Implementation Rationality: The Nexus of Psychology and Economics at the RAND Logistics Systems Laboratory, 1956-1966s

by

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CHOPE Working Paper No. 2015-09

September 2015

Center for the History of Political Economy at Duke University

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Version 3

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Abstract

In October 1956, the RAND Corporation established the Logistics Systems Laboratory (LSL) with the goal of using simulation to translate the broad findings of normative microeconomics into detailed, implementable procedures for US Air Force operations. The laboratory was housed in the training simulation facilities that had been recently vacated by psychologists working at the RAND Systems Research Laboratory. Economists at the LSL, interwove their marginal cost-benefit analysis with the psychologists' focus on process, adaptation, and group behavior. Over the course of a decade, economists and psychologists at the RAND Logistics Systems Laboratory conducted game simulations structured by the four separate laboratory problems. Economists went from using simulation to demonstrate the superiority of optimal policies derived from deductive economics to using the experiment as an inductive tool. One of the concerns in this historical case study is with how economics leveraged psychology to grow a regulatory system when individual units pursuing their own interests did not promote effectually the interests of society. This dilemma was one of a few stimuli generating a new focal point for rationality, that of efficient implementation. More recently, economists on the BIS Basel Committee on Banking Supervision were engaging in implementation rationality through simulation in the form of the Regulatory Consistency Assessment Programme (RCAP). The examination of iterative modeling and solving for rules of action at the LSL and in the RCAP suggest that the explicit narrowing of modeling choices that bind the rationality of the individual units would be best iterated through a process that takes into account the human factor. Interactions with experimental psychologists opened a door for economists to non-standard modeling and an iterative, heuristic specification of economizing rules of action that had a greater chance of implementation.

Keywords: normative microeconomics, cost-benefit analysis, procedural rationality, implementation rationality, systems analysis, simulation, experiments, regulation, history of economics, Murray Geisler, RAND Logistics Systems Laboratory, RAND Systems Research Laboratory

JEL codes: B21, C6, C92, B4, D03, D61, G28

Acknowledgements

I am grateful for research support from The Institute for New Economic Thinking (grant number IN011-00054) and for the permission from the Institute for Operations Research and the Management Sciences to reproduce the image in figure 1. An earlier version of this paper was discussed at an April 2015 *History of Political Economy* conference on "Economizing Mind, 1870-2015: When Economics and Psychology Met . . . or Didn't". I appreciated comments from participants at that conference and an anonymous referee for the *History of Political Economy.* I welcome feedback on the current draft.

How do you translate the broad findings of normative microeconomics into detailed, implementable procedures for operations in a system? How do you get individuals or smaller organizational units who have been maximizing in their own self-interests to act together as a rational organism? How do you convince managers to forsake customary rules of thumb and implement optimal decision rules derived by economists? How do you get economists designing those optimal rules to economize on their time and thought and, if necessary, make do with less-than-perfect rules of action that are good enough? One way to approach these questions is to pair experimental psychologists with thinking-at-the-margin economists. You underwrite the costly pairing with a considerable US Air Force war chest. You give license to the blurring of observing, designing, and controlling a system. You cultivate adaptation in the modeler and the subjects of the model. For over a decade, the RAND Logistics Systems Laboratory's game-like simulations with Air Force personnel fostered these conditions.

In 1946 the US Air Force funded the Project for Research and Development (RAND) at Santa Monica California. They did so in the hope of continuing the cooperation the US military had initiated with the civilian scientific community in World War II. In the early 1950s economists at the RAND Logistics Department were doing what they called "classical" analytical studies to improve efficiency and reduce costs of Air Force logistics system functions. Miliary logistics involves procuring, maintaining, and distributing people, parts, and mechanisms of warfare. Most of the early RAND studies drew on normative microeconomics, including working on probability distributions for demand for parts, quantifying marginal costs and marginal military worth, and deriving optimal decision rules. This was an exemplary demonstration of Thomas Schelling's assertion that during the Cold War, military think tanks hired economists to "practice the science of economizing" (Schelling 1960, 4). RAND economists and Air Force staff were often dissatisfied, however, with resistance to implementing the fruits of logistics research such as that on optimal inventory control.

Normative economics focuses on what ought to be. It is usually only framed in an indicative mood –the analysis only *indicates* the best choice outcome. Rarely does prescriptive economics follow through in an imperative mood to articulate or control a process for achieving that outcome.[1] The resistance of Air Force personnel to implementation of optimal decision rules led RAND economists such as Murray Geisler to seek insight from RAND experimental psychologists. In October 1956, RAND established the Logistics Systems Laboratory (LSL) to use simulation to "bridge the gap between research and implementation" (Geisler 1959, 360). At the RAND LSL, marginal analysis that focused on rational choice outcomes was interwoven with the psychologists' focus on process, adaptation, and group behavior. This nexus generated persuasive evidence of the superiority of economizing protocols as wells as data-reporting and rule-based implementation systems necessary to effectively implement these protocols. Simulation also took the economists to complex problem solving realms off-limits to their mathematical equations. That journey often led to what Herbert Simon would call satisficing: the adaptation, in the face of bounded rationality, of optimal to good-enough decision rules.[2]

Simon's military-funded work on bounded rationality had eventually led him to distinguish between "substantive rationality" and "procedural rationality."[3] In Simon's

[1] The contrast of moods is drawn from Norbert Wiener's use of the terms. In clarifying his concept of cybernetics in control engineering Norbert Wiener (1953) argued that outgoing messages could be in the indicative mood with the aim of exploring the universe or in the imperative mood with the intention of controlling the universe.

[2]Simon, channeling Voltaire described the dilemma with "the best is the enemy of the good" or "optimizing is the enemy of satisficing" (Simon 2000, 26). Although Simon was the one to name and leverage the concepts of satisficing, bounded rationality, and procedural rationality, it was all around him in want-to-be-optimizing economists working for a military client who required rules of action amenable to computation and implementation.

