, and Avraham Shtub. The methodology posed by Eilat, et al., involves generating portfolios of projects by comparing ratios of inputs (project costs) to outputs (MOEs); while simultaneously accounting for the project risk.[xv] The second methodology that was utilized within the CIPSM is attributed to Dr. Ted Lewis. Dr. Lewis uses network theory, which most officers have seen applied in the types of models described in Appendix B of the Counterinsurgency Field Manual (FM 3-24),[xvi] to determine which infrastructure components are "critical nodes" within a given infrastructure network, and also to calculate project risk.[xvii]

Before a more detailed discussion on the aforementioned ORSA methodologies can be provided, it is necessary to address two related concepts that are fundamental to understanding the CIPSM: project design life and project risk. The first concept, project design life, is simply the length of time that a critical infrastructure component, or project, will be able to provide meaningful outputs to an affected population.[xviii] In the United States, most critical infrastructure components have design lives that are set by an industry standard. For example, wastewater treatment plants typically have a twenty to thirty year design life.[xix] However, given that most stability operations environments will occur in developing countries, great care must be taken to ensure that critical infrastructure components are not "over-designed" for the host nation population.[xx] The implications of an over-designed infrastructure component will typically be an "uneconomical," or "inefficient," project that is too expensive to construct, protect, and maintain over the life cycle of the project, relative to the anticipated benefits and risks associated with the project. The CIPSM accounts for life cycle concerns in two different ways. First, the model allows decision-makers to place emphasis, via numerical weights, on certain projects that have larger HN community buy-in and may bear fruit more quickly, while placing less emphasis on projects that do not.[xxi] Second, as will be seen shortly, the model's costs and MOEs are based on monthly averages over the design life of the project. Hence, all project ratios of inputs to outputs are compared on an even basis.

The second relevant modeling concept, project risk, is more precisely represented within the CIPSM as the "probability of project success."[3] Before an understanding of project "success" can be obtained, though, it is necessary to understand how an infrastructure project might possibly fail. Consider the water treatment plant (Project #9) that will not be able to provide an essential service (i.e., it will fail, at least temporarily) if any of the following independent events occur: terrorist attack (first failure mode), mechanical failure (second failure mode), or the failure of another infrastructure component upon which the water treatment plant is dependent, such as the power lines which provide electricity to the plant (third failure mode). Simple calculations, which have been omitted, quickly show that even though an infrastructure component's resilience, or probability of success, against a particular failure mode might be fairly high, the probability of success drops quickly if the project is dependent upon numerous other projects in order to provide its primary output. While it turns out that the water treatment plant (Project #9) is not dependent upon very many critical infrastructure components that are listed, consider the hospital (Project #3), which is dependent upon an external power source for electricity, as well as water and wastewater systems, a communication system, etc., in order to provide an adequate level of service to the supported community. Thus, it only takes a short while to understand the rationale behind Dr. Lewis' diagram (Figure 4) and the relationship behind the concept of a project's probability of success. Similarly, given that most of the projects are dependent upon the power lines (Projects #19 -- #21), Dr. Lewis and the CIPSM would consider these to be "critical nodes" in the partial network portrayed in Figure 6.[xxii]

[3] The probability of project "success," within the context of this paper, refers to an infrastructure component's ability to withstand various failure modes, and its ability to deliver its level of service, or output, to the target population, over the duration of the project's design life.

Table 1 provides a summary of the inputs and outputs that were used as the basis for comparing projects, initially, and then portfolios of projects. Justification supporting the inclusion of the inputs (budget categories) and outputs (measures of effectiveness) are included within the endnotes. However, it should be noted that two of the budget categories, *the average amount of security/ protection dollars per year over the life cycle of the project* (Input #2), and *the average amount of operations and maintenance dollars per year over the life cycle of the project* (Input #3), are directly associated with preventing two of the aforementioned failure modes.[xxiii] That is to say, the more one invests in the security budget (Input #2) of a project, either by building a better fence or hiring more guards, the less likely the critical infrastructure component is going to fail due to a terrorist attack of some kind. However, this project must account for diminishing returns within the applicable MOEs and probabilities of success. The same logic holds true for the Operations and Maintenance (O&M) budget (Input #3) of the infrastructure project.

