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Invited Review

Operations Research in Defense and Security Systems: Some U.S. Experience With Extensions to the Developing World

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Abstract

Operations Research has its origins in the Military as a consequence of the Allied Forces concerted and successful efforts to defend Britain during World War II. Since then, the assortment of tools employed had been extended extensively to form a discipline with a wide appeal variously known as Operations Research, Systems Analysis, Management Science, the Science of Better, etc. We provide a paintbrush of its evolution, methodology, and prototypical problems with emphasis on its applications to significant problems faced by the military. In particular, we outline how new challenges in defence involving protection against natural disasters can benefit from an adroit wedding of classical OR techniques of mathematical programming and soft computing to evolve a powerful modeling and optimization tool based on fuzzy sets theory. Their applications to related challenges facing the developing world, as typified for example, by Nigeria, are then examined.
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Keywords: systems analysis and operations research, methodology, mathematical programming, fuzzy dynamic programming, soft computing, networks and logistics, modeling, optimization and simulation, military problems, defence, security protection and extensions, floods and disaster control planning.

1.0 Introduction

It is generally well known and believed that the discipline of Operations Research (OR) emanated from a variety of activities deeply rooted in World War II which witnessed the mobilization of an assortment of people of various disciplines: scientists, mathematicians, engineers, managers, etc to bring their talents towards the war effort. Like most historical renditions of such developments, variations of accounts connected with its history abound. There is reasonable agreement however, about crediting the origin of the term to a meteorologist Albert P. Rowe, who as a superintendent at Bawdsey Research station in Suffolk, England was among a group charged in 1936 by the British military to devise ways for using fighter aircraft along with the newly acquired radar technology to provide adequate protection to the British homeland under siege during World War II. A parallel group, the US Navy's Antisubmarine Warfare Group (ASWORG) headed by the physicist late Prof. Philip M. Morse of MIT and assisted by chemist George E. Kimball worked on various scientific, quantitative studies of operations of war. The description of Operations Research as the "scientific method for providing executive departments with a quantitative basis for making decisions" is however credited to another physicist Charles Kittel who defined it in his 1947 paper published in *Science*, "On the nature and development of Operations Research". Kittel's definition was subsequently modified by Goodeve who in his 1948 paper, described it as "a scientific method of providing executive departments with a quantitative basis for decisions regarding the operations under their control". It is within this definitional context that most operations research work has taken root. The current surge of interest in the field of data science and variations of artificial intelligence developments and applications can be traced to the maturity of the field and profession.

1.1 Military Applications of OR: Early Beginnings and Success Stories

Apart from the well known applications of classical OR methodologies during World War II, there were several important but apparently less publicized successes such as the so called "big secret" applications. Some of these were directly associated with the Bay of Biscay anti - U-boat offensive, the destruction of German blockade runners in the South Atlantic, the initiation of large convoys, which were deployed barely one or two months after they were initially conceived. Other successful applications involved the use of OR on various facets of thousand plane raids, large merchant-vessel convoys, bombing raids of Japan, and submarine wolf packs. We may recall some key agencies such as the previously mentioned US Navy's Anti Submarine Warfare Group (ASWORG) headed by Professor Philip Morse of MIT.

1.2 Other Applications Spurred by New Tools and Technologies

We may ask what role, if any, did technological developments in other disciplines play in spurring advances in the nascent field of operations research? It is pertinent to note here that important classical OR methodologies such as linear programming (Dantzig) and its variants as well as dynamic programming (Bellman) which were primarily deployed in resource allocation models became more important in applications with the development of improved computing devices. For example, together with other tools such as Monte Carlo simulation which involve repetitive calculations on a massive scale, they created the impetus for the development of electronic computers. With the assembly at the Los Alamos Scientific Laboratory of such renowned scientists as Stanislaw Ulam, Enrico Fermi, Richard Feynman, Edward Teller, Nicholas Metropolis, von Neumann, Richard Bellman, to name a few, and the computational help of the then nascent Electronic Numerical Integrator and Computer (ENIAC), applications to the development of thermonuclear weapon systems (also known as the superbomb) surged. Other wartime OR and, in particular, *Monte Carlo simulation* spin-off applications, albeit not dependent on computers, abound. An example is the work of Samuel Wilks of Princeton University for the National Defense Research Council which sought an answer to the problem of determining the number of bombs required to "blast a safe corridor through an enemy mine field". This was solved using *simulation* and *statistical sampling theory***.** Subsequently, a good number of these distinguished scientists assembled in places such as the Rand Corporation and the Systems Development Corporation (SDC) both in Santa Monica, California developing these and additional tools primarily under research sponsorship by the U.S. Air Force, the Army, and related Defense and Security Agencies. We might take a moment here to ask a related question of a local nature. After the Nigerian Biafra War, for example, what did Nigeria do to assemble groups of scientists and technologies created during the war effort to generate new and advanced forms of technology families for defence of national resources and interests similar to the birthing and advancement of the powerful technology of Operations Research? Is this an example of a lost opportunity which prevails in various facets of Nigeria's developmental trajectory?

1.3 SA/ OR is a Common Feature/Thread of IE/OR/SE Programs.

In late 2015, during my Nigerian National Merit Award Winners Lecture, entitled "Vistas of Seminal Contributions to Industrial and Systems Engineering/Operations Research: Transferability Imperatives to the Developing World", I proffered the serious and concerted pursuit of academic and professional programs in the triplet: industrial engineering, systems engineering, and operations research as an instructive engagement capable of aiding the developing world in rapidly closing the development chasm between them and the so called developed economies of the world. In particular, I stressed that Operations Research tools were common to all three. Thus, it is instructive here to use it to illustrate the practice of these professions. In a university, the classical breeding ground for new intellectual empires, where would you expect to locate an Operations Research program? Depending on the Institution, the Departmental/School, or College location may vary. For example, in the U.S. and especially at the graduate and doctoral level, we may find a stand alone department such as the Department of Operations Research. This is the case at the birth place of formal OR academic programs, the Case Western Reserve University, Cleveland, Ohio where I held my first formal academic appointment as Assistant Professor of Operations Research and Member of the Systems Research Center from 1968 to 1972. At the Massachusetts Institute of Technology (MIT), where the inaugural President of the Operations Research Society of America, (ORSA) late Professor Emeritus Phillip Morse held academic appointments until his death, there is The Operations Research Center, but degree programs are coordinated by the Sloan School of Management and other Schools at MIT. At Columbia University where the first formal Society of Operations Research Scientists, the Operations Research Society of America (ORSA) under the Presidency of Phillip Morse was launched in 1952 and the University of California at Berkeley, it is within the Department of Industrial Engineering and Operations Research. At the University of Michigan, it is under the Department of Industrial and Operations Engineering. At Cornell, it is in the School of Operations Research and Information Engineering. At Stanford, it is in the Department of Management Science and Engineering. At the Georgia Institute of Technology (Georgia Tech, with the largest and consistently top world rated program in the US), The University of Arizona, The University of Florida, the Ohio State University, and the University of Southern California (USC), it is within the School/Department of Industrial and Systems Engineering. The point here is that formal academic degree programs, especially at the graduate levels, may be found in three principal departments: Engineering, Management, or Mathematics, Statistics and Computational Sciences or some combinations but hardly in a stand alone department. This exemplifies their multidisciplinary nature, both in their theoretical foundations and applications to diverse problem domains.

1.4 But What then is SA/OR, in Theory and Practice, and What Are Its Trademarks?

Like several professions, over time, the methodologies embodied in the practice of OR and its variants- Systems Analysis (SA), Cybernetics, Management Science (MS), and in recent times, Data Science, have been developed and used by different organizations and societies such as The Operations Research Society of America (ORSA,1952) and The Institute for Management Science (TIMS,1953)which merged in 1995 to form The Institute for Operations Research and Management Sciences (INFORMS, 1995), and the various Operations or Operational Research Societies (Operational Research, as it is called in Britain, Europe and the British Commonwealth), in various countries of the world which have an international umbrella- the International Federation of Operations Research Societies (IFORS). These tools are marketed under various brand names. For example, INFORMS has adopted the promotional name, "*the Science of Better*" heralding these tools as those whose main purpose is to do whatever needs to be done better than ever before. In our monograph which was published by the National Academy of Science in 1975 and beamed especially at developing nations, we adopted the acronym, *SA/OR* and we will do so in the sequel. We proffered SA/OR as a demonstrated tool for policy and program planning in developing economies which are especially confronted with the task of planning with limited data, in the face of so many uncertainties, under immense pressure, to distribute and expend limited resources to a bewildering array of competing needs while at the same time achieving maximal effectiveness. Optimality, the eventual global goal, was not necessarily and explicitly considered in the immediate circumstance, so we use efficiency and effectiveness rather loosely and somewhat interchangeably, although we are quite aware of their definitional differences.

Let us take a moment to concretize our current thinking on the concept of SA/OR especially as perceived by the professional community and with particular reference to its theory and practice. The work mission of SA/OR possesses *three* defining characteristics. First, SA/OR may be viewed as *scientific research* applied to operating problems. This conforms to the definition provided by its founders and as articulated earlier. For us, it involves putting people with scientific and quantitative training to work as applied researchers on the operational and resource allocation problems of organizations and enterprises. Generally, the practitioners possess training in probability theory, higher mathematics, analytics, engineering, information and data science as well as computer systems and their usage, econometrics, economics, and to some extent cognitive and other social sciences. Such training, we mused, could be acquired in programs offered by local institutions, foreign counterparts, and short courses mounted by foreign and expert natives living abroad, and recently through online programs such as MOOCS. We recommended that developing countries should consider setting up prototype SA/OR groups who would ideally report to administrators that are committed to their success but we warned that despite their known and proven successes, they should not be seen as a panacea for the problems faced by the developing countries.

The second defining attribute of SA/OR is its use of the *systems* approach to problems envisioning and solving. The systems approach conceives of entities or units as a whole marked off from the environment by boundaries and containing subparts whose interactions are conditioned by the presence of the other subparts or subsystems. A fundamental challenge of SA/OR is to appropriately select a system or subsystem to be analyzed; to correctly define its boundary; to identify the elements, components, and subsystems; to develop models that describe the interaction of these components and very challenging, to appropriately represent the objective function(s) for the system. Finally, SA/OR is distinguished by its use of the *scientific method* whose distinctive feature includes insistence on measurement and the use of conceptual models described in quantitative terms; and on experimental verification of its theoretical predictions and its awareness that its concepts are conditional and subject to change. The scientific method provides a kind of feedback control for the administrator who can compare what is actually happening with what he believes is happening or should be happening.