[3] See for example, Simon, 1973, 1974, and 1976. In his 1964 essay on "Rationality" Simon contrasted two types of rationality, the economist's "attribute of an action selected by a choice process" and the psychologist's

framework substantive rationality was the achievement of the best outcome given an optimizing goal. Examples include the rational consumer achieving maximum utility or the rational producer achieving maximum profits. Procedural rationality was the process of adapting the original optimizing ends and means to take into account information gathering and processing costs, by, for example, changing the model in an effort to minimize the use of limited computational resources. Simon perceived consumers, producers, and economizing mathematical model builders as organisms with limited computational capacity. He asserted that economists should learn from psychologists as well as from their own discipline's experience with normative operations research and focus more on the process of how decisions are made.

This history of the RAND Logistics Systems Laboratory introduces the concept of *implementation rationality*, characterized by the attempt to maximize the speed and/or scope of implementation of optimal decision rules. The rationalization of the implementation process includes observing inconsistencies in and resistances to the attempted application of optimal theory, feeding back critical observations to the individuals and system designers, training the users to be more system-rational, and tweaking the rules of behavior that could discipline the individuals to be more system-rational.

This case study of the attempted mapping from the optimal to the operational illustrates the advantages of economists focusing on a process of iterative modeling that includes human interactions. This history is also a thorny take on the microfoundations of a macro approach. One of the concerns in this historical case study is with how economics leveraged psychology to grow a regulatory system when individual units pursuing their own interests did not promote

"processes of choice that employ the intellectual faculty" (Simon 1964, 574). It was not until 1973, however, that Simon explicitly used the phrases "substantial rationality" and "procedural rationality". After that, he used the terms frequently in economic articles (see for example Simon 1978a, 1978b, 1979).

effectually the interests of society. This dilemma was one of a few stimuli generating a new focal point for rationality, that of efficient implementation. As with procedural rationality, this new focus prompted modeled optimization at the level of outcomes to evolve through an adaptive process. This in turn can lead to optimization at the level of the individual being purposely bounded in order to give priority to a best or good enough outcome for the system.

This history of the RAND Logistics Systems Laboratory starts with Murray Geisler's work on optimization with George Dantzig in the Air Force Project for the Scientific Computation of Optimum Programs (Project SCOOP) in the late 1940s. The narrative proceeds to his use of classical economics at the RAND Logistics Department in the early 1950s. As Geisler was applying cost-benefit analysis, the RAND experimental psychologists were starting to use man-machine simulations at the Systems Research Laboratory (SRL). Beginning in 1956, psychologists from the SRL and economists from the Logistics Department joined forces to work on several major Air Force optimization problems at the RAND LSL.

Project SCOOP

Murray Geisler started off his career in military research by doing simulations with mathematical equation structures. Armed with a master's degree in economics and statistics from Columbia University, Geisler joined the Air Force Project SCOOP at the US Pentagon in Washington DC in February 1948. In his directive to all echelons of the Air Force, General Hoyt Vandenberg, gave a general indication of the Project SCOOP method envisioned to design military programs. Programming in this context meant planning rules of contingent action and resource allocation to support that action:

> The basic principle of SCOOP is the simulation of Air Force operations by large sets of simultaneous equations. These systems of equations are designated as

> “mathematical models” of operations. To develop these models it will be necessary to determine in advance the structure of the relationships between each activity and every other activity. It will also be necessary to specify quantitatively the coefficients which enter into all of these relationships. (Vandenberg 1948, 1)

Project SCOOP was engaged in mechanizing the planning of USAF operations using the latest computer technology. In the late 1940s and first few years of 1950, a triumvirate guided the project: George Dantzig, Chief Mathematician; Marshall Wood, Chief Economist and Head of the Planning Research Division; and Murray Geisler, the Head of the Division’s Standard Evaluation Branch. Dantzig was instrumental in developing the linear programming framework consisting of an optimizing objective function maximizing gain or minimizing pain, a Leontief-inspired input-output model indicating technological relationships, resource constraints in the form of linear inequalities, and the simplex algorithm that leveraged the constraints to get convergence to an optimal solution. The Project SCOOP team and its allies in the Air Force had great hopes that with electronic digital computers a near full-mechanization of operational planning could be achieved through computing optimal decision rules derived from linear programming.

Project SCOOP’s first major mathematical simulation of a military operation was that of Operation Vittles, the US contribution to the airlift to aid allied occuping troops and German civilians in the western sectors of Berlin during the Soviet blockade from June 23, 1948 to May 12, 1949.[4] The planning team used a model that included an objective function maximizing the tonnage of coal and vittles delivered to Berlin, subject to the resource constraints related to aircraft, trained crews, airfield runways and budgets. The hope was that linear programming

[4] The history of Project SCOOP and details of their programming of Operation Vittles is documented in the chapter on the bounded rationality of Cold War operations research in Erickson, Klein, et al. 2013, 51-80.

could lead to decision rules that acknowledged tradeoffs such as the fact that the opportunity cost of delivering more food today was forgoing the delivery of equipment to construct more runways that would have led to a higher food delivery rate three months in the future. The US Air Force's electromechanical punched card calculators, however, could not effectively solve the multiplications connected with the large input-output rectangular matrix of the linear programming model of Operation Vittles.

Digital computers to solve large USAF linear programs would not be available until the installation of a UNIVAC computer in 1952. Even a UNIVAC, however, could not do the matrix procedures on the scale that Project SCOOP had envisioned for the programming of Air Force mobilizations with a planned input-output matrix of the entire US wartime or peacetime economy. Given limited computational resources, the SCOOP team programmed Operation Vittles and other larger military operations using a suboptimal triangular model that encompassed smaller optimizing rectangular matrices that could be computed.

Although the triangular model turned out to be a satisfactory procedural solution to limited computational resources, Project SCOOP was unable to fully combat resistance to the implementation of integrated planning, centralized control of information flows, and decision rules as suggested by optimizing economists and mathematicians. Reflecting on Project SCOOP, Geisler remarked that, "We learned a lot about the difficulties of introducing a new system and learned how far people might go to avoid change. We also learned how close the researchers had to be to the implementation process to be sure the technical procedure was being followed" (1986, 11). In his next career move to RAND, Geisler would confront the issue of resistance to implementation head on.