The only other input or output parameter requiring further explanation is the weighted average of the number of displaced civilians that will be prevented over the lifecycle of the infrastructure component (Output #3). In their groundbreaking research, Oxford University economists Paul Collier and Anke Hoeffler use proprietary data sets and sophisticated models to determine possible causes of civil war. One of the significant conclusions of their report is that the occurrence of displaced civilians in a stability operations environment prolongs the duration of the conflict and exacerbates grievances against the HN government and other, non-homogenous members of society.[xxiv] Aside from the obvious negative impacts associated with dislocating people from their homes, Collier and Hoeffler suggest that one of the most significant problems occurs when displaced civilians emigrate abroad and continue to provide financial support to the various factions that they left behind[xxv] – not unlike the situation that has existed in the United States when various immigrant groups have continued to provide funding to "terrorist groups" within their country of origin.

Input	Description	Short Name
#1	The amount of capital budget/ new construction dollars *(a one time cost)*[xxvi]	New Construction
#2	The average amount of security/ protection dollars per year over the life cycle of the project[xxvii]	Security
#3	The average amount of operations and maintenance dollars per year over the life cycle of the project[xxviii]	O&M
Output		
#1	Weighted average of the number of people served by infrastructure project per month over the lifecycle of the infrastructure component[xxix]	Average number of people served
#2	Weighted average of the number of people employed over the lifecycle of the infrastructure component[xxx]	Average number of people employed
#3	Weighted average of the number of displaced	Average number of

	civilians that will be prevented over the lifecycle of the infrastructure component	displacements prevented

Table 1. Summary of the Critical Infrastructure Portfolio Selection Model Inputs and Outputs.

An example of the raw data that was used to generate parameter (input and output) values is shown in Table 2. As stated previously, one should note how raw data values are broken down into time periods and that the values within each of the columns are weighted according to a decision-maker's needs. Values of zero indicate that the infrastructure project does not *directly serve* members of the HN population in accordance with the particular measure of effectiveness during the time period in question. While this approach may appear to under-represent the contribution of certain infrastructure projects, such as airport's electricity co-generation system (Project #2), the CIPSM requires the user to understand existing infrastructure dependencies to capture these contributions.

		Output #1 (Avg # of People Served Per Month)			
	Time Period Weights	**0.7**	**0.25**	**0.05**	
		0 -- 6 mos	6 mos -- 4 yrs	4 -- 10 yrs	**Weighted Sum**
1	Airport: Runway (rehab)	0	100000	230000	**36500**
2	Airport: Utility building (electricity), co-generation, and rehab distribution system (construct)	0	0	0	**0**
3	Hospital (rehab)	1000	2500	3500	**1500**
4	Railroad junction/ segment of rail (rehab)	0	0	0	**0**
5	Shrine (rehab)	5000	5000	5000	**5000**
6	Rehabilitation of water distribution network	500000	1250000	1500000	**737500**
7	Rehabilitation of WTP	500000	1250000	1500000	**737500**
8	Construction of Transmission System	0	1250000	1500000	**387500**
9	Construction of Water Treatment Plant	0	1250000	1500000	**387500**
10	Construction of Distribution System/ Facilities	0	625000	1500000	**231250**

Table 2. Raw Data Used to Generate Output #1 Values for the First Ten Projects.

A simple drop-down tool bar and related spreadsheet functions enable the user, via the CIPSM, to capture these dependencies (Figure 9). However, to facilitate a better understanding of the nature of these relationships, consider Projects #1, 2, 19, and 20. The airport runway (Project #1) is dependent upon the electrical co-generation system (Project #2). Similarly, the electrical co-generation system (Project #2) is dependent upon the power line (Project #20), which is also dependent upon another power line

(Project #19). Given that Project #19 is the furthest project "upstream" in the infrastructure system under consideration, it goes without saying that Project #19 is certainly a "critical node" as defined by Dr. Lewis, and, by extension, captures all of the benefits that are dependent upon (or downstream from) Project #19. Another, more common way of referring to these dependencies within a network diagram is to say that Project #19 is the "parent node," while Project #20 is the "child node." Similarly, Project #20 is the "parent" of #2, and so on, with the lowest level "child node" being the airport (Project #1). Therefore, it is natural to assume that projects which can be classified as "parent nodes" tend to reside within the lower level tiers of critical infrastructure sectors (see Figure 4), and in general, should receive the lion's share of resources in order to rebuild, protect, and/ or maintain them. However, this is not always the case.