It is important to pause here and comment on the special feature of the perspective of OR/SA presented here. This robust viewpoint is informed by a unique group of experts assembled in 1974 by the US Academy of Science on behalf of the Board of Science on International Development (BOSTID) for the U.S. Agency of International Development (AID) to prepare a monograph to advise the executives of the developing economies of the world on how to utilize the technological knowledge provided by the discipline of operations research and systems analysis to uplift their economies and fast track their developmental trajectories. Our Committee was privileged to have as our Chair, Professor Emeritus Phillip McCord Morse, a pioneer practical operations research expert who led a number of successful group practitioners during the world war projects, returned to MIT and subsequently became the pioneer President of The Operations Research Society of America (ORSA). He was supported by a broadly based cast of experienced experts from various parts of the developing world and experts from the nation's research and teaching power houses. We ensured that our working definition of operations research and systems analysis was robust enough to be inclusive and the illustrative examples included in our monograph representative of reported OR/SA successful applications to various constraining problem scenarios. I have taken the liberty to reflect this resoundingly apt viewpoint in my subsequent presentations of OR/SA including this paper.

Applying the preceding concepts in practice typically involves six identifiable stages which are iterative with feedback mechanisms appropriately installed. The stages and processes are imbedded in what is usually referred to as the *systems analysis paradigm*. These may be summarized in the following checklist which is adapted from Rudyard Kipling's "Just So Stories"

"I keep **six** honest working men
(They taught me all I knew);
Their names are What and Why and When
And How and Where and Who."

The foregoing is best illustrated via the systems analysis paradigm used in several of my work and teachings and depicted in Figure 1.

1.5 What are the Prototypical SA/OR Problem Areas?

The growth and expansion of the discipline may be best appreciated by examining some of the problem areas which have been studied leading to some theoretical developments that are used in applications. While this classification may not be exhaustive or sacrosanct, the following list is illustrative of the areas of work where most professionals in the field have some *basic or concentrated training and expertise*.

- Allocation,
- Inventory, Maintenance, and Replacement,
- Queuing
- Stochastics
- Sequencing and Coordination
- Routing, Logistics, and Supply Chain
- Reliability and Productivity
- Search and Combinatorics,
- Competitive and Gaming (Game Theoretic Situations including Warfare).

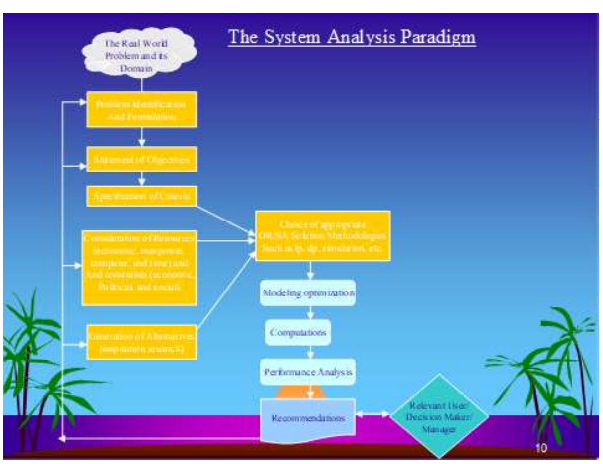

Figure 1: The Systems Analysis Paradigm

The foregoing topical areas may be found in SA/OR or Industrial and Systems Engineering programs of various universities under the following classical departmental areas which may change, expanded or be collapsed depending on the size and configuration of the department and faculty. See for example, (www.isye.gatech.edu):

- Optimization and Computational Science
- Stochastics
- Logistics and Supply Chain
- Simulation
- Maintenance and Replacement Studies
- Manufacturing
- Health and Humanitarian Systems
- Human Machine Systems
- Statistics and Quality
- Economic Decision Analysis
- Computational Finance
- Analytics
- Data Science, and
- Informatics

1.6 What are Some Prototypical Examples of SA/OR in Practice?

While there are numerous examples of successful SA/OR studies in the literature, from classical to novel, from national and international level, to project level, from my own personal experiences to other individual level, and while there exists an excellent documentation of these in the INFORMS Franz Edelman Award Winning Series as well as the relatively new Daniel H. Wagner Prize for Excellence in Operations Research Practice, (see: www.informs.org), it is instructive to list here some that we documented for developing economies in our 1974 study for the US National Academy of Sciences. These are used to show case some non military successes reported outside the developed countries and may be particularly relevant for transferability to Nigeria which had aspired in its Vision 20-2020 to be among the 20 top industrialized countries of the world by year 2020. The examples selected for our illustration of the application of SA/OR to national development are successful applications in some of the so called BRIC countries of Brazil, Russia, India, and China with South Africa joining them in 2010. The application potential has been extended, as well, to those in the so called Asian Tigers (South Korea, Malaysia, Singapore, and Taiwan). The application areas, tools, and environments span the gamut from tactical to strategic.

1.7 Illustrative Example 1: Baroda Bus Study- A Simulation Approach for Routing and Scheduling

We begin with a study performed in India, one of the BRIC countries as far back as in 1972, by the Operations Research Group, a private Consulting firm in India, for the Guraj State Transport Corporation operating a fleet of 100 buses over a route some 3,000 kilometers long, and carrying over 138,000 passengers daily for a load factor of about 47 per cent. Of interest initially was how to meet the ever increasing demand for busses. An immediate response would be to assign more busses to the routes. The OR group however decided to first explore whether the increased demands could be met by *first improving the schedules* before embarking on a proposition to acquire more busses. Thus, the problem addressed became the determination of a satisfactory bus schedule to aid in the optimal deployment of the limited number of buses over the ever expanding bus routes necessitated by a city experiencing vast growth rate. The efficiency of Routing and Schedule frequencies was successfully investigated obviating the necessity of incurring increased financial investment. This study illustrated how a private Consulting Company can use SA/OR to address a real world problem faced by a city whose functioning was being challenged by spiraling increased demands on its system. This could readily be done for many Nigerian cities by an indigenous Nigerian consulting firm. Lagos, Nigeria, a mega city, would seem to be the best candidate for an application of this genre. Other cities such as Abuja, Port Harcourt, Enugu, Kaduna, Kano, Ibadan, and Benin City are other possible candidates.

1.8 Illustrative Example 2: A World Bank Study on Water and Power in the Indus River Basin

This study was designed to provide the Government of Pakistan the basis for it to use in developing successive five year plans based on a systematic exploitation of power and water resources in West Pakistan. The major models involved a variation of Leontif input-output model used to represent sectoral demands or consumptions, and two other models consisting of a computer simulation of the power network operating regimes and a linear programming model of the agricultural sector used to test the efficiency of the proposed projects under various alternative inputs. Over 500 projects were considered for execution in two time periods. According to my mentor, friend and co-author Dr. Warren Hall, who acted as a Consultant on this project, the modeling philosophy of dynamic programming, particularly that imbedded in the Principle of Optimality which we used in our original studies in the California Central Valley Water Resources Planning project, was used here to beneficially guide the prosecution of the complex World Bank project. This study and analysis were used to generate over $2 billion worth of investments on the basin. Again, a local consulting company can perform a similar study in and for Nigeria.

1.9 Illustrative Example 3. South Korea National Economic Models

This example showed how the Economic Planning Board of a National government, working with the USAID, successfully employed quantitative analysis in its national economic planning effort. The methodology involved a blend of an assortment of techniques including an input-output consistency model, a medium term macroeconomic model, a short term stabilization model and two SA/OR models- one involving a mixed integer linear programming model for the steel and petrochemical sector and the other, a linear programming model for regional balancing. The work generated a series of investment guidelines. The developed plan was used to (i) justify higher levels of foreign assistance, (ii) turn around emphasis on foreign trade, from import substitution to export expansion, with an emphasis on labor intensive industries, (iii) establish an annual plan-budgeting process that helped to divert increased resources to those sectors such as electric power and cement identified as bottlenecks, and (iv) made it possible for the Korean authorities to accept as part of their decision making framework, the interdependence of trade, investment and monetary policies. Nothing prevents a local Nigerian Ministry of Planning to work with USAID or any such group to perform the same or similar functions with equally valid results for the Nigerian economy.

1.10 Illustrative Example 4. INVENTORY Management Problems in Guyana Mining Corporation Guyana, South America

In the mid-1970s, several organizations in Guyana responsible for the bulk of the country's export industries began to notice a sharp and steady decline in their productivity performance. They blamed it on poor maintenance practices which in turn were triggered by poor inventory management systems and policies for the timely acquisition of spare parts needed for the upkeep of these industries. Foremost among them was the Guyana Mining Corporation located in Linden which produced the bulk of their bauxite sold in the foreign market. This led to all sorts of spare parts management abuses and poor ordering policies. Eventually, a management consultant was hired to proffer solution to what they diagnosed as an inventory management problem. A workshop and tutorial on inventory management was requested and conducted for Guymines by AESO Systems Inc. Again, the poor maintenance problems and associated inventory management issues constraining performance of many industries in Nigeria and notably the non performing Nigerian refineries can be studied and optimal solutions presented by bona fide consulting companies such as AESO Systems Inc.

2.0 Some Illustrative Sectoral Examples

In this section, we merely list a number of successful and instructive examples spanning various sectors of an economy to show the wide variety as well as diversity of areas and uses.

2.1 Optimal Allocation of Scarce Foreign Exchange Across Sectors of A National Economy To Boost National Productivity

AESO Systems International (ASI) an engineering, computers and management consulting company which I founded in the US in 1979, was hired to provide some tutorials on industrial maintenance and modern inventory management methodologies for the Guyana Mining Corporation (GuyMines) in Guyana as a way to arrest the declining productivity in that premier national industry which was responsible for generating the bulk of the foreign exchange of that South American country. At a closing seminar of the workshop, it was determined that the inventory and associated problems faced by Guymines was also persistently encountered by other major foreign exchange earning industries and sectors in the country. All industries experienced a cascading decline in their productivities, their foreign exchanging earning capacities as well as funding received from the Central Bank of Guyana which was similarly constrained in its supply of foreign exchange for allocation to these industries. The demands for foreign exchange were for the acquisition of spare parts needed for maintenance of machines for optimal productivities of the industries and, in turn, for maximal generation of foreign exchange to be allocated back to them by the Central Bank. Our consulting company AESO Systems International (ASI) was hired again to develop an optimal operations plan for the country to allocate their scarce foreign exchange availabilities while managing coordinately their spares inventories in all of their primary foreign exchange earning industries. Among the various tools of operations research and control employed in the studies, AESO Systems developed an optimal foreign exchange allocation algorithm which is applicable in many settings and transferable to other similarly challenged economies. The methodology for this facet of the study we developed was peer reviewed and published in the premier British Journal of the Operational Research Society, the *Operational Research Quarterly*. It was also subsequently proposed to the Nigerian government.

2.2 Agriculture

Modern agricultural systems benefit from use of an assortment of operations research inspired methodologies. Problems of interest reported include: Crop planning; natural animal population; poultry; pest control; equipment use planning. Optimal irrigation planning has been studied using dynamic programming. Stochastic programming and inventory theory are used to determine optimal size of exploited animal populations. Dynamic programming has also been used in optimal pest control studies. Logistics methodologies have been of particular interest. Ditto for inventory theory and production planning concepts.

2.3 Healthcare Delivery

The list of problem domains includes manpower and facility planning; patient staffing and scheduling; hospital blood bank inventory; menu planning; diagnosis-patient treatment; maintenance-resource allocation; emergency room; multi-phasic screening; organ donor management, patient safety studies. In recent times, interest in epidemics modeling and control management has soared. Examples are SARS, and various forms of COVID related issues including expedited equipment production and distribution routines. The assortment of tools includes: stochastic processes, mathematical programming, queuing theory, inventory theory, information systems and simulation, etc.