The RAND Logistics Department

James Huston (1966) and other military historians have described logistics as “military economics” or “the economics of warfare.” A key dilemma facing US military logistics during the Cold War was to be ready for a potentially catastrophic Soviet nuclear strike with little advance notice. Such a strike had to be prevented with a credible threat of a swift and bold contingent counter strike. These needs for readiness and for prepared, overwhelming force were countered by the need to cut defense budgets to ameliorate pent-up post-war demand for a private, peacetime economy to flourish. In this context, logistics resource allocation became one of the three key branches of military-inspired mathematical decision theory along with strategy and tactics. In 1953, the RAND Corporation established a logistics research program at the request of the US Air Force. Appropriately, it was housed in the Economics Division and staffed mainly by economists.

Murray Geisler left Project SCOOP and joined the newly-formed RAND Logistics Department in February 1954. His traditional economic approach to research on cost-effectiveness is best illustrated by his work with other RAND economists on “flyaway kits” for the bombers in the Strategic Air Command (SAC). These were war-readiness kits of spare parts that would in the event of expected combat have to be flown to bases overseas. The mathematical decision problem was to design these kits to minimize stockouts of parts likely to ground the bomber, subject to a given kit weight. The team of economists working on this problem determined empirically that a Poisson probability distribution was a good fit for modeling demand for the high priced spare parts (see for example Brown and Geisler 1954). This enabled the research team to compute the “marginal protection” of each additional unit of a line item part per one pound weight. They then sorted the calculated marginal protections from highest to lowest value. At each rank in the descending marginal protection list calculated the cumulative weight of that extra addition and all the higher ranked items. The weight constraint then determined where the cutoff was for the selection of items in the flyaway kit. Table 1 shows a hypothetical example of the selection protocol for up to five units for each of four line item parts. If the total weight constraint on the kit was 15 pounds, the preferred kit would be comprised of line item parts, with unit number, in ranks 1 through 10.

Table 1. Hypothetical example of a Marginal Protection flyaway kit.
Source (Karr, Geisler, and Brown 1955, 24).

Rank	Marginal Protection	Part and Unit	Unit Weight	Total Weight
1	2.827	D-1	0.1	0.1
2	1.264	A-1	0.5	0.6
3	.528	A-2	0.5	1.1
4	.451	D-2	0.1	1.2
5	.160	A-3	0.5	1.7
6	.142	C-1	2.0	3.7
7	.126	B-1	5.0	8.7
8	.053	B-2	5.0	13.7
9	.050	D-3	0.1	13.8
10	.038	A-4	0.5	14.3
11	.023	C-2	2.0	16.3
12	.016	B-3	5.0	21.3
13	.008	Z-5	0.5	21.8
14	.004	B-4	5.0	26.8
15	.004	D-4	0.1	26.9
16	.003	C-3	2.0	28.9
17	.002	A-6	0.5	29.4
18	.001	B-5	5.0	34.4

A major step to getting the Air Force to implement their protocol was to prove that the Marginal Protection flyaway kits were preferable to the contemporary standard recommendation for kits by the Strategic Air Command (SAC).[5] The Logistics Department had data on the frequency of stockouts of B-47 spare parts from Operation High Gear in a North African desert. That data also measured the performance of the then currently used SAC flyaway kit. Geisler, Herbert Karr and Bernice Brown compared how their Marginal Protection kit would have fared with the SAC kit. Both kits faced a 40,000 pound limit in combining 15,000 spare parts for 78 B-47 bombers. According to their calculations, the Marginal Protection Kit would have reduced the number of unsatisfied demands from 42% to 27% (Karr, Geisler, and Brown 1955, iv). The Logistics Department generalized and codified their protocol for designing military supply tables for spare parts based on marginal analysis suggested by the economists (see for example, Geisler and Karr 1956).[6]

The Air Force formally adopted the protocol for designing Marginal Protection flyaway kits and incorporated it into their *Supply Manual*. In practice, however, there appeared to Geisler little operational use of their protocol.[7] In "Reflections on Some Experience with Implementing Logistics Research," Geisler (1965, 2) acknowledged that Project RAND's relationship with the US Air Force "places some responsibility on us to make it work, particularly from the Air Force

[5] The type of prove the US military usually needed before implementing a new protocol was not that it was optimal, but that it was preferable to the status quo, and the proof of preferable had to be rigorously persuasive. During World War II Abraham Wald and his colleagues at the Columbia Statistical Research group used a lot of manpower to prove sequential analysis was superior to the then currently used sampling plan for testing and inspecting ordnance. It was not until after the war in 1948 that Wald and Jacob Wolfowitz proved that compared with all tests of identical power for deciding between two alternative hypotheses, the sequential probability ratio test minimized sample size (see Klein 2000, unpublished).

[6] Other economists practicing normative optimization have gone to similar lengths to translate results into implementable optimal actions. For example, during World War II, Milton Friedman, George Stigler, and Allen Wallis constructed nomograms so that Navy personnel could construct accessible graphs to implement Abraham Wald's sequential analysis (Klein 2000). In another case, in order to disseminate his findings from experiments with empirical production functions at the Iowa Agricultural Experiment Station Earl Heady (1957) constructed a template for a "pork costulator" disc for farmers to determine the least-cost corn/soybean meal mix for different hog weights.

[7] Geisler thought that one of the reasons the Marginal Protection protocols were not widely implemented was that weight became less of crucial issue soon after the protocols was published. One could speculate that another reason was that although marginal benefit/marginal cost comparisons were the kernel of their protocol, the team never explained the economists' use of the expression "marginal" in their reports to the Air Force, leaving the non-initiated to think that the adjective was synonymous with "not important."

point of view. We have to help the Air Force to make use of our results." In that essay, Geisler dwelled on the problem of "effecting implementation in the logistics system of the US Air Force," and he acknowledged, "the implementation decision itself has generated its own 'cost-effectiveness' analysis" (Geisler 1965, 3, 5).