	Infrastructure Project	Dependent Project #1	Dependent Project #2	Dependent Project #3	Cumulative Contribution to Output #1 (This column accounts for project dependencies)
1	Airport: Runway (rehab)				36500
2	Airport: Utility building (electricity), co-generation, and rehab distribution system (construct)	Airport: Runway (rehab)	These projects omitted for the sake of clarity		36500
19	Electrical power distribution line segment A (rehab)	Electrical power distribution line segment B (rehab)			264772
20	Electrical power distribution line segment B (rehab)	Airport: Utility building (electricity), co-generation, and rehab distribution system (construct)			64485

Figure 2. Project Dependencies and Cumulative Output Values for the First Measure of Effectiveness, Weighted Average of the Number of People Served by Infrastructure Project per Month Over the Lifecycle of the Infrastructure Component.

Project input (budget) values still need to be accounted for before projects can be deemed "efficient" or "inefficient." Recall that a project's or portfolio's efficiency is determined by its ability to transform inputs into outputs. Furthermore, just as decision-makers are able to adjust weights associated with measures of effectiveness (or outputs), the CIPSM permits decision-makers to adjust weights associated with budget categories (or inputs). The CIPSM then compares the ratio of weighted outputs to weighted inputs for every project, while simultaneously accounting for the probability of project success to determine which projects are efficient enough to be considered for inclusion in a portfolio (see Figure 10).[4]

[4] The details of this process, which exceed the scope of this paper, are explained in much greater detail in Lindberg's thesis.

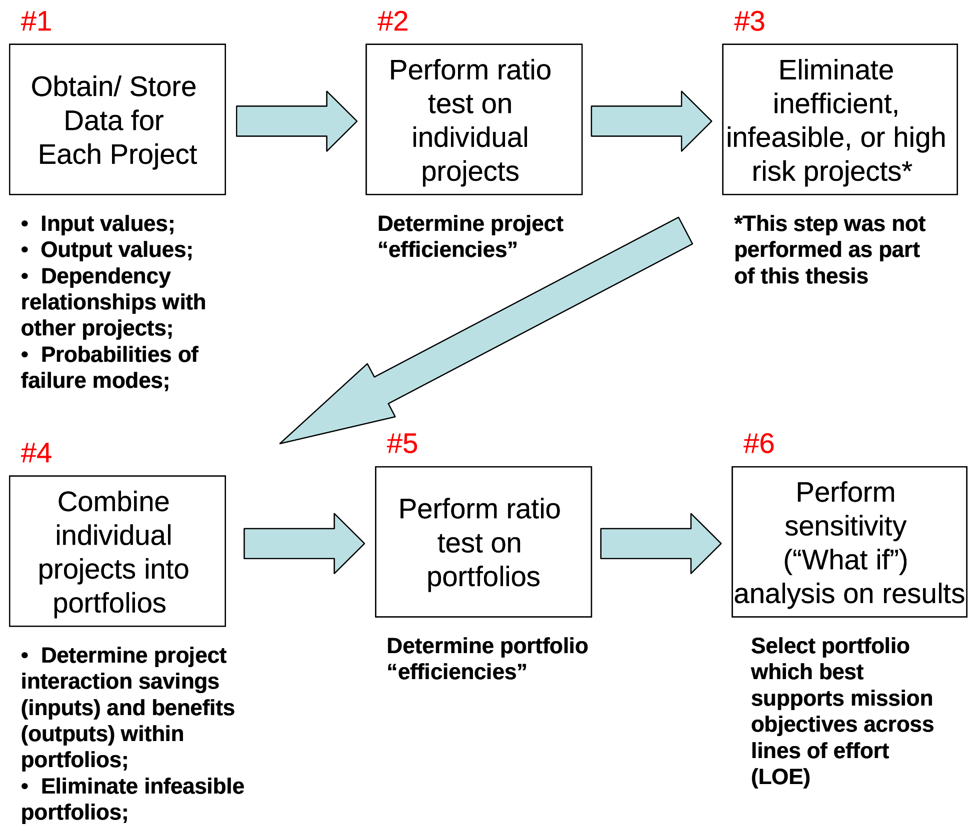

Figure 10. Overview of the Major Steps Contained within the Critical Infrastructure Portfolio Selection Model (CIPSM).