2.4 Urban Planning and Management

A sample of problem areas includes urban water and land management; community development; emergency units development and deployment; refuse collection; mail and package distribution and logistics, waste management, street sweeping, etc. Systems analysis; mathematical modeling, linear programming, scheduling, simulation, and economic analysis, fuzzy systems, engineering economic analysis including pricing theory, information systems constitute the primary set of SA/OR tools typically employed.

2.5 Education

Planning and investment in education; information systems; allocation of faculty, classroom scheduling; library and housing system; local school district management; manpower planning etc. The list of tools used include: management information systems; Markov modeling; mathematical programming and inventory theory.

2.6 Tourism

The problem domains include investment planning; resource allocation; management. Investment allocation model for tourism sector of a developing country. The reported tools include optimization and particularly 0-1 integer programming which was used for investment allocation to touristic projects.

2.7 Criminal Justice System

Courts scheduling; patrol scheduling; crime information system; prison system effectiveness evaluation have generated considerable amount of attention in the reported studies. The predominant IE/OR/SE tools reported are linear modeling, feedback dynamics, queuing theory and simulation which are used for the analysis of a total criminal justice system, for court scheduling and to reduce crowding of the court system.

2.8 Water Resources

Optimal Allocation of water for multi purpose activities; optimal operation of reservoirs; release rules; irrigation systems; pollution control planning and taxation of polluters constitute the initial set of projects and issues that have attracted the attention of analysts. In these studies, Dantzig-Wolfe decomposition algorithm; linear programming, dynamic programming; inventory and queuing theory; stochastic modeling; economic analysis and simulation have been used to develop daily, weekly, monthly and annual operation policies for reservoirs. One of the first reported studies includes our work for the State of California, then later applied to the Texas Water Plan and now, almost universally, including developing economies.

2.9 Disaster Control Planning and Management

Planning for the prevention of disasters- natural and man-made, seems to be of considerable interest to communities both nationally and internationally. Included in the effort is the development of optimal resource allocation models for the efficient design of strategies, efficient deployment of intervention and relief programs, etc. Illustrative examples include flood control planning as in Katrina and between structural and nonstructural measures; Sunamee; Las Vegas casino hotel fire; the Columbia Accident; etc. Use of mathematical programming tools in conjunction with fuzzy sets, genetic algorithms, root cause analysis, forecasting and probabilistic risk assessment methods has been reported to be powerful in modeling these various phenomena and to gain insight on possible control policies to be considered. They provide a quantitative and rational basis for decision making in these usually socially, emotionally and politically charged environments.

3.0 Overview of Recurring Problem Domain and Methodology of SA/OR

From the foregoing and bewildering documentary of problem domains, tools, and actual real world applications of SA/OR, let us summarize the issues involved using one or two of them as a vehicle for our discussions. It can be readily seen that most of the problem areas can be reduced to that of a quest for information and guidelines on how best to utilize some limited and scarce resource to address an array, usually large, of competitive demands, and many times, with many unknowns in the data or available information. The other set of problems involves the optimal or efficient movement or transport or transfer of resources located at some point in time in some domain of temporary residence (source, origins) which are needed or in demand at some other set of locations or sinks or destinations and one is interested in doing so at minimum cost or maximum efficiency. It could involve delivering an arsenal from current locations to target points to inflict maximal damage on the site with minimum cost. The first set of problems is generally called ***resource allocation*** while the second is ***logistics.*** The favored modeling tools for treating problems of this genre are usually within the framework of ***optimization*** and ***simulation***. In the sequel, we will expatiate on both of them. We will utilize a problem which involves both problem domains, models, and tools as our vehicle. We will see these recurring themes in our sample applications to the military. For completeness, a **logistics problem** and its most common manifestation, the **traveling salesman problem**, as they occur in **optimization,** will now be briefly reviewed.

3.1 What Relevant Combinatorial Optimization Problems are Involved?

Logistics is the collection of activities associated with acquiring, moving, storing and delivering supply chain commodities (i.e. products in all stages of manufacture, services and information). It encompasses the business functions of transportation, distribution, warehousing, material handling and inventory management, and interfaces closely with manufacturing and marketing. The design of an optimal logistics network requires the formulation of a mathematical model making some simplifying yet realistic assumptions to reduce the vast number of variables and complexity of the relations in the model. Logistics is quite prevalent in supply chains and in many military optimization problems. A highly popularized variant and spin-off, rooted but not identical, inspired primarily by recent heightened attention paid to artificial intelligence, and directed mostly at the financial space, is block chain. We note parenthetically, the similarities and dissimilarities between the two.

Some of the data required as INPUT into the network design modeling are: (i) the location of customer demands (obtained from census data and sales by geography), (ii) the location of manufacturing and warehousing facilities, (iii) transport costs (distances and geocodes) and rates via different modes, (iv) customer service requirements, etc., (v) various system capacities. The logistics network design problem can be decomposed into several parts which can be separately modeled as well-known network optimization problems. Among the more common problems encountered in logistics are the Traveling Salesman problem, the Vehicle Routing problem, the Set Partition problem, Multi-commodity network flow problem, Generalized and Quadratic Assignment problems etc. Some of these are described and formulated as integer programs. ***The Traveling Salesman***

Problem (TSP) is one the most popular problems in network and combinatorial optimization in SA/ OR. Classically, this problem can be formulated as an optimization problem in a variety of ways: LP, MIP, and DP. Others include Heuristics and Intelligent Programming. This problem is the basis for many scheduling algorithms in production and manufacturing logistics. The logistics network design problem can be decomposed into several parts which can be separately modeled as well-known network optimization problems.

It can easily be stated as: starting from his home base, node 1, a salesman wishes to visit each of several cities, represented as nodes 2, … , n, exactly once and return home, doing so at the lowest possible travel cost. This problem can be formulated as an optimization problem in a variety of ways and it forms the basis for many scheduling algorithms in production and manufacturing logistics. We did this, for example, in our classic 1982 book, Bellman, Esogbue and Nabeshima, *Mathematical Aspects of Scheduling and Applications*, published by Oxford University Press in its Advanced Series in Mathematics and Computer Science.

An important offshoot and an extension of the TSP is the ***Vehicle Routing Problem*** which can be stated as follows:
Given (1) a fleet of K capacitated vehicles domiciled at a common depot, say node 1, the problem of determining the best possible set of delivery routes, (2) a set of customer sites j = 2, 3, . . ., n, each with a prescribed demand d_j, and (3) a cost c_{ij} of traveling from node i to node j, what is the minimum cost set of routes for delivering (and/or picking up) the goods to the customer sites (e.g. military depots).

Traditionally, this implies starting from the common depot, delivering to all the customer sites and then returning to the home depot without visiting any of the sites more than once. Sub tours are usually banned. A military example would be a pilot that takes off on a bombing mission consisting of n enemy targets and does not return home until all the identified or targeted enemy sites have been hit. There are many variants to this core problem which we will not address here. As stated earlier, solving these problems is quite difficult but the most prevalent optimal procedures include linear programming, integer programming, and dynamic programming.

Since most of the network optimization problems encountered in designing a logistics network are NP-hard, we often resort to heuristics and approximation approaches such as simulated annealing, taboo search, genetic algorithms, fuzzy logic and neural networks, which provide a good balance between the quality of solutions and the cost (time) required for computation. Many data issues make the elegant formulations of mathematical programming quite challenging in real world applications. For example, geocodes are needed for many types of quantitative analysis tools where proximity among facilities, such as facility location or vehicle routing, is important. Geocodes also allow the logistics network to be visually represented. In many developing economies, however, one finds that these data are not readily available or tend to change very rapidly as a result of deterioration occasioned by, for example, natural disasters (e.g. floods, and massive erosion) which can suddenly wipe out links and connected routes in a network. The question is how to cope with these data problems and vagaries which may render many of the elegant mathematical models that were discussed before impotent. This situation suggests the use of fuzzy numbers, which are a linguistic representation that allow for imprecision and uncertainties of a non probabilistic nature. Fuzzy numbers can be created and used to circumvent this difficulty. Algorithms from the growing field of fuzzy optimization can then be deployed to optimize logistics network design in this environment. With improved computing devices and fast computer codes, a number of large logistics network problems can be readily solved now. Hence, considerable progress has been achieved in the field of logistics leading to an array of practical software packages and algorithms for vehicle routing and delivery systems. This is a credit to good SA/OR as well as developments in available computing devices for data processing. This is a recurrent feature of SA/OR development that it benefits immensely from parallel developments in both hardware and software computational technologies.

3.2 What is Simulation?

Simulation is an attempt to mimic a real world phenomenon, process or system over time without necessarily altering its physical composition. It involves the generation of an artificial history to draw inferences concerning the operating characteristics of the real system that is represented. It has now evolved into one of the top three technologies useful in understanding the behavior of systems. In fact, it is no longer considered the "technique of last resort". In its present form, it has become an indispensable problem-solving methodology of an SA/OR analyst and indeed across many scientific disciplines. A good analyst would use it to correctly and usually cost effectively describe and analyze the behavior of a complex system and to ask "what if" questions about that system. It could also be used as an aid in the design of systems which can be real or conceptual. Its utility is expanded if it is coupled with an intelligent, robust and sophisticated statistical analysis routine.

Simulation, modeling and optimization which are recurrent in large logistic network problems, are central to operations research and systems analysis. They are the brains behind computerization of processes and systems. They precede algorithm development which precedes software development which results from programming. Let us now divert our attention to how these may occur in the Military SA/OR activities, starting from challenges posed to established academic or research institutions and including private consulting houses.

3.3 A Revue of Postwar Military OR Applications and Activities in Education and Research Institutions

A good number of applications of SA/OR in postwar era mirrored those of the war period with the notable exception that they began to be applied to non tactical, strategic problems and in many cases extended to civilian type of problems in manufacturing, transportation, healthcare and urban guidance socio-technical systems. This made sense since a majority of the OR workers in the war era were civilians drawn into the war effort. Think tanks, research centers whether in academia, government or in private corporations began to mushroom. To reiterate, the power of research in generating information, especially of the quantitative variety, which can be used to develop or influence policies and aid decision making is immeasurable. The U.S. Military uses many such established resources to conduct research central to its mission. The list of these institutions includes any of the several Defense universities such as the West Point, the Air Force Academy, Defense Acquisition University, The Air Force Institute in Dayton, Ohio, The U.S. Space Institute, the Naval Post Graduate School, to name a few. Universities and Professional Organizations such as the Military Operations Research Society (MORS), The Operations Research Society of America (ORSA), and subsequently The Institute for Operations Research and Management Sciences (INFORMS), the Military Applications Society (MAS), Operations Research Society became primary promoters of Military OR. The role of such institutions as the RAND Corporation was quite significant especially in the early stages. Publications such as the *Military Operations Research* and *Phalanx* and Awards and Prizes stimulate considerable interest in doing credible MOR work. But in the final analysis, good work marked by successful practical results validate any acclaim and credits received by SA/OR. A few of such examples is instructive and we present them in the sequel. We begin with studies commissioned and conducted by established university and research institutions.