The logistics department also encountered resistance to implementation of economizing inventory control policies. The value of these optimal policies had been demonstrated in computer simulations comparing the costs of alternative air base stocking and requisitioning policies (Peterson and Geisler 1955). The computer simulation of supply operations at a typical Air Force base introduced a flexible restocking policy sensitive to demand and price and based on a classical microeconomic comparison of the stockage costs with the alternative of resupplying on demand. One of the several conclusions was that the "it is more economical to have items costing under $10 requisitioned from the depot every three or six months, rather than every month, even if obsolescence charges on base stocks are as high as 50 per cent per year" (Petersen and Geisler 1955, 69). Implementation of the "economical" policies revealed by all-computer simulations, however, was slow in coming. As Geisler and his colleagues later reflected,

> Our experience in trying to secure Air Force acceptance of policy findings resulting from all-computer simulations led almost naturally to the development of the game-simulation technique as a potential means of providing the additional support and detail needed by the Air Force for implementing such policy recommendations. (Geisler, Haythorn, and Steger 1962, 20)

The game-simulation technique referred to was that adapted from the successful, psychology-led training simulations at the Systems Research Laboratory. It therefore relied heavily on the human factor and was focused on information processing. In 1956, the RAND Logistic Department began using the expertise and simulation techniques of the RAND experimental psychologists. As Murray Geisler noted after several years of game simulations, "putting people into the simulation helps to ensure the completeness, compatibility and workability of the model being constructed. People thus provide quality control, feedback, and learning qualities which are most helpful and economically desirable in dealing with very large and complex models" (Geisler 1960, 1).

Systems Research Laboratory, 1951-1956

If the US military was engaging economists to practice the art of economizing through optimization leading to quantifiable rules of action, what was it employing the psychologists to do? Essays in *Psychology in the World Emergency* (Flanagan, Filmore, et al. 1952) indicate psychologists were examining psychological warfare, testing and matching personnel through classification and selection, training individuals and teams, and studying human capabilities. A 1989 review essay on "Psychology and the Military" described the strong two way relationship that had begun in World War I and continued through the Cold War:

> Perhaps no other institution has been as inextricably linked with the growth and development of psychology as the military. This symbiotic relationship, born of the expediency of World War I, rests on two roles: (a) the military as a test-bed or applied laboratory for the examination of psychological processes, and (b) the military as an impetus to initiate and direct research and innovation in psychology. (Driskell and Olmstead 1989, 43)

In 1916 the percentage of American Psychological Association (APA) members in academia was 75%. By the 1980s, only 34% of psychologists with PhDs were in academic positions. James Driskell and Beckett Olmstead (1989, 53) attribute this to the growth in applied psychology stimulated by the success of psychological contributions in World War II. In 1946, the APA created a Division of Military Psychology to facilitate discussion among the hundreds of psychologists doing military research after the war. John L Kennedy was one of those psychologists channeling his interests in human engineering into military research. At the end of World War II he worked for the Special Devices Center of the Office of Naval Research to construct a model of an alertness indicator that would sound off an alarm if the frequency of a drowsy sailor's alpha brain rhythm slowed below 10 cycles per second (recounted in Kennedy 1953). By 1950, Kennedy was a senior social scientist at the RAND Corporation evaluating, among other things, the research on extra-sensory perception (ESP) including telepathy, clairvoyance, and precognition (Kennedy 1952).

In August 1950 Kennedy proposed a study of how groups of Air Force personnel behave under the stress of a possible intrusion of Soviet bombers into US air space. Kennedy was also interested in how they learn to improve their performance in response to stress. RAND accepted the proposal and Kennedy began planning a man-machine simulation of an Air Force system with two more experimental psychologists, William Biel and Robert Chapman, as well as a mathematician, Allen Newell.[8] In 1951, the four researchers set up the Systems Research Laboratory in a room behind a Santa Monica billiard hall and brought in a few more psychologists and coders. In their first RAND research memorandum in January 1952, the design team explained, "(t)he Systems Research Laboratory will be studying particular kinds of models

[8] The early history of the Systems Research Laboratory is discussed in Chapman and Kennedy 1955; Chapman, Kennedy, et al. 1959; Baum 1981; Ware 2008, 94-98. In *Von Neumman, Morganstern, and the Creation of Game Theory,* Robert Leonard (2010), examines the relationship between the SRL and the rest of the RAND mathematics department and stresses Kennedy's point that the limits of game theory and mathematical modeling made empirical research through simulation a necessity.

– models made of metal, flesh and blood. Many of the messy and illusive variables of human and hardware interactions will be put into the laboratory" (Chapman, Biel, et al. 1952, 1).

It was the presence of these regular interactions and the interdependence of the components of the model that made it imperative that the experimental psychologists study the whole system, or organism as they often called it, rather than seeing the whole as a mere aggregation of individuals.[9] It was the performance of the whole, not that of the individuals, which would be monitored and human learning capacity would not be "realized without explicit identification of their dominant motivation with system purpose and reinforcement of proper response with system success" (Chapman, Biel, et al. 1952, 11). Their research program consisted of "(g)etting the model to the laboratory, training the organism, and experimentation" (Chapman, Biel, et al. 1952, 11). The psychologists' organism/system approach would eventually become a key input in the future collaboration with economists at the logistics laboratory.

What was measured in this modeling of and experimentation on a system was the speed and accuracy of information processing, which the SRL team asserted was a more general class of behavior than decision making. The information processing center that they chose to specifically model in the laboratory was an Air Defense Direction Center (ADDC or ADC for Air Defense Center). After the first successful Soviet test of an atomic bomb on August 29, 1949, the USAF had installed over 100 ADDCs spread over the country to identify and track foreign intrusion into US air space. Effective human interactions with machines at these sites,

[9] They explained their "organism concept" with this definition: "An organism is a highly complex structure with parts so integrated that their relation to one another is governed by their relation to the whole" (Chapman, Biel, et. al 1952, 10). Ironically the artificially constructed system was invested with the biological analogy of the organism. The system's communication channels served as the neurological analogy of nerve networks. The human elements were treated as abstract atoms: "The Information Processing center has a number of human operators. There is division of labor among these humans and a command structure or hierarchy as well" (Chapman, Biel, et. al. 1952, 3).

including radar monitors, computers, and red telephones, were crucial to the defense of the US. For the experimenters the centers had the advantage that the typical behavior of the group was observable because most of the ADC responses to stimuli were verbal. Also the achievements, such as the percent of air traffic correctly identified and effectively tracked by the crew, were easily measured.