Finally, Figure 11 shows those portfolios of projects that were considered to be efficient, and therefore, recommended courses of action. It should be noted that efficient portfolios are also considered to be "economical" in the sense that they are able to accomplish objectives, as evaluated by the MOEs, at a cost commensurate with the risk. However, just because a portfolio is "economical" does not mean that it will satisfy other criteria deemed critical by the chief decision-maker. As an example, consider a scenario in which a village lacks an adequate amount of potable water. Even though there might be several different efficient portfolios of several different critical infrastructure projects, the portfolio(s) containing the water treatment plant is (are) probably the portfolio(s) that should be considered for final evaluation.[5]

[5] This final evaluation would be conducted outside of the scope of the CIPSM.

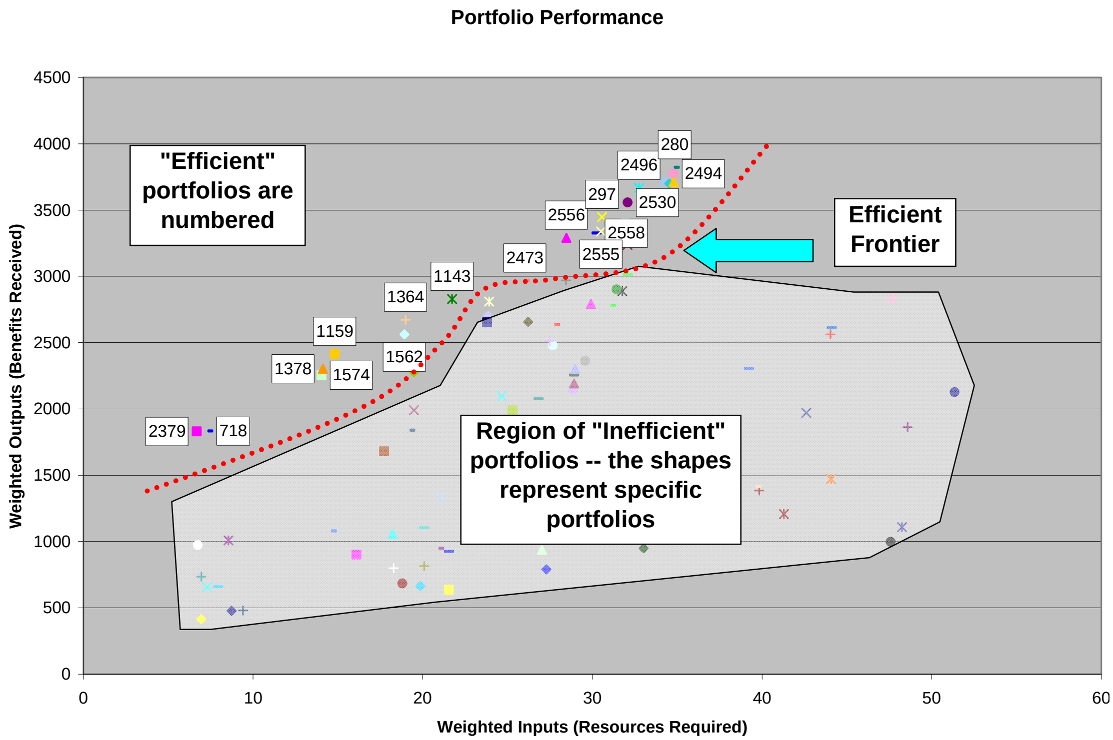

Figure 11. Plot of Feasible Portfolios of Critical Infrastructure Projects.