3.4 MOR Case Study # 1: The Power of Quantitative Analysis for Decision Making in the Navy.

When the U.S. Navy leaders were preparing for their 1997 quadrennial defense review, they needed some quantitative basis for making their decisions and justifying any contemplated course of action. They turned on the OR team at the Naval Postgraduate School for research assistance. The request was for a study to quantify the economic benefits of "forward-engaged naval forces" and to communicate them to policy makers. Having a quantitative basis other than anecdotal justifications made it easier to justify investments and budget allocation as well as approval decisions. Such decisions could involve determining the optimal number of aircraft wings for the Air Force, the divisions for the Army, and the aircraft carriers for the Navy which should accompany any advance or forward engaged forces. Three critical tasks posed to the Naval School were (i) an analysis of the flexibility and effectiveness of naval forces with respect to crisis response to the President as well as the national command authority, (ii) a quantitative analysis of the dependence of crisis response ability by the forward engaged forces on force structure, and (iii) the economic benefits of such a forward engaged naval forces. Using and tracking oil prices in post Iraqi invasion of Kuwait as well as an econometric model, the interdisciplinary team assembled by the Naval Postgraduate School, viewed the problem essentially as a scheduling-optimization problem involving ship maintenance requirements, constraints on crew deployment periods, battle group and air wing requirements and other deployment parameters. From their efforts to quantify the economic benefits associated with forward engaged naval forces, the group estimated the total world impact to have been $83.6 billion. On the basis of benefit –cost analysis, it was thus easy to justify any funding request for investment on the forward engaged naval forces project.

3.5 MOR Case Study #2: Determining Optimal Mix of Strategies

In modern warfare, especially *long range warfare planning*, it is generally appreciated that information and knowledge about the enemy, its arsenal and tactics, is important but this is relatively useless if one is without the requisite weaponry to mount the attack. Similarly, the converse is true. We add that possessing both without adequate delivery mechanism including associated strategies is also impotent. There is therefore a need to determine adequate if not optimal balance of all three components in other to be in a position to mount a cost effective operation. This scenario which is faced in decision making in complex operations falls within the framework of resource allocation. Some of these issues were faced during the Gulf War which employed variations of modeling and optimization technologies within operations research. A multitude of scenarios illustrating this application abound. One component of the more complex problem involves determination of the long range bombing strategy (BDA) where conventional weapons are delivered from fixed wing aircraft and a bombing damage assessment has to be made using sensors to determine if more bombing is advisable or not. This decision is impelled by a need for cost effective operation. This usually takes place in highly uncertain dynamic environments and on the recognition of decision making with incomplete data and information. Typically, a BDA involves a determination of whether the state of a target is functional, destroyed, damaged, or in repair. Uncertainties on the data about targets abound but most analysts model these as crisp functions using *stochastic optimization* usually via probability theory. A good deal of the data or information is devoid of information which are usually not measured or captured and others are based on perception factors. We contend that a tool not completely dependent on crisp sets is applicable here. An approach to facets of this problem using probability based crisp sets to represent partial or incomplete information was reported by Yost and Washburn who modeled it as a single allocation optimization problem that combines attack assets and bomb damage assessment sensors. They decomposed the complex problem into two levels and formulate the model as a combination of *linear programming* (at the Master Level) and *stochastic dynamic programming* (SDP) at the target level. The SDP was actually a variation of Partially Observable Markov Decision Process model. Although not specifically alluded to, this application to a military problem is similar to our work performed in the mid sixties which involved the Dantzig- Wolfe decomposition algorithm applied to the California Water Project (Hall and Shepard). Impressive computational results were achieved in this case to a great deal due to the availability of new and powerful computational resources such as fast Pentium II PCs and efficient LP algorithms such as the CPLEX callable library (ILOG 1997) as reported in an earlier section of this paper. The foregoing problem solving paradigm may apply to a related family of problems involving the *weapons acquisition process.* Here, we may be faced with the problem of determining the optimal investment portfolio for a basket of equipment or weapons from a diversity of sources, with specified use purposes, enemy type, as well as location, and timing. We observe that many of the problems treated here with crisp models can benefit from the introduction of fuzzy sets and systems modeling methodology which is illustrated in some detail subsequently with reference to flood control planning.

3.6 MOR Case Study # 3 Using Scenario Analysis

We now discuss another case study benefiting from advances in computing and modeling technology. Decision making under uncertainty continues to challenge decision makers and SA/OR analysts alike. We report another tool and a case study that documents its use in several problem scenarios faced by the US Army. One of the popular SA/OR methodologies for modeling and optimization under uncertainty is ***scenario analysis***. In its simplest form, one postulates several possible scenarios facing a decision maker and assigns known probabilities to their likelihood of occurrence. The utilities of actions taken given these various scenarios are also derived, or given. Of interest then is the determination of the optimal course of action when these scenarios or their combinations occur. This problem can then be transformed into some version of a deterministic linear programming model, usually large scale, and then solved using some of the available commercial modeling languages and LP solvers such as GAMS and CPLEX respectively. Various questions bordering on sensitivity analysis can be easily performed to respond to what if type of issues.

In SA/OR, *scenario analysis* is used in many areas including *multistage investment modeling with scenarios in finance*, policy analysis, quality improvement, space exploration missions etc. As reported by Laferriere and Robinson, It has been used in the US Military in many situations. A case in point is its successful implementation by the US Army TRADOC Analysis Center, White Sands Missile Range (TRAC-WSMR), New Mexico as part of an analysis capability when seeking optimal policies for design forces along with some equipment under specified Army requirements. A partial list of examples of the use of this technique over a ten year span in the past decade include (i) an Armor Anti Armor Mix Methodology, (ii) LM VII Artillery Ammunition Mix, (iii) an Analysis of Amphibious Assault fire Requirements, and (iv) Marine Corps Antiarmor Study. We note again that as powerful as this tool is for planning under uncertainty, assumptions of probabilities based on crisp data delimit their utility.

3.7 MOR Case Study # 4 Involving the Use of Multi-attribute Decision-making

Many decisions in the real world involve ***multiobjectives*** in the face of an assortment of constraints and usually occurring in an uncertain environment. Without the power of analysis of the type provided by SA/OR, it is difficult to imagine how a decision maker can justify a choice or an investment in some chosen policy. Decision Analysis, a sub area of SA/OR is employed in many Defense sectors in the U.S. to plan and operate in many theatres. A good example of its practical and effective use in decisions on the optimal Army Base and Closure (BRAC) 2005 problem was reported rec by Ewing Jr., Tarantino, and Parnell (2006). A Commission appointed by the President and Congress of the United States provided a recommendation which was passed into law in November 2005 stipulating how existing bases and infrastructures should be reshaped or realigned, sometimes involving closing decisions, with the ultimate goal of positioning the nation to face future demands or needs more cost effectively. The Commission's recommendations based on the SA/OR study and evaluation of several studies by the U.S. Department of Defense (DOD) is said to have the potential of saving the nation $1.5 billion annually after the completion of the BRAC implementation. A Military value analysis team, consisting of decision analysts, operations research analysts, and Army installation experts from the Army Basing Study office, the Center for Army Analysis, and the United States Military Academy, employed the tool of multiple-objective decision analysis to develop a qualitative installation military value model based on a six point installation capability index as well as missions (sub-capabilities). Attributes and value measures were developed and used in the multi-attribute evaluation process configured as a military value portfolio analyses study. The key mathematical model was solved as a 0-1 integer program whose objective value was the maximization of the military value of installations in a given portfolio. Three forms of sensitivity analyses performed on the model helped to answer various what if questions that led to a more robust and acceptable solution to a very complex, controversial and politically charged social problem.

3.8 MOR Case Study #5 : Using Multi-objective Value Analysis on a DOD Military Training Problem

As a final and recent example illustrating a practical application of SA/OR to persistent problems faced by the DOD and the Military in particular, we consider the application of ***multi-objective value analysis*** to the problem of evaluating the usefulness of certain aspects of the basic training provided all U.S. enlisted soldiers upon first entering the Army. The problem was viewed as a portfolio selection problem in which the goal was to allocate scarce resource across multiple tasks in order to obtain the maximum value from all of them. The analysis provided a basis for assessing the military value and utility of training tasks as well as helping to determine the sequencing of tasks. By eliminating non productive tasks and modifying others, a cost effective approach to training was instituted. The study claimed that the process led to a better understanding and eventual acceptance of the methodology of multi-objective decision analysis within this segment of the Army that had hitherto not been subjected to intensive evaluation of its activities.

3.9 MOR Case Study # 6: SA/OR Support of DOD By Private Consulting Companies

Some of the early workers in the OR during the War, returned home to the continuation of their war OR activities either through the universities, through government agencies and research centers or think tanks, while others started their own SA/OR consulting companies. While their work primarily mirrored those of the war era, they soon branched into other areas including civilian types of SA/OR. There are now quite a considerable number of such consulting companies out there. In this connection, we mention Daniel H. Wagner and Associates, Inc. which specializes in innovative mathematical solutions to problems encountered in both government and business as well as software and ready made products for financial analysis; Metron Inc; AESO Systems, Inc an engineering, computers and management systems consulting company in Atlanta, and Applied Mathematics, Inc. To illustrate this type of MOR work, we report here, some of the projects embarked upon and successfully executed for the Military by one such organization which was presented in a recent session of INFORMS. A partial list of successfully completed projects reported, mostly involving facets of submarine warfare, include: (i) computer programs used by clients to model complex processes in real time with a view to improve performance (ii) develop and test submarine search tactics (ii) develop portable launch system for torpedoes (iii) develop algorithms to track submarines using sonar data (iv) determine optimal tactics for evading torpedoes, (v) determine optimal search speed, depth and track patterns for submarines, (vi) provide on scene technical expertise in testing submarine tactics, (vii) develop models of probability of detection of a submarine by various sensors for real-time use on submarines, (viii) develop tracking algorithms for use on submarines, (ix) determine effectiveness of satellite laser communication systems by submarines, (x) conduct reconstruction of Naval exercise, (xi) develop algorithm for a thickness gage, (xii) examine effectiveness of airborne laser system for detecting people in water, (xiii) develop models for blending positions of drifting buoys in order to estimate ocean current, (xiv) develop measures of effectiveness for airborne laser system for bathymetry, (xv), develop algorithms for identifying outliers in large data sets, (xvi) develop coastal radar ship tracking algorithms using monostatic and bistatic data, (xvii) develop algorithms for use in continuous sweep testing in wind tunnels, (xviii) develop statistical test for evaluating weapons for use against Go-Fast boats, (xix) develop mathematical model for burn rates of protective clothing, (xx) evaluate effectiveness of cruise missiles.