The physical life-size model installed in the lab was a replica of the Tacoma air defense radar station. Printouts of symbols every 30 seconds from an IBM electronic card-programmed calculator simulated the airplane tracks that would have appeared on a radar screen. Over the course of two and a half years the SRL ran the four air-defense experiments listed in Table 2.

Table 2 The four man-machine simulations of the RAND Systems Research Laboratory

Name of Experiment	**Dates**	**Temporal Structure**
Casey	February-May 1952	54 4-hour sessions
Cowboy	January 1953	22 8-hour sessions
Cobra	February 1954	22 8-hour sessions
Cogwheel	June 1954	14 4-hour sessions

A key laboratory concept was that of "'growing' human organizations under a set of realistic but controlled or controllable conditions" (Simon 1952, Preface). The research team's working hypothesis was that performance in information processing could be improved at a greater rate and to a higher standard if the learning was done at the group level rather than training individuals separately. The human subjects in the first Casey experiment were 28 University of California Los Angeles students who had never worked in an Air Defense Direction Center. In subsequent experiments the subjects were 33-40 ADDC personnel who had not worked together before. The task load for the Casey students was comparable to peacetime air traffic and the experimenters only gradually and slightly increased the task load in the course of the simulations. The team soon "learned its way right out of the experiment"; in that respect the experiment was a failure (Chapman, Kennedy, et al. 1959, 260). The college students were able to quickly reach the performance of professionals in the field and started to lose interest in the experiment.

The SRL had begun as a study of how groups behaved under stress of a realistic emergency situation, but in the course of that first experiment the striking result was how quickly a group could learn to act effectively if the team had a daily debriefing with a report on the discrepancy between actual and desired performance and a forum for airing problems. By harnessing the learning ability of the team, the designers had enabled the group to adapt to the most efficient use of resources and to grow as an organization.

When the research team was digesting the results of the Casey experiment in the summer of 1952, they brought in Herbert Simon, a consultant with the RAND Mathematics Division, as an expert on organization theory. Simon's first encounter with Allen Newell and with experimental psychologists using simulation to look at an adaptive problem-solving process would be a defining step in his research trajectory.[10] The SRL team also benefitted from that encounter and Simon returned to the laboratory in subsequent summers.[11] In his first report for the SRL, Simon defined a program as "the rules that guide the behavior of the subjects in choice

[10] Hunter Crowther-Heyck discusses three salient gains for Simon from his interaction with the RAND SRL: the initiation of his long-lasting friendship and professional collaboration Allen Newell, Simon's exposure to cutting edge computers ("his 'secret weapon' in his psychological research"), and his insights on artificial intelligence from simulation experiments with humans and computers humans processing symbols (Crowther-Heyck, 205). Willis Ware (2008, 138-140) documents Simon, Newell and Clifford Shaw's artificial intelligence research at RAND.

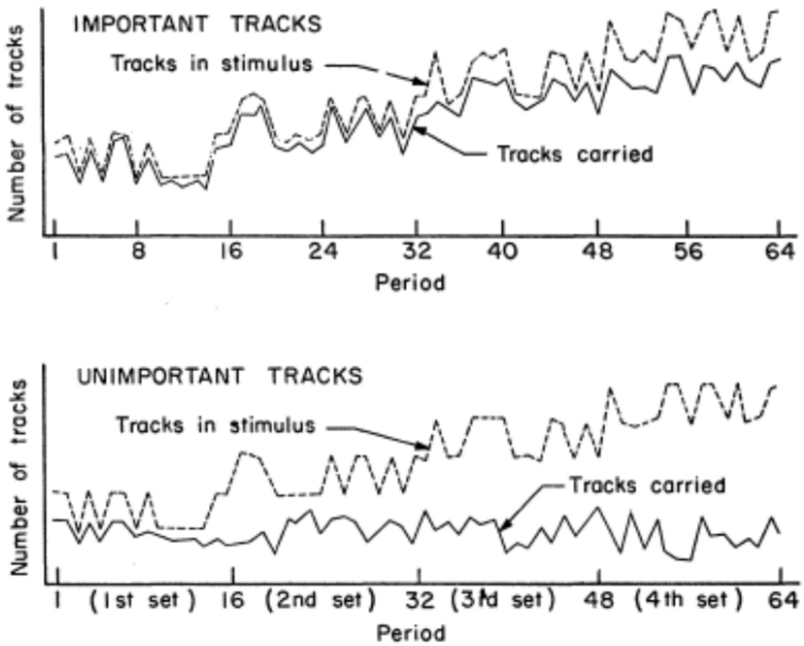
[11] From 1952 to 1954, the social psychologist Robert Freed Bales was also a consultant at the SRL. Bales's connection of his earlier work on abstracted "situations" to the simulated communication and control system as well as his perception of the ADDC as a symbol aggregating and transforming process leading to a decision is discussed in Erickson, Klein, et al., 2013, 125-12.

situations" (Simon 1952, 8).[12] He suggested the experimenters write out the programs in functional forms that would lead to new functional categories. Simon noted that as the task load was increased for the Casey group, the subjects realized the inadequacies of their program and adapted it. Simon honed in on a key way in which they learned and adapted by establishing priorities for reporting air tracks. Simon suggested that for data analysis purposes the experimenters should distinguish the success rate on the important radar tracks from the success rate on the unimportant tracks that did not match the planes reported to the group as civilian aircraft with clearance from the Civil Aeronautics Administration's traffic controllers. As can be seen in Figure 1, in subsequent experiments the key characteristic of group learning as the task load increased was learning how to distinguish important radar tracks and unimportant tracks and give priority to the former. In the experiments that evolving prioritized focus laid the conditions for major increases in the success rate for "carrying" the important tracks.