Table 3 provides a prioritized list of the efficient critical infrastructure projects that were considered within the research. Note the two critical pieces of information contained within Table 3. First, that the list is prioritized based on the number of times that an individual project appears in one of the eighteen efficient portfolios, and that Project #19, the security and routine maintenance of the electrical transmission lines connecting the city to the larger power grid, appears in all but one of them. The study found that the number of times that a project appears in an efficient portfolio is an adequate measure for the "criticality" of the individual projects, and a decision-maker would generally be well-served by investing resources in a portfolio containing these "critical" projects. However, the second item to note within Table 3 is that there are certain "strategic" level critical infrastructure components (e.g. Project #4, railroad junction, and Project #13, oil pipeline section) that appear very few times in an efficient portfolio. This is due to the small number of people *directly receiving first-order benefits (outputs)* from these critical infrastructure components. Clearly, oil revenue is the single largest element of the Iraqi economy and the rail and pipeline network are essential in order to distribute it to markets. However, if planners focus solely on maximizing community (or micro)-level needs, via the measures of effectiveness, then it is quite possible to obtain similar results.[xxxi] It is for this reason that great care must be taken when aggregating output values associated with measures of effectiveness within the CIPSM. In all cases, decision-makers and their respective staffs must understand the relevant assumptions underlying any quantitative model and be prepared to acknowledge that no model, regardless of how well designed, represents reality with one-hundred percent accuracy.

Input #1 Value *(Millions of $)*	Output #1 Value *(1000s of people per month, Avg over design life)*	Probability of Success	# of Times Appearing in Efficient Portfolio	Project #	Description
0.01	5499.45	81%	17	19	Electrical power distribution line segment A (rehab)
0.01	32.98	66%	13	20	Electrical power distribution line segment B (rehab)
0.01	267.05	66%	11	21	Electrical power distribution line segment C (rehab)
0.05	1472.59	81%	9	23	Road (surfaced) segment/ vehicle bridge B (rehab)
0.03	2497.04	66%	9	25	Communications tower (construct)
1.52	387.50	28%	8	18	Wastewater treatment plant (construct)
0.05	482.56	81%	8	22	Road (surfaced) segment/ vehicle bridge A (rehab)
0.03	376.27	81%	8	24	Road (surfaced) segment/ vehicle bridge C (rehab)
1.06	1846.79	53%	6	6	Rehabilitation of water distribution network
0.03	780.29	35%	5	16	Bank (estab. Modern transaction features)
0.22	862.50	66%	5	17	Rehab of Sewage and industrial waste collection/ transmission system
0.00	5.00	43%	4	5	Shrine (rehab)
0.37	1706.25	35%	3	7	Rehabilitation of WTP
0.03	0.00	66%	2	4	Railroad junction/ segment of rail (rehab)
0.40	0.00	66%	2	13	Oil pipeline section (rehab)
1.50	1706.89	66%	2	15	Road intersection/ interchange B (rehab)
0.55	36.50	28%	1	2	Airport: Utility building (electricity), co-generation, and rehab distribution system (construct)
1.50	610.58	66%	1	14	Road intersection/ interchange A (rehab)

Table 3. List of Individual Projects Within Efficient Portfolios, Prioritized by their Frequency of Appearance in an Efficient Portfolio.

One should also note that there are several projects that do not appear in any efficient portfolios (Table 4). In some instances, that is because the projects violated anticipated budgetary constraints.[xxxii] However, in most instances, the projects were not included because the model indicated that these projects did not transform budget amounts (inputs) into measures of effectiveness, or outputs, as economically as other projects. The value of this table is to demonstrate to decision-makers that these infrastructure components, initially perceived to be vital, either have unacceptably high levels of risk that must be mitigated, thereby improving the project's probability of success; or disproportionately low service (output) levels, relative to the investment required. In the event of the latter case, planners should check to ensure that they have aggregated at the appropriate level to ensure that they capture accurate output levels.