3.10 MOR Case Study # 7: Department of Defense (DOD) Explores Partnerships with the Entertainment Industry

As indicative of progress of Military OR and continuing interest in promoting the tools quite prevalent in these studies, we report a current effort to push the frontiers of these technologies with a view to exploiting them to mount more serious attacks on complex real world problems facing the Department of Defense. A case in point is in the area of Modeling and Simulation which highlights an attempt to leverage the common threads in the methodologies of two hitherto disparate professions that use simulation and gaming, in some cases similar but in others divergent ways, to reinforce and learn from each other. Specifically, we report the efforts of The US Academy of Science and their Initiatives for cooperation between the DOD and the Entertainment Industry. It recognizes that the technology of modeling and simulation has become increasingly important to both the entertainment industry and the U.S. Department of Defense (DOD). Whereas this technology is central to video games, theme park attractions and entertainment centers, and special effects for film production, for DOD, it is the basis for the provision of a low-cost means of conducting joint training exercises, evaluating new doctrine and tactics, and studying the effectiveness of new weapons systems. It is recognized that both industries were aggressively pursuing development of distributed simulation systems that can support Internet-based games and large-scale training exercises. As a consequence of these common interests, it became instructive for both the entertainment industry and DOD to explore ways of more efficiently achieving their individual goals through mutual cooperation in order to advance the technology base for modeling and simulation. Such cooperation could take many forms. It is possible to engage in collaborative research and development projects, share research results, or coordinate ongoing research programs to avoid unnecessary duplication of effort.

A workshop, convened by the National Research Council's Computer Science and Telecommunications Board, showed several areas of mutual research interest in modeling and simulation. The list includes but not restricted to the following: (i) technology immersion-image generation, tracking, perambulation, and virtual presence; (ii) networked simulation, (iii) standards for interoperability, etc. For example, it turned out that a number of immersive activities are already in progress. This includes the evaluation of commercial computer games for training purposes by the U.S. Marine Corps, use of game machines as personal training units by the U.S. Army, the evaluation the use of commercial flight simulator programs to supplement standard training regimens by members of the Air National Guard. Both the entertainment industry and DOD are interested in developing immersive systems that allow participants (whether game players or soldiers) to enter and navigate simulated environments. The utility of these systems is virtually endless. For example, it is quite possible to facilitate the training of groups of combatants or, increasingly, individual combatants for particular missions when access to the actual location is either hazardous or clearly impossible. Some joint research agenda is therefore possible to enhance each other's capabilities.

3.11 MOR Case Study 8: Using New Modeling Tools for Uncertainty Systems Such as Fuzzy Sets, Computational Intelligence, and Soft Computing in New Concepts of Defense Namely, Protecting the Nation Against Disasters

Disasters, whether natural or man-made, by friendly or enemy forces, defined or undefined have begun to attract the nation's attention. The severity of the attendant damage, and the consequent toll on human lives, property, and other scarce resources, as well as the effect on human psyche, is becoming exponentially catastrophic. It is irrelevant whether such disasters occur within or outside the shores of the U.S. In either case, the U.S. is usually called upon to respond, expeditiously and appropriately. It appears however, that no readily available Agency is equipped to respond as expected. No matter the nature of the response, some Agency of the government, at some level, is blamed for the inadequacy or lack of response. This has led to the call from many quarters for the Military to assume primal responsibility and function for both the planning and response facets of protection against calamitous disasters. According to Redlener, "We still lack the capacity to *imagine* what would or could actually happen in a catastrophic scenario". He continues, "There needs to be a lead agency in charge. There is no uniform agreement on who should be, when, and the perfect communication channels for the most cost effective and timely response. This was very much evident during the well reported Katrina debacle in the United States especially as demonstrated by New Orleans, and reportedly during the Sunamee floods in far away South East Asia with catastrophic effects on both the local and the international community, as for example, affecting the Swedes who lost many of their citizens in that catastrophe. A school of thought believes that whatever agency is in charge has to have irrefutable credibility and expertise. There is a growing sense that in high-consequence disasters involving large-scale damage and population risk, the Department of Defense and U. S. military forces should *always* be the lead agency. No other government entities have equivalent experience, organizational structure or logistic capacity."

When disaster hits, it is not usually clear who should be immediately responsible and for what, who should be consulted, in what order, or how what should be done.

The new concept of defense is akin to that postulated by the Department of Homeland Security, DHS (see the Chart below extracted from their web site showing their organization and strategic goals) which advocates a seven component strategy involving awareness, prevention, protection, response, recovery, service, and organizational excellence necessary to implement the strategies. If the military accepts the challenge of providing security for the nation, it is clear that an optimal combination of strategies should be desired, hence the role of optimization methods of Operations Research. We illustrate this case study by considering decision aids for management in defense systems and assignments which are structurally different from the classic concept of war. As a typical example, consider the problem of protecting communities, regions or a nation from the deleterious effects of disasters such as floods as in Disaster Control Modeling. This could be extended to include terrorism and bioterrorism attacks on civil infrastructure and the food chain, virus or biological warfare, terrorist attacks on defenseless communities involving kidnapping and demands for ransom payments, etc.

3.12 Top U.S. Disasters as of July 8th, 2005

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The new concept of defense is akin to that postulated by the Department of Homeland Security, DHS (see the Chart from the DHS web site) which advocates a seven component strategy involving i) awareness, ii) prevention, iii) protection, iv) response, v) recovery, vi) service, and vii) organizational excellence necessary to implement the strategies. If the military accepts the challenge of providing security for the nation, it is clear that an optimal combination of strategies is desired. This again is in the province of Operations Research technology.

4.0 Mathematical Modeling of The Flood Control Problem (FCP)- a Case Study on Disaster Control Planning

Disaster control planning, can be viewed as a

Examples of Natural Disasters Worldwide and in the U.S.

major challenge in resource allocation, a central problem domain of Operations Research. In this case, one can think of it as the allocation of a precious scarce resource to two approaches (measures) with resultant impact on the disaster. Consider two such measures: **structural** and **non structural**. Structural, as the name suggests, implies the erection and construction of structures for damage abatement while non structural may consist of policies to provide similar effects. The problem boils down to how much resource to allocate to each, over a given

Top U.S. Disasters

as of 8th July, 2005

Event	Year	FEMA Funding
Northridge Earthquake (CA)	1994	$6.961 billion
Hurricane Georges (AL, FL, LA, MS, PR, VI)	1998	$2.251 billion
Hurricane Ivan (AL, FL, GA, LA, MS, NC, NJ, NY, PA, TN, WVA)	2004	$1.947 billion
Hurricane Andrew (FL, LA)	1992	$1.813 billion
Hurricane Charley (FL, SC)	2004	$1.559 billion
Hurricane Frances (FL, GA, NC, NY, OH, PA, SC)	2004	$1.425 billion
Hurricane Jeanne (DE, FL, PR, VI, VA)	2004	$1.407 billion
Tropical Storm Allison (FL, LA, MS, PA, TX)	2001	$1.387 billion
Hurricane Hugo (NC, SC, PR, VI)	1989	$1.307 billion
Midwest Floods (IL, IA, KS, MN, MO, NE, ND, SD, WI)	1993	$1.140 billion

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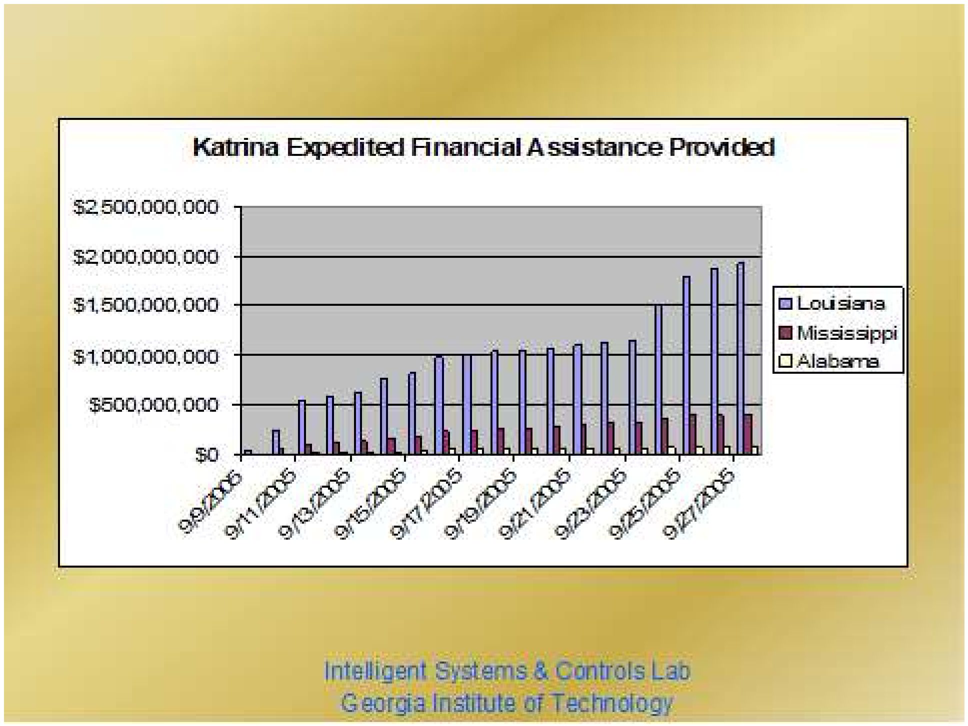
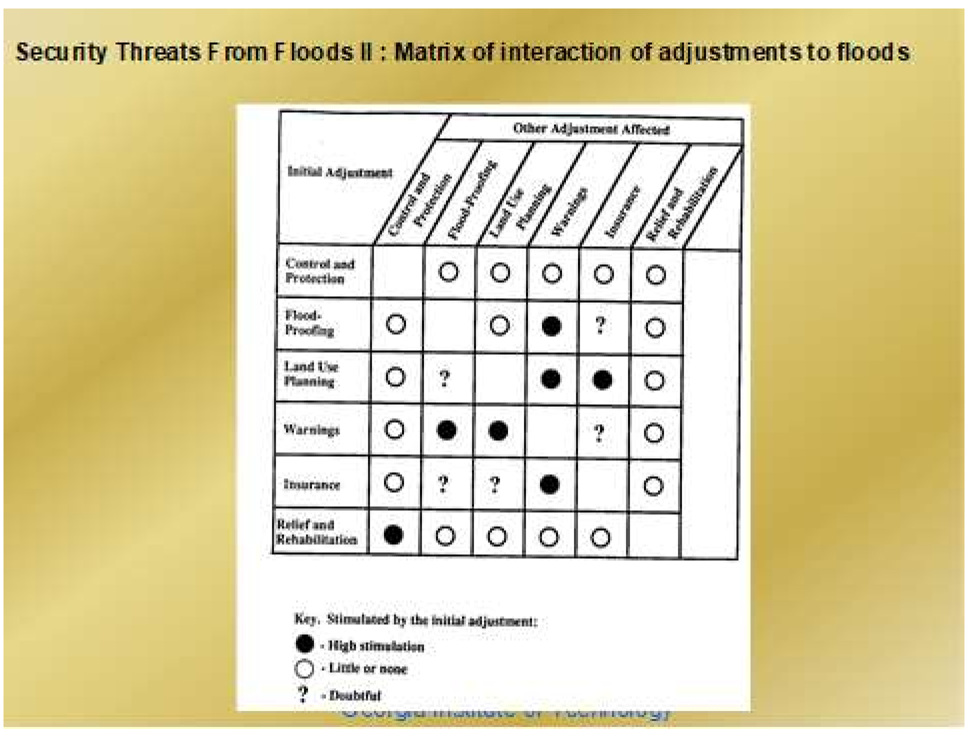
planning horizon, such that the realized benefit is maximized or disastous impact of a catastrophe is minimized. Consider the case of **Flood** and designate it as the **Flood Control Problem** (FCP).