Simon also said that in the laboratory's data analysis, they should, "maintain a distinction between propositions about optimal programs, propositions about the ways in which programs evolve, and propositions about the ways in which the experimenters can influence the evolution of programs and the program that is reached in equilibrium" (Simon1952, 31). In the 1970s, Simon would come to perceive the first distinction about optimal outcomes as being associated with substantive rationality and the second with procedural rationality. The third I would argue is associated with implementation rationality.

[12] Simon's definition captures the military' use of the word "program" in the 1940s and early 1950's to mean program of action for military operations. If you substitute the word "computer" for "subject", the definition also captures the current computer science usage of "programming", what the military in the early 50s would have call coding.

Figure 1. Source: Chapman, Kennedy, et al. 1959, 265.



At first the crew responded to nearly all of the tracks in the task environment, as the uppermost graph indicates; it soon learned, however, that effective air defense could be achieved while attending to only a portion of the tracks. The lower two graphs indicate how this was done: differential treatment was accorded important and unimportant tracks.

Kennedy's idea for a man-machine simulation laboratory had started as a study on stress and learning in groups. It culminated in a very successful, fully incorporated training program for the Air Defense Command. In their 1959 reflective essay on the SRL, Chapman, Kennedy, Newell, and Biel (1959, 268) asserted that at the very least simulation was a technique "for building organization potential artificially when the price of failure in the real world while learning is prohibitive." The researchers did end up with a conclusion on stress: the stresses of failure and discomfort "guided the direction center's learning." They also drew several conclusions about learning. The most important thing learned was "to distinguish between information useful for task accomplishment and that which was not. Crews focused their attention on important classes of tracks at the expense of unimportant classes" (Chapman, Kennedy et al. 1959, 268). Why they learned that was down to "practice, under realistic conditions, and knowledge of results" (Chapman 1958, 72).

Over the course of five years of laboratory simulations, the researchers had experienced their own group learning process. They developed into an effective organization that could manufacture and promote a lucrative "System Training Program". The SRL had channeled the capacity of man-machine simulation to grow groups that made system-rational choices. Their own organization grew rapidly after it codified the training program. In August 1954, the USAF and the SRL tried out the training program at the Boron California Air Defense Direction Center. Two months later, the Air Force asked the RAND group to install the System Training Program at all 150 radar sites. By 1957, the System Training Program employed 500 people including 200 psychologists. In October 1956, the newly-named System Development Division joined forces with the MIT Lincoln laboratory to work on software for the SAGE (Semi-Automatic Ground Environment) systems of computers for Air Force defense. Within a month the Systems Development Corporation was an autonomous, fully incorporated enterprise that became one of the leading software contractors and employers of programmers and psychologists in the nation.[13] William Biel became a corporate officer at the SDC, but John L. Kennedy left for Princeton University to serve as chair of the psychology department, and Allen Newell went to the Carnegie Institute of Technology to collaborate and complete his Ph.D. with Herbert Simon. Kennedy, Newell, and Simon continued to serve as occasional consultants to RAND. When the SDC abandoned their RAND simulation laboratory, the RAND Logistics System Laboratory

[13] These landmarks are documented Claude Baum" *The System Builders: The Story of SD*C and Martin Campbell-Kelly's *From Airline Reservation to Sonic the Hedgehog: A History of the Software Industry*. T. C. Rowan (1958) described the System Training program for both the manual air defense system and the planned SAGE system. A 1956 *Business Week* article, "At RAND: Massed Brains to Meet Air Threat," also gave insight into simulation details at the Systems Development Division and the burgeoning interactions between training and computer programmers on the SAGE system. In a "psychology in action" section of *The American Psychologist* Goodwin (1957) discussed system training at the newly incorporated SDC.

moved in (see Figure 2). In addition to the facilities, the LSL inherited several psychologists, including William Haythorn, laboratory staff, and the simulation conceptual framework from the SRL.

Figure 2. Photograph of RAND Simulation Research Laboratory facilities that the RAND Logistics Systems Laboratory took over in October 1956. The undated photograph of the SRL shows the air surveillance crew of an ADC on the ground floor, the weapons direction personnel on the second floor. The psychologists and other SRL and USAF staff are monitoring the simulation on the third floor.
Source: Baum 1981

Logistics Systems Laboratory

The researchers at the newly-formed RAND Logistics Systems Laboratory (LSL) classified their approach to simulation as a "game simulation" in contrast with the SRL's training simulations. Both were man-machine simulations that involved the processing of symbols rather than of physical goods, but the SDC training simulations had focused only on improving human performance while keeping the rest of the system elements fixed. For the logistics researchers varying the other elements was the focus of the simulation. The human factor was added to the logistics simulations in order to augment the complexity that would facilitate detailed operational rules of action. The addition of Air Force personnel in a simulation experiment also ensured exposure to an economic way of thinking, and enhanced post-experience persuasion and implementation.

Over the course of a decade, the RAND Logistics Systems Laboratory conducted game simulations structured by the four separate laboratory problems (LPs) listed in Table 2. Each iterative man-machine simulation experiment took two years and cost well over a million dollars (over $8 million in 2015$). Each LP employed over 100 staff members, including 25 professional economists, psychologists, mathematicians, and logistics experts from the USAF.

There were four teams of 25 Air Force participants who were used for a month at a time in successive experiments of each laboratory problem. The primary machine in the first couple of man-machine simulations was an electronic IBM 702 to which punch cards had to be driven several blocks from the laboratory. The usual pattern for each laboratory problem was eight to nine months of designing, modeling and creating the mock-up, followed by four months of actual simulation, and three to four months analyzing and reporting on the results. .