Input #1 Value *(Millions of $)*	Output #1 Value *(1000s of people per month, Avg over design life)*	Probability of Success	# of Times Appearing in Efficient Portfolio	Project #	Description
1.50	36.50	66%	0	1	Airport: Runway (rehab)
0.67	1.50	35%	0	3	Hospital (rehab)
2.22	2167.75	66%	0	8	Construction of Transmission System
5.62	1356.25	35%	0	9	Construction of Water Treatment Plant
3.27	1340.54	53%	0	10	Construction of Distribution System/ Facilities
7.95	1200.00	35%	0	11	Construction of Reverse Osmosis (RO) Plant
4.00	0.00	23%	0	12	Oil storage facility (rehab)

Table 4. List of Individual Projects Not Included in a Single Efficient Portfolio.

The final step that is performed in this methodology is to ensure that the recommended, efficient portfolios will not change based on adjustments to parameter (input and output) values. This process is known as "sensitivity analysis" (Figure 10, Step #6). While the details of this process have been omitted, one of the critical findings was that an individual project's efficiency was dictated almost solely by two parameter values, Input #1, *the amount of capital budget/ new construction dollars*, and Output #1, *the weighted average of the number of people served by infrastructure project per month over the lifecycle of the infrastructure component.* This finding was demonstrated to be statistically significant and could assist planners in making quick assessments as to the relative efficiency of a project[6].

Conclusions

There is ample literature to suggest that the operating environment of the future will be replete with security conditions necessitating U.S. involvement in stability

[6] Quick assessments could be made by using the regression model results which are available in Lindberg's MMAS thesis which is available through the Defense Technical Information Center (DTIC) and the Combined Arms Research Library (CARL).

operations.[xxxiii] There are also numerous sources which cite the important role that infrastructure construction, protection, and maintenance have played within stability operations throughout the history of the United States.[xxxiv] The Critical Infrastructure Portfolio Selection Model is an analysis tool designed to help decision-makers determine what the most efficient and balanced portfolio combinations of critical infrastructure projects are within a stability operations environment. The CIPSM is also designed to help decision-makers prioritize the construction, protection, and maintenance of critical infrastructure components which best accomplish objectives across stability operations lines of effort at a cost commensurate with the risk.

David Kilcullen, General David Petraeus' senior counterinsurgency (COIN) advisor in Iraq, suggests that COIN operations, which consist largely of stability operations and pose the country's largest, near-term threat, must balance immediate and long-term perspectives and objectives.[xxxv] It is for this reason that the CIPSM incorporated weighting mechanisms that enable decision-makers to prioritize various time horizons: zero to six months, six months to four years, and four to ten years, within their portfolio selection strategies. Furthermore, while this research placed heavy (70%) emphasis on a project's ability to deliver services to an affected population between zero and six months of initiation, developers would be well served in conducting a separate sensitivity analysis on these particular output weights with a new data set before implementing the Critical Infrastructure Portfolio Selection Model as part of a more comprehensive DSS.

Sensitivity analysis conducted on a sample data set from the research for which this article is based,[xxxvi] indicates that the types of infrastructure projects selected for investment by the model are largely determined by only two significant parameters: one input parameter, *the amount of capital budget/ new construction dollars required to undertake the project* (Input #1); and one output parameter, *the weighted average of the number of people served by infrastructure project per month over the lifecycle of the infrastructure component* (Output #1). Since the budget parameter (Input #1) for a project is almost always the most readily available and widely documented piece of data for a particular infrastructure project, this data requirement does not impose an additional data collection burden upon the commander on the ground. Similarly, since both the "population served" and "design life" parameter values, which are both required in order to calculate the value for Output #1, are readily obtained via routine infrastructure intelligence and reconnaissance efforts, this should also not present a particularly onerous data collection and management requirement.

Furthermore, the CIPSM can be implemented using simple arithmetic commands in MS Excel, or a more robust enterprise management system, as opposed to more sophisticated operations research/ systems analyst (ORSA) techniques. An ancillary, and not inconsequential, benefit of omitting the more sophisticated technique is that the tool will be much simpler, and more easily exportable to a wider array of computer systems and users.

One of the pressing needs of every organization that works in Iraq, and ostensibly, in any stability operations environment, is to “triage the environment,” and stick to priorities.[xxxvii] While it may be impossible for a single tool to accomplish these pressing needs, the Critical Infrastructure Portfolio Selection Model is certainly a step towards achieving this desired vision in support of decision-makers at every echelon of command and influence in this challenging, contemporary operating environment.