A general mathematical statement of the (FCP) studied by a former student, turned world renowned guru, Morin et al. may be stated as follows:

Find an adroit combination (x, y) of structural (x) and non-structural (y) measures so as to:

$$\begin{aligned} &\text{maximize} && f(x, y) \qquad \text{(FCP)} \\ &\text{subject to} && (x, y) \in \Phi(x, y), \\ &&& x \in X, \\ &&& y \in Y. \end{aligned} \qquad \ldots 1$$

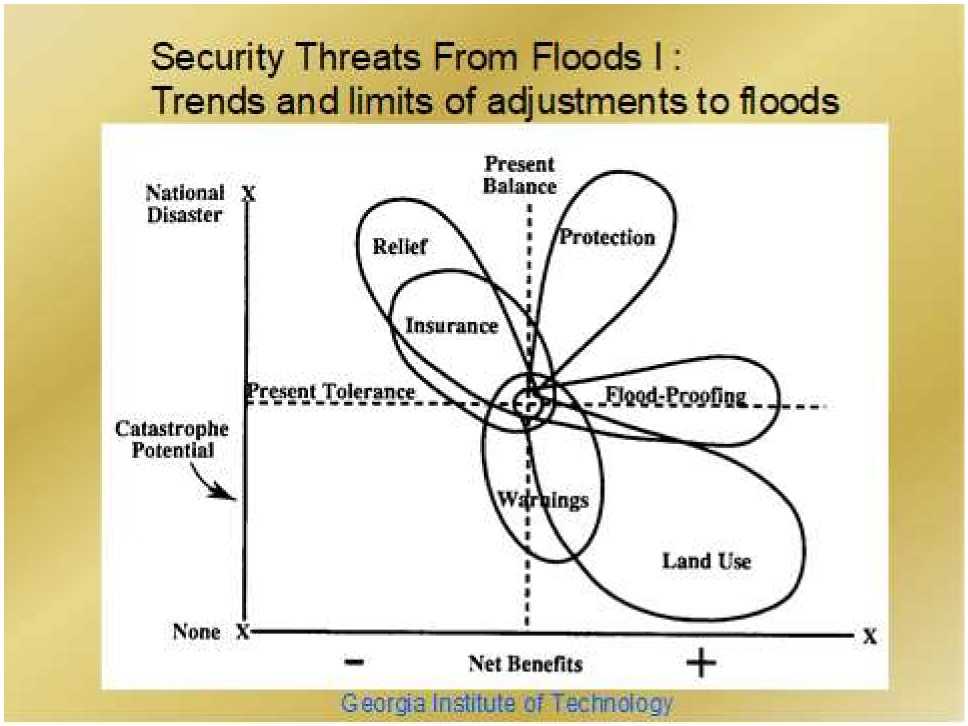




Initial Adjustment	Other Adjustment Affected: Control and Protection	Flood-Proofing	Land Use Planning	Warnings	Insurance	Relief and Rehabilitation
Control and Protection		○	○	○	○	○
Flood-Proofing	○		○	●	?	○
Land Use Planning	○	?		●	●	○
Warnings	○	●	●		?	○
Insurance	○	?	?	●		○
Relief and Rehabilitation	●	○	○	○	○	

Key. Stimulated by the initial adjustment:
● - High stimulation
○ - Little or none
? - Doubtful

In the above, the vector x = (x1, x2, . . . , xN) represents the structural measures, and the binary decision variable xj = 1, if structural measure j is selected and 0 if it is not. Similarly, the vector y = (y1, y2, . . . , YK) represents the non-structural measures. Here again, yk is the level of the k-th non-structural measure selected, f (x, y) is the objective function; e.g., the discounted net reduction in flood damages resulting from plan (x, y), Φ (x, y) is the. set of feasible plans (x, y), i.e. those satisfying the planning, financial, engineering, and social constraints, and X and Y, respectively, are the sets of feasible structural and non-structural measures.



4.1 A fuzzy approach to the flood control problem (See: Esogbue, Theologidu and Guo [1992])

One of the shortcomings of the above approach is its local nature and an inherent difficulty, computational and otherwise, to apply it on a regional or national level. For us, a more serious and compelling concern is its inability to incorporate satisfactorily and directly persistent as well as pervasive systemic variables which are intrinsically fuzzy and imprecise. In other words, Morin et al.'s approach suffers from all the well known objections to the use of crisp models to represent sociotechnical systems punctuated with the presence of social and political variables.

In view of the foregoing concern, we proposed a novel approach to the Flood Control Problem (FCP), by recourse to the tools of Fuzzy Sets and Possibility Theory. The driving force for this approach is the strong belief that in the environmental systems analysis field a substantive departure from the conventional crisp quantitative way of modeling is needed. Such an approach would provide the researcher with a more close-to-reality representation of complex or ill-defined phenomena as employed by planners. We are convinced that this should lead to more effective common sense control policies for a wide variety of practical problems.

We note that the FCP integrates engineering, economic, environmental, social, and management aspects and therefore deals with entities and relations which are often not precisely known or difficult to quantify realistically and with precision. A fuzzy approach appears to be more natural and appropriate than classical methods. In particular, the difficulty of dis-associating, crisply, the impacts (benefits) of interacting control strategies usually the case with non-structural measures is minimized by allowing the use of fuzzy and sometimes qualitative variables or descriptors.

4.2 The decomposition optimization procedure

Following our model applied to the cancer research allocation process and Saaty's analytic hierarchy process, we decomposed the problem into levels or phases for analysis. Essentially, our approach is as follows: As soon as the flood hazard areas are determined on the basis of some hydrologic and hydraulic analyses, a group of specialists such as those at the National Flood

Insurance Program (NFIP) from each Federal Emergency Management Agency (FEMA) Regional Office is appointed. This group then meets with community officials and a study contractor to discuss the places within the region that have to be studied. We call this the time and cost meeting. A set of structural and non-structural measures is proposed according to the particular geological and hydrological characteristics of the area. Thus, at this stage, the types of measures, characteristics (scale, etc.) and locations will be determined.

The procedure we propose essentially decomposes the problem into two phases complemented by a third. The first phase of the optimization procedure consists of determining the optimal sequencing and the optimal timings of combinations of structural and non-structural measures in each region in order to reduce the regional flood damages to a minimal or at least to an acceptable level within some budget limitations. A fuzzy dynamic programming-type optimization procedure is proposed for this phase as detailed in Section 6. In this phase, the stage of the dynamic programming formulation will be determined each time a new measure is included and tested (in order to be either accepted and realized or rejected) in any current combination of measures. Thus, for each region we obtain a set of the K best policies for reducing flood damages. This set of controls which now constitutes the control space for each region then becomes an input to the second phase of the optimization process.

The second optimization phase determines the optimal scheduling and sequencing of flood protection measures on a national scale. Here, each region comprises the stage of the dynamic programming formulation. The goal is to maximize a weighted average of flood damage reductions in each and every of the 10 regions that correspond to a Federal Emergency Management Agency (FEMA). The weights will be determined by National Flood Insurance Program (NFIP) specialists on the basis of emergency priorities, budget and other political considerations.

The third is basically a linkage program. It consists of a model for coordination between the input-output phases of the preceding two to produce the desired system's outputs.
Next, we illustrate the development of a generic model useful in treating the problem with focus on either the regional or national level.

4.3 Fuzzy Mathematical formulation of the flood control problem (See Esogbue, Theologidu & Guo[1992])

We now revisit and review the fuzzy mathematical model of the flood control problem which we first presented in Esogbue et al 1992 paper cited in the reference. Suppose the *system* under control is a geographical region of a country (such as the US) in which structural and non-structural measures are to be constructed so as to minimize the total amount of flood damages encountered in that region.

The region is presumed to be represented as a fuzzy system. Its state may then be equated with an index describing the level of the total flood damages that is observed or expected to be attained before and after a combination of structural and/or non-structural measures has been selected and put into use respectively. Before proceeding with the development, why is a model of the system as a fuzzy one more appropriate? Here is why.

When defining the system, imprecision may be experienced in at least two ways:
(i) First, we are not usually able to assess exactly or even probabilistically the damages in monetary terms especially when loss of human lives and of other non-materialistic factors is involved. Even when figures are provided, we must appreciate the fact that they are indeed, at best, approximate and consider how they are usually derived at the time of occurrence in the first place, not exactly from a laboratory-like environment.
(ii) Second, it is not possible to measure as well as predict precisely the utility (effects) of the structural and non-structural measures constructed. This is particularly the case with non-structural measures where no exact

mathematically defensible model exists for their measurement. We tackled this problem via fuzzy systems modeling and assessment technological tools.

Both of these two sources of fuzziness are important in determining what is to be called the state of the system; thus, the system must appropriately be considered to be fuzzy.

One could argue that a combined approach of stochastic dynamic program and Fuzzy Set Theory such as we did for reservoir operations planning studies would be closer to reality and ultimately more efficient due to the probabilistic nature of hydrological and hydraulic phenomena. However, the actual hydrological and hydraulic data would be different from the average ones and thus the results from the optimization procedure should be revised in order to lead to valid conclusions. Moreover, since the evaluation of safety and economic efficiency is considerably subjective and qualitative the regular fuzzy dynamic approach is, for practical purposes, preferable and sufficient. We have shown this to be the case first in connection with our work with medical diagnosis where the fuzzy model we developed out performed the extant computerized Bayesian based models. This was also the case in our major efforts in the area of non point source water pollution control planning.

Returning to the flood control problem modeling, the *input* (control) to the system is the decision about what mix of structural and/or non-structural measures will be used, at different times in the planning horizon and at different areas or regions of the country (USA), to mitigate flood damage effects.

The *state* variable, 'level of overall flood damages' will be defined over the fuzzy sets via linguistic variables such as : '*significant* flood damage level', '*moderate* flood damage level' or '*insignificant* flood damage level'.

The *evolution* (state transitions) of the system is governed by a set of functional equations developed in a subsequent section.

The *output* (immediate return) of the system is measured in terms of the flood damage reductions achieved. The returns are also defined over the fuzzy sets: '*significant* flood damage reductions', '*moderate* flood damage reductions', '*insignificant* flood damage reductions'. Alternatively, the output can be measured in terms of the difference between output and input states or flood damage levels before and after the application of controls. The reason for treating the returns as fuzzy variables is that the utility of any measure can only be *approximately* estimated in the real world as it is greatly dependent on future hydrological occurrences, the strategies already in place, as well as the combination of strategies under consideration. Clearly, these confounding interdependencies obviate the ability to provide crisp reliable qualitative estimates, even by a so called expert.

The *constraints* imposed on the controls concern the following:

(i) Limitations in financing.