The evolution of economists' valuation of the function of simulation experiments is evident in the history of the four laboratory problems. Economists went from using the simulation to demonstrate the superiority of optimal policies derived from deductive economics to using the experiment as an inductive tool. As the experiments progressed, economists realized that simulation that incorporated information processing and problem-solving revealed optimal or good-enough decision rules in a way that existing mathematical and computational tools could not. In a briefing to the Advanced Logistics Course of the Air Force Institute of Technology soon

Table 2 Comparison of Laboratory Problems. All of the rows but the last two are reproduced from Geisler, Haythorn, and Steger 1962, 5. ADC- Air Defense Command; AFLC- Air Force Logistics Command; AMA- Air Material Area; AMC- Air Material Command; SAC- Strategic Air Command; TAC-Tactical Air Command

Characteristic	LP-I	LP-II	LP-III	LP-IV
Primary Purpose	Pre-Service Test	Developmental	Pre-Service test	Developmental
Major policies	Supply and information system	Operations maintenance interactions	Degree of support centralization & integration	Maintenance management & maintenance information system
Simulated organizations	ADC bases & AMA's with data processing center	Titan-Atlas Missile Squadron and Wing	AMA, with missile bases sketched in	SAC multi-weapon base
Stresses	Operations	Operations, reliability & resources	Program. Repair capacity & system responsiveness	Operations & responsiveness
Goal	Minimize budget, given operational program	Maximize alert, given resources	Minimize stock-outs given program & budget	Maximize operations per support dollar, given operational program
Computer use	Great	Very little	Great	Medium to great
Participants' major role	Follow rules at base & manage an AMA	Develop management rules	Follow rules & evaluate feasibility	Develop management rules
Sources of participants	ADC, AMC & ATRC	SAC & ADC	AFLC	SAC, ADC,TAC, & AFLC
Number of participants	50	35	42	?
Number or runs	1	3	15	?
Lab Simulation Dates	Early 1957 - end of 1957	Early 1958 – late 1958	Mid 1959 – mid 1960	On and off, late 1960 - 1965
Board Game for designing LP and for post-simulation training	Monopologs	Baselogs	Misslogs	

after LP4 began, Murray Geisler described their current perspective on the purpose of game simulations,

> the study of decision rules in the context of a given organization and environment…. the definition of these tactical rules is usually only partly worked out in advance of a game-simulation. The function of the simulation itself is the further development of the rules by exposing them to a variety of situations, by determining the effects elsewhere in the organization, and by trying to discover better ways of making similar decisions. (Geisler, Haythorn, and Steger 1962, 21).

A key goal of each simulation was "to produce a reliable image of the real-world environment—so reliable, indeed, that the adaptation of proposed policies to such an environment would require the development of usable procedures, reports, and the like, in sufficient detail for ready transference to the real world" (Geisler 1959). That transference, as well as the preliminary design of the first three Laboratory Problem (LP) simulations, was aided with the RAND logistics department's construction of three board games to train military personnel in an economic way of thinking in their logistical decision making.[14]

The first of the four major experiments (LP-1) was on the optimal inventory control policies that the logistics department had explored two years earlier with their all-computer simulation. LP-1 simulated and compared two different decision-making protocols for an Air Material Command depot supplying spare parts for fighter planes and bombers at ten bases: the

[14] In 1956 , William Hamburger designed "Monopologs," a board game to simulate an Air Force supply system consisting of a depot supplying widgets to five air bases and to train depot managers through feedback on player's total costs of 31 months of decision making. Jean Rehkop Renshaw and Annette Heuston made further revisions to Monopologs in 1957 and 1960. The Logistics Department also crafted two other games to help in the preliminary design of the next two man-machine simulation problems and ease the implementation of rules of action derived from optimization research: Baselogs, to study the interactions between logistics and operations on a fighter-interceptor Air Defense Command base (Gainen, Levine and McGlothlin 1958); and Misslogs, developed to illustrate interactions among operations, supply, maintenance, and personnel in a ballistic-missile squadron. The latter was billed as an educational tool for USAF personnel, "that gives the player, who must work within a limited budget, a clear-cut view of the tradeoffs he can make to achieve maximum readiness" (Voosen 1959, 1).

current system and the one proposed by RAND economists. Each of the two logistics systems was given the same emergency stress tests as well as routine maintenance requirements. Participants followed the protocols of their respective system. The LSL compressed time with each day treated as a month and the Air Force participants made decisions at the beginning and the end of each day (month). The RAND-proposed optimized system proved the most cost effective over the "three-year" simulation yielding half the procurement expenses on high-cost parts with no additional stock-outs or planes out of commission. The economists' policies led to about the same expenditures on low costs spare parts as the then current USAF policies did, but there were less than half the stock-outs or planes out of commission. Participants, formal Air Force briefings, and the Monopologs board game spread news of the results, but RAND and the USAF also gained insight on the stumbling blocks to implementation. As Geisler (1962, 243) explained with optimal inventory control: "the implicit rationality of the policies does not always look right when they are put into use, and so amendments to them are made such that the resulting policy is something quite different." Indeed, the simulations at times resulted in recommending feasible solutions for good enough, rather than optimal, outcomes, what Herbert Simon would call "satisficing."

The LP-1 game simulation ultimately led to a far greater degree of implementation than the all-computer simulation had. This was aided by the fact that personnel from the Air Material Command served as participants in the simulation, as well as part of the laboratory staff, and frequent observers during the floor run. When they returned to their base in Sacramento, the Air Material Area personnel who had served as the laboratory staff implemented many of the RAND logistics research policies that had fared very well in the comparison with the status-quo policies. The Air Material Command ended up implementing policies that the RAND economists had derived. These included the deferred procurement and the automatic supply of low-cost items (Geisler, Haythorn, and Steger 1962, 21).

With Laboratory Problem 2, the LSL researchers switched from demonstrating the effectiveness of pre-determined optimal policies to investigating and exploring alternative policies. Observers to the LP-1 run had included staffs from the Advanced Research and Logistics System who were working on inventory control systems for the new Thor, Atlas, and Titan missiles. They helped in providing data for LP-2, which simulated maintenance operations for a missile squadron. The AMC and the RAND researchers were in uncharted territory for developing logistics policies for the first generation missiles. For one thing, there were no existing bases to use in the modeling of a mock-up. The main purpose of LP-2 was therefore developmental with a goal to provide precise notions of significant decisions that would maximize the alert level of a missile squadron (minimize the time to launch) given resources.