Recommendations

Beyond the U.S Army’s use, the Critical Infrastructure Portfolio Selection Model, should be considered for implementation within the U.S. Joint Forces Command (USJFCOM), geographic combatant commands, Army and Joint Staff Operations and Planning Staffs, the State Department's Office of the Coordinator for Reconstruction and Stabilization (S/CRS), and the U.S. Agency for International Development (USAID). Even without full implementation, utilizing Lewis’ method of critical node analysis to identify and aggregate infrastructure dependencies in order to determine the total number of people served by critical infrastructure projects, could be adopted relatively easily. Existing geospatial information systems available down to the lowest levels of tactical command make this critical node analysis even more practical. However, one of the significant obstacles preventing this from happening is the lack of a common “infrastructure database” standard across all levels of command and leadership. The adoption of the DoD Real Property Classification System (RPCS), or other U.S.-based infrastructure classification standard, at the joint and interagency level, would greatly facilitate this process.

Decision-makers at all levels should utilize the aforementioned aggregation techniques, in order to more accurately determine the probabilities of project success. Once armed with this knowledge, risk mitigation efforts could be implemented more effectively – particularly if one were able to receive “buy-in” on these risk mitigation efforts from local and national-level HN leaders.

Finally, the Critical Infrastructure Portfolio Selection Model, should be utilized by other governmental organizations and international institutions such as the Government Accountability Office (GAO) and the World Bank as an initial accountability tool to ensure that the primary departments engaged in international affairs, DoD and DoS, are serving as effective stewards of financial resources, while seeking to measure the progress towards national security objectives.

Recommendations for Future Research

A measure of effectiveness that was not used, but should certainly be considered when assessing the long-term effectiveness of a national strategy, is the amount of foreign-direct investment (FDI) that foreign companies are pouring into the affected country -- particularly in non-primary commodity economic sectors. Both Collier and Hoeffler, as well as Thomas Oatley, in his third edition of *International Political Economy: Interests and Institutions in the Global Economy*, state that FDI, particularly in non-primary commodity export sectors, is a sound measure of effectiveness.[xxxviii] With this in mind, an input-output, or systems dynamic model, which includes the host nation's economic sectors and other significant entities, such as the level of infrastructure sector development and the level of security, is probably the next logical research contribution before complete system implementation would make sense. The input-output model helps identify economic sectors that provide the greatest "value added," while the purpose of the systems dynamic model is to reflect relationships and determine rates of change amongst model components as parameter values are changed elsewhere in the model. On a similar note, Kilcullen postulates that small, local programs, not dependent upon commander's emergency response program (CERP) funds, tend to perform better, since local "buy-in" and long-term viability is more likely in the long run, and this recommendation is supported by the analysis results of the Critical Infrastructure Portfolio Selection Model.[xxxix]

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245026 (accessed 12 May 2008). This paper and study broke time segments into four year periods following the onset of "peace" in developing countries. Thus, the Critical Infrastructure Portfolio Selection Model allows decision-makers to weight projects over similar time periods.

[xxii] For the sake of clarity, the arcs (or lines) between nodes, were omitted from the image. However, the relationships were reflected within MS Excel when the calculations were performed as part of Major Lindberg's thesis.

[xxiii] Major Lindberg's thesis estimated these two budget amounts (Input #2 and #3) as being between ten to twenty five percent of the new construction cost (Input #1) of the project. This appeared to be consistent with various references on the subject, although the "Security" budget amount (Input #2) has much greater variability and is much less well documented.

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[xxvii] Ibid.

[xxviii] Ibid.

[xxix] Ibid. This MOE is not without precedent and has been used, in various forms, by numerous reporting agencies and organizations, military and non-military, alike. See the GRD Reconstruction Report reference citation.

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[xxxi] Lindberg's thesis focused solely on supporting the critical infrastructure needs of an individual city. Hence, the "boundary conditions" that were established did not extend much beyond the city, and certainly not beyond the provincial, level of concern.

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