The budgeting constraints are deterministic. The amount of money available to each state or to each of the 10 FEMA (each FEMA is responsible for a number of states) is known exactly or at least the total amount made available by the National Flood Insurance Program is known. However, the constraints applied on the controls in the DP formulation will be expressed via fuzzy set terminology.

There are two reasons justifying such a preference. The construction of a structural measure involves a fixed cost given its particular characteristics and assuming precise knowledge of future economic conditions. However, the latter is rarely the case and hence if we want to be as close to real conditions as possible we should incorporate this source of imprecision, *ab initio*, into our model. On the other hand, the actual cost and benefits involved with the non-structural measures, such as adoption of tax incentives to encourage wise use of the flood plain land, placement of warning signs in the flood plain to discourage development, installation of flood forecast and warning systems with an appropriate evacuation plan, can never be estimated accurately nor precisely, thus contributing as an additional source of imprecision (fuzziness) of information. For this reason, we define the cost of any structural and/ or non-structural combination over the fuzzy sets '*high', 'medium', 'low'* cost that may correspond to discretized financing levels. Then, the membership function values can be interpreted as the degree of willingness of the planners to invest the corresponding amount of money for the construction of a given mix of measures.

If, however, the financial constraints are.- not rigid, i.e. they are of the form: in region A, we do not want to spend more than x dollars or we are willing to spend at least y dollars for region B or the expenditure for region C should be, roughly between pre-selected bounds, then the membership function values would indicate the degree that each alternative (control action) satisfies these predetermined restrictions.

(ii) Timing preferences

It is assumed that the timing of any measure to be undertaken is independent of any other's and it is furthermore not known beforehand. It is related to the existing environmental, social, political and other considerations. A membership function with values dependent on these constraints indicates the most preferable for a measure to be put into use.

The *fuzzy goal* at each stage is concerned with the desired flood damage reductions to be attained as a result of an optimal mix of structural and non-structural flood control programs. Alternatively, it is the desirable flood damage levels as a consequence of applied controls.

As in the applied fuzzy systems literature, a fuzzy decision is the intersection or the confluence of the fuzzy constraints and the fuzzy goals while an optimal policy is a sequence of controls maximizing the membership value of the system in the fuzzy set of, significant flood damage reductions' or 'minimal flood damage levels'. The foregoing concepts and operations were first proposed in Bellman and Zadeh [1970] and amplified by Esogbue and Bellman [1984] as well as various writings of others. They were sharpened further in a review paper on theory and applications by Kacprzyk and Esogbue [1996] and Kacprzyk [1997].

4.4 Multistage control of a fuzzy system in a fuzzy environment

4.4.1 The fuzzy flood control model: Some preliminaries

The behavior of the fuzzy system is generally assumed to be governed by the following state and output equations:

(5) $x_{i+1} = f(x_i, u_i)$,

where xi, xi+1 $\in$X are fuzzy states and times *ti* and *ti+1* respectively denoting the level of flood damages before and after the control ui+1 in region i has been put into use. The function f : X x U -> X is a function from the product space of U and X to the space of the fuzzy sets in X. Fuzzy decision control systems of this genre are usually treated via fuzzy dynamic programming, branch and bound, or a combination of both approaches. The theories behind the approaches are well documented in the above referenced works and therefore are omitted here.

In the sequel, we provide models of the flood control problem viewed as fuzzy multistage decision processes or equivlently, fuzzy dynamic programming processes. The organization of the developments is as follows: We begin with the definition of symbols and notation employed in the models as well as in the flow charts that accompany them. We next present the models for the regional, national and coordination phases. For the first and second phases, we first show the core model and then provide an expanded version along with a practical algorithm for its implementation.

4.4.2 Fuzzy control model

We define the following symbols employed in the models

n: the index of region,

k: the index of flood control measure,

j: the index of flood control investment level,

i: the index of flood damage level.

At the *national* level, Phase 2, the following are used:

C(j): the membership function of constraint for the nation,
G(j): the membership function of goal for the nation,
Cn(j): the membership function of constraint for region n,
Gn(j): the membership function of goal for region n,
$\bar{J}$: the upper bound of total investment for the nation, while
Wn: the weight or criticality of region n,

In the foregoing, C(j) and G(j) are defined on the set of all of the possible investment levels for the nation. Cn(j) and Gn(j) are defined on the set of all of the possible investment levels for region n. When used in regions, the symbols have the following additional meanings:

In (i): the membership function of initial states in region n,
Fn(i): the membership function of final states in region n,
Gn(i): the membership function of goal of states in region n,
n: the upper bound of total investment for region n,
Cnk(j): the membership function of constraint for measure k in region n.
Here In(i), Fn(i) and Gn(i) are defined on the state space (all of the possible flood damage levels for region n), while Cnj(j) is defined on the decision space (all of the possible investment levels for measure k in region n).
Additionally, let:
Tn,kj(i, i): the fuzzy matrix of state transform for measure k in region n with investment level j. Here Tnkj(i, i) is an l x l matrix, where l is the dimension of the state space (all of the possible flood damage levels for region n), and represents the fuzzy relation between the membership function of states before and after measure k has been put into use at the investment level j.

The essential aspects of a very general model of a fuzzy decision system solved by branch and bound method of integer programming was first proposed by Kacprzyk. Because of the simple structure of the model, the solution algorithm involved only a single directional search down the branch of a decision tree. Our approach (Esogbue is however different as discussed in Section 9.0.

4.4.3. Core fuzzy model of flood control for regions - Phase 1

A general description of the ensuing model is that of a multi-stage decision-making process for a fuzzy system in a fuzzy environment.
The usual concepts of stage, decision, and state are defined respectively as follows:
stage = the (structural or non-structural) measure for flood control
decision = the level of investment for measure (in $), and
state = the level of flood damage (in $).
The necessary data for the model are the following:
In (i) = the membership function of initial states,
Gn(i) = the membership function of goal of states,
Cnk(i) = the membership function of constraint for measure k (k = 1, 2, . . . , K), and
Tnkj(i, i) = the fuzzy matrix of state transform for measure k with investment level j (j = 0, . . . , J; k =1, . . .K).
We may then postulate the following fuzzy mathematical model of the problem as:

$$\Phi_n = \bigvee_{j_{n1},\ldots,j_{nK}} \{[C_{n1}(j_{n1}) \wedge \cdots \wedge C_{nk}(j_{nk}) \wedge \cdots \wedge C_{nK}(j_{nK})] \wedge \bar{G}(F_n)\}$$

$$\text{s.t.} \quad F_n = T_{nKj_{nK}} * \cdots * T_{nkj_{nk}} * \cdots * T_{n1j_{n1}} * I_n$$

$$\bar{G}(F_n) = 1 - \|G_n, F_n\|.$$

In the foregoing * is the max-min product operator, Fn is the membership function of final states and ||Gn, Fn|| is a relative distance between Gn and Fn.
Solution of the above model will provide the following output data for use in the next optimization phase:
jnk*: the optimal investment level for measure k (k = 1, . . . , K) in region n, and
Φ_n: the optimal effect of flood control program for region n.

We call this the **core** model. Note that for each measure, the decision set includes a 'null' decision, i.e. investment level jnk = 0, which means measure k will not be used at all. Correspondingly, the grade of membership function of constraint Cnk(0) = 1, and the matrix of state transform Tnk0 =I (unit matrix) keeps the membership functions of states identical before and after stage k.

4.4.4 A core fuzzy model of flood control for the national level – Phase 2

The *core model* for the problem at the *national level* which we term phase 2 may be viewed as that of a multi-stage decision-making process for a *non-fuzzy* system in a *fuzzy* environment. This results in a fuzzy dynamic program. In this phase, the usual concepts of stage, decision, and state may be defined as follows:

stage = the region for flood control,
decision = the level of total investment for region (in $), and
state = the effect of flood control for region.

As before, we define the following necessary input data.

Cn(j) = the membership function of constraint for region n (n = 1, 2, . .. 10),
Gn(j) = the membership function of goal for region n (n = 1, . . . , 10), and
Wn = the weight or relative importance of region n (n = 1, . . . , 10).

The fuzzy mathematical program to be solved here may then be stated as:

$$\Phi = \bigvee_{j_1,\ldots,j_{10}} (R_1(j_1) + \cdots + R_n(j_n) + \cdots + R_{10}(j_{10}))$$

$$\text{s.t.}\quad R_n(j_n) = [G_n(j_n) \wedge C_n(j_n)] * W_n, \quad n = 1, \ldots, 10,$$

$$W_1 + \cdots + W_n + \cdots + W_{10} = 1.$$

where * is the algebraic product operator and Rn(jn) is the return function for stage n, i.e., region n.

Solution of the foregoing generates the output data jn* and Φ, with

Jn* : the optimal investment level for region n (n = 1, . . . , 10), and
Φ : the optimal weighted-sum of effect of flood control for all the ten regions in the nation.

4.4.5 Fuzzy model for coordination - Phase 3

Finally, we present a linkage program for coordinating the preceding two phases. This phase is basically a single-stage decision-making process for a non-fuzzy system in a fuzzy environment by standard fuzzy decision-making. Before presenting the model, let us additionally define the following which are essentially input data to the model.

C(j): the membership function,of constraint at the national level, and
G(j): the membership function of national flood control goal.

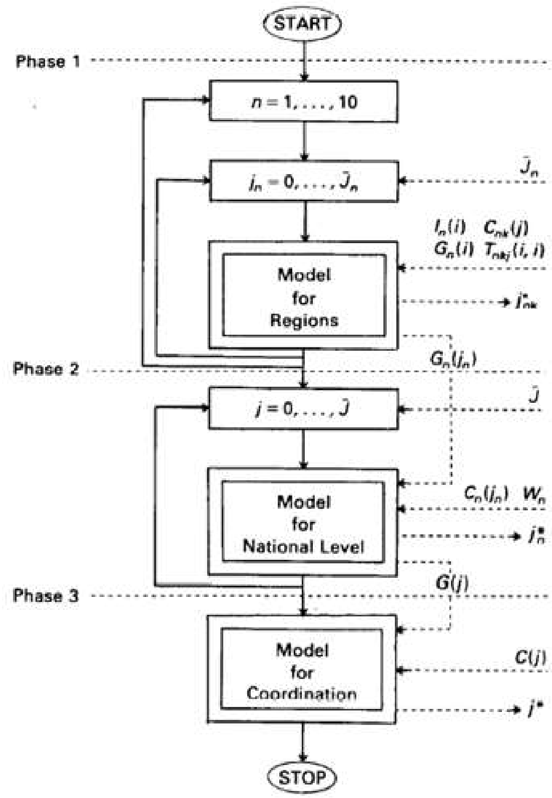


Figure 2: Flow chart and information transmission in the National Flood Control Model Programming.

The resultant mathematical program is then

$$\Phi = \bigvee_{j\in[0,J]} [G(j) \wedge C(j)]$$

Solution of this optimization problem leads to the output data

j* : the optimal investment level for flood control management for the country, and
Φ : the degree to which the optimal flood control plan satisfies the national objective.

A three step practical algorithm for Phase 3 model follows.