The context for LP-3 was the decision facing the USAF Air Material Command (AMC) as to whether to stick with a management structure based on inventory class lines of specialization in part type no matter what the weapon or to switch to an organizational structure based on each weapon system (Haythorn 1958, 77). As with LP-1, the researchers simulated the two organizational structures with a goal of minimizing stock-outs given a fixed budget. The RAND logistics team also expected the simulations to lead to a determination of “the degree of responsiveness which seems both feasible and desirable from a cost-effectiveness standpoint” (Geisler, Haythorn, and Steger 1962, 53). Although the results indicated little difference in outcomes of the two management structures the simulation generated new, detailed economizing procedures.

The Laboratory Problem- 4 experiment was unique in that the simulation was not used to test previously determined policy rules or compare management structures, but rather to fully solve for a rational choice framework for a complex base maintenance problem. The researchers resorted to simulation because such a solution had defied analysis with existing computational resources. The specific LP-4 problem was how a primarily manual system at an air base could be designed to minimize maintenance turnaround time. Geisler alluded to the significance of this non-standard route to rational choice:

> The characteristics of analytic solutions are therefore optimality and calculability. Simulation, on the other hand, is a heuristic process in which the analyst attempts to obtain "optimal" solutions by iteration of the simulation model, but he must specify the conditions for each run by interpretation of the previous runs….Thus the choice between analysis and simulation seems to be between optimal solutions of problems fitting certain calculable forms or smaller numbers of variables versus non-optimal, but more detailed and non-standard kinds of models. (Geisler 1962, 244).

With LP-4, the simulations in the LSL facilities became more intermittent, popping up according to a need to examine a certain problem in base maintenance. For some parts of the problem the logistics researchers relied on an all-computer simulator they had developed to be used in conjunction with the LP-4 man-machine simulation. The Base Operations Maintenance simulator was used to determine, for example, what shift-manning policies maximized sorties (Geisler and Ginsberg 1965, 21). Also the LP-4 staff took the experiment to the real, real world, working at Air Force bases in Missouri and Thailand to run field tests. The field experiences in Thailand proved the most challenging because the base there was in combat mode with frequent sorties to support US engagements in Vietnam.[15] The LP-4 researchers were trying to develop base maintenance protocols to increase sorties subject to resource constraints. Even though the RAND staff had by then resorted to merely increasing, rather than maximizing, sorties they still experienced in the urgency of a combat situation a far greater resistance to testing and implementation of new policies than they had at the Missouri base.

The logistics man-machine simulations ceased in 1966, by which time the attention of RAND and the Air Force was focused fully on the Vietnam War. Geisler concluded that the Logistics Systems Laboratory had "provided a good transition between the logistics researcher and the logistics operator." He was not able to claim the full implementation of optimal decision rules, but he asserted that the LSL had "helped to accelerate the transfer of sound feasible findings to the real world" (Geisler 1986, 33).

Conclusion

How do you translate the broad findings of normative microeconomics into detailed, implementable procedures for operations in a system? The RAND Logistics System Laboratory economists, with the help of psychologists, discovered that a big part of the answer was that you have to *grow* a system. This synthesis included building networks of information flows and feedback loops. Murray Geisler and Allen Ginsberg (1965, 4) summarized this research objective of game simulation designed for making decisions about resource allocation as achieving a "better definition of a system through suggesting new ideas, firming alternatives, integrating system functions, examining administrative feasibility and demonstrating effectiveness."

The chief contribution of economists to this enterprise was optimization including a formal maximizing or minimizing criterion function for each of the laboratory problems (see

[15] The US government dates its war in Vietnam from August 5, 1964 to May 7, 1975.

goals on Table 2). The economists also initiated optimal decision rules for most of the simulations and explicitly clarified tradeoffs and opportunity costs. The contributions of the psychologists included experimentation through simulation, the analytical framework of a system or organism rather than the individual, a receptivity to adaptive processes, and a focus on interactions monitored and controlled within an information processing structure.

One of the major obstacles the system definers/designers faced was the conflict between the goals of and incentives facing agents in different organizations that would comprise a system. The psychologist William Haythorn, who had worked with the SRL before joining the LSL described that dilemma:

> Some components of the system emphasize operational support, some emphasize operational readiness, some emphasize economy. … That is, each component of the system may interact with other components so as to require coordination. Otherwise, the operational effectiveness of system components may be unrelated or negatively related to overall systems effectiveness. (Haythorn 1958, 77)

Another lesson learned was that under the right conditions simulation is one way to grow an effective system by revealing the most effective reporting policies and communication channels. As the SRL psychologists found, "a system's environment can be inferred from, and its actions controlled by, information—a vital commodity to any organization" (Chapman, Kennedy et al. 1959, 251). For prescriptive economics, simulation proved an appropriate bridge between research and implementation when dealing with complex behavioral systems focusing on processing symbols, whether they were symbols of planes on a radar screen or reports on airplane parts needed.[16]

The economist's attention to implementation of rational choice protocols that maximized gains for an entire system has not been confined to military research and planning contracts. More recently, economists on the Basel Committee on Banking Supervision were engaging in implementation rationality through simulation in the form of the Regulatory Consistency Assessment Programme (RCAP). The Bank for International Settlements established the program to insure consistent, effective implementation of Basel III banking regulations (see Basel Committee on Banking Supervision 2013). As with Geisler's work at the RAND Logistics Systems Laboratory, RCAP used simulation experiments to test for and further enhance consistent implementation. Over the course of 20-trading days in the summer of 2012, the Basel Committee on Banking Supervision used a hypothetical test portfolio to conduct a simulation with 16 international banks. Each day the banks calculated the weighting of the riskiness of their assets to determine the amount of capital they would set aside to meet the legal requirement of holding capital equivalent to 7% of the value of risk-weighted assets in their identical hypothetical portfolios of initial values and "common trading strategies implemented using primarily vanilla products" (see Basel Committee on Banking Supervision 2013, 67). The second stage of simulation introduced more exotic flavors of trading strategies. In response to the daily changes in the market-determined values of the portfolio assets over the 20-day period for each simulation, banks calculated on a daily basis their 10-day 99% VaR (Value at Risk) and on a weekly basis their Stressed VaR and IRC (Incremental Risk Capital). The banks reported their risk metrics calculations on a common form.

[16] The use of simulations in economics and scientific modeling is explored in Morgan