Step 1: Run the model for coordination of (16) to get j*.
Step 2: Using j* and the solution stored in Phase 2, find jn* for region n (n = 1, . . . , 10).
Step 3: Using jn* and the solution stored in Phase 1, find jnk* for measure k in region n (k = 1, . . .

, K; n=1,..., 10).

A schematic view of this three phase solution procedure showing the interactions and data flows is given in Figure 2.

5.0 Security: Generalizations And Extensions -A Global Phenomenon

5.1 Synthesis of Some National Security Challenges and Needs Identified for Nigeria

In our 2014 invited lecture to the 7th Forum of NNOM Laureates entitled ***A Safety Systems Technology Embedded Agenda for National Development*** and shared with various institutions of higher learning and agencies of government including the Presidency, we postulated that there is a compelling need for a major paradigm shift in Nigeria to one that recognizes and accepts Technology and specifically, safety systems engineering, as a major enabler for national development and addressing above class of problems.

There is a need for programs, academic or center based, that through research and teaching, can help the nation address its variegated **security** challenges. We should resist the temptation to simply act using standard cookbook microwave, imported tools, on-line or otherwise. We need to restore and improve security by encouraging indigenous solution methods borne out of creative research and commitment, to national problem solving. Security threats occur in many theatres. Let us outline some of them in the sequel.

In the area of **health care**, EBOLA, for example, was a debilitating epidemic or pandemic that hit Africa, mostly West Africa with Nigeria placed initially in the "No Go" country list. Considerable amount of human capital was lost. The impact on deceleration of economic development was significant. For example, one could examine if some useful lessons were learned from the EBOLA outbreak experience and the way it was successfully handled in Nigeria which present unique opportunities for Nigerian researchers and experts in evidence based policy making? The same question could be posed for lessons learned from COVID-19. Why should the vaccine for an African problem be developed by foreign countries such as Canada, the USA and not Nigeria or Liberia? Is vaccine development within Nigeria not worthy of massive and sustained investment both by the government and private sectors rather than leaving it entirely to the West with resultant capital and intellectual flight issues? When will the hitherto conventional trend be reversed?

We posed these questions as far back as 2014 and 2015 after the EBOLA experience. Apparently, while some lessons were learned, not much had changed, at least with respect to the fundamentals. For example, local vaccine production which was recommended after EBOLA was still being debated during COVID and Variants. The nation still depended on imported vaccines to respond to the quest of optimal management of the pandemic. The systems cost of these national missed opportunities is incalculable.

A total systems security imbedded development agenda which we proposed for the country in 2014 must ensure that the country's national and international food chains, transportation systems are secure, for both passengers and freight, which promotes growing a strong economy. This is more compelling in view of the fact that African countries, including Nigeria, are major importers of goods needed for industrial development. Oil production and transportation systems including vehicles should be better protected using intelligent tools and agents. Impact on national supply chains due to consequent higher shipping costs, increased inventories, border closures, increased travel times, and other changes as a direct result of heightened global security awareness especially with respect to Nigeria is estimated to be considerably higher. To show that Nigeria has been careless with respect to security of lives and infrastructure with little or no attention paid to warnings received a priori, consider the devastating bomb attack on the train from Abuja to Kaduna by terrorists on 28 March, 2022 occurring less than six months after another attack by bandits was inflicted on trains and rail infrastructure. Some passengers were killed while others were injured and/or kidnapped for ransom money. This man-made disaster was a glaring case of monumental failure by government to protect her citizens through lack of adequate security architecture. When a government supported science and technology based intervention to the myriad of socioeconomic challenges of the public is subjected to unpredictable attack vis avis a technology centric arsenal, then the government and indeed the nation are under attack. In peace or war, provoked or not, this is completely unacceptable. The target in this instance was the train, a transportation infrastructure but it could have been the airspace, waterways, and other natural resources such as the educational system or the healthcare system; the location may vary, urban centers, villages, educational or places of worship; by extension, the attack is elastic and the loss potential, total.

In summary, a variety of policies and regulations need to be put in place to help secure cargo, individuals, national assets, and physical infrastructure of global supply chains. We can call on a variety of proven OR/SA tools of programs and institutions, especially those with Military OR specialization as outlined in this paper, to come to the rescue of the nation.

5.2 How Prepared is Nigeria to Discharge her Increasing Security Responsibilities?

To be sure, various Nigerian functionaries are already addressing the various aspects of Nigeria's security problems some of which were enumerated earlier. The health sector is a good example. The degree to which it has been successful in addressing them is however, another matter. Vision 20:2020, for example, had a comprehensive 3 pillar driven plan to catapult the country to one of the top 20 nations of the world by year 2020. It failed to live up to that aspiration. Food Security, for example, was given special focus (see pp.29-30) of that document. For this important area of Food Security, it was "guaranteed in pillar 3 while fostering sustainable social wellbeing and productivity of the people was pillar 2." Despite modest improvements in food security, however, none of these lofty and said to be guaranteed goals were achieved nor was the prognosis for their full attainment realized.

While the federal government had a number of ongoing programs purportedly addressing food security and while some intellectuals had written variously on the topic as for example in Ngoddy [38], pp 14-19, there is hardly any model that integrates all aspects of the problem into a cohesive national economic plan for Nigeria using the safety systems engineering inspired model as was done for example, in Fig. 7for the Middle East [53].

The government set up an array of Councils and Commissions supposedly to address several aspects of the march towards full attainment of Vision 2020 but apparently these Councils and Commissions were characteristically so poorly funded that they were hardly functional and thus grossly ineffective. This phenomenon of (under)funding is so commonplace in Nigerian institutions that it is said to be largely responsible for their underperformance. Funding and prudent financial management problems especially in security critical organizations need to be addressed in accordance with global best management practices. We made sure, at our NASA Aerospace Safety Advisory Panel (ASAP) deliberations, to have budget funding concerns imbedded in our prescriptive protocols for organizational excellence in high impact technological missions. These and similar performance delimiting concerns are discussed in journals and international conferences such as that which I and several Nigerian Military officials attended in New Delhi in 2006. Nigeria should begin to show interest in benefitting from experiences of her citizens who have been exposed to some global best management practices.

Corruption, though delimiting to the progress of most nations, is ranked high among factors inhibiting their national competitiveness. Nigeria has persistently ranked very low in various development indices (127th out of 144 in global competitiveness; 170th out of 189 in doing business report; 123rd out of 132 in social index, and 17th out of 178 in fragile state for the

2014-2015 rankings). For corruption specific indices, Nigeria's corruption perception indices (CPI) showed a steady upward climb until 2014 when it dipped about 6 places [36]. Though still the highest when compared to the MINT countries, the rankings were: Mexico 103th, Indonesia 107th, Nigeria 136th and Turkey 64th. Corruption and security ranks highest in hits in the Nigerian Press. Their links, as in the reported case of US$470 million CCTV failure in giving security protection for the Federal Capital Territory ABUJA, is the most transparent effect of corruption on national development published in the open literature. We had warned that for Nigeria to achieve the goals of Vison 20: 2020, she should show a steady decline in these rankings. This did not happen so it was not surprising that Vision 20: 2020 dreams were largely unmet.

The role of critical organizations such as Nigerian Space Research and Development Agency (NSRDA), National Emergency Management Agency (NEMA), NAFDAC, Nigerian Information Technology Development Agency (NITDA) and related IT organizations, scientific research groups such as Nigerian Academy of Science (NAS), Nigerian Academy of Engineering (NAE), and universities, working together with the military, security and Diaspora groups needs to be recognized.

For Nigeria to be reasonably ready to contain the rising tide of security challenges she faces, she should immediately address certain critical needs. Top among them is a need for key agencies and operatives to be adequately funded, both in levels and timing, for requisite take off and productivity. This calls for optimal funding and resource allocation protocols as well as accounting and accountability strategies. Funding challenges constitute security problems in their own right as shown in the 2006 International Seminar on Defense Finance and Economics, New Delhi, India as well as the entrenched safety culture at NASA.

There is also a need to immediately slam the door on all wastes and corrupt practices as well as to redirect and redistribute resources to critical national exigencies. The need to embrace the interplay of systems approach facilitated by systems engineering technologies to methodically address these interrelated pressing national problems in an orderly fashion must be equally addressed.

5.3 IE/OR-SE Imperatives for Nigerian Security Agencies

To mount a serious effort in confronting the bewildering array of escalating security challenges facing her, Nigerian security empowered organizations such as Nigerian Defense Academy (NDA), National War College, National Center for Strategic Studies, Kuru , etc must embark on capacity building in novel fields such as operations research and related tools of systems engineering particularly safety systems engineering to ensure efficiency and robustness in its programs, operations, plans and procedures and organizational excellence. Creativity and knowledge based programs must be emphasized to address national priorities. Research especially applied research capacity building is a necessary component of this knowledge development and acquisition. This extends to specialized universities such as the Federal Petroleum University of Petroleum Resources (FUPRE).

New Federal Universities especially those with military and defence sponsorships such as the Admiralty University of Nigeria (ADUN) must seriously consider programs especially Military Operations Research in their offerings. Other specific institutions in this category include NDA and similarly charged security agencies. They are encouraged to institute educational programs leading to degrees in fields such as military operations research, as is done in the U.S. with universities such as Georgia Tech and MIT in addition to security centric institutions such as West Point Academy, Air Force Academy, Naval Postgraduate School, Defense Acquisition University, Rand University.

Human capacity building relationships appropriately sculptured with premiere institutions with scientific underpinnings including engineering, computer science, information and management science, medicine should be encouraged. Examples are Nigerian Academy of Science, Nigerian Academy of Engineering, Nigerian Computer Society, National Information Technology Development Agency (NITDA), Nigerian Space Research Development Agency (NSRDA), NABDA, SHESTSCO, Nigerian universities and the frequently recommended Nigerian Science Foundation. Some presence in university campuses as well as the Abuja Technology village is advisable. New Federal Universities especially those with inbuilt association with the Military and Defence Agencies such as the Admiralty University of Nigeria (ADUN) are strong candidates for the location of Operations Research Programs with specializations in Military Operations Research. This is forward thinking.

Applied research addressing practical safety systems/security centric problems facing the nation is considered an imperative. Requisite funding should be provided for these activities. US examples worthy of emulation include: The Rand Corporation, Defense Advanced Research Projects Agency (DARPA) as funders, and Georgia Tech Research Institute (GTRI) with strong reputation for meeting the mission critical needs of the U.S. military and other federal agencies supporting defense and homeland security. GTRI proudly serves and helps to protect the nation by providing expert systems centric solutions to tough technical problems thereby creating a strategic advantage and a reliance on home bred solutions to national security challenges.

Systematic involvement of and partnerships with dedicated and experienced Nigerians as well as other Africans in the Diaspora in these pursuits is considered not only visionary but necessary. A major government deficit however, is inability and/or unwillingness to systematically cultivate this relationship.

Capacity building in IT, logistics, including e-logistics, intelligent systems, and the new ubiquitous systems technology and RFID systems will ensure currency. Up to date facilities and research environment should be designed and maintained as the aforementioned organizations move into their new facilities.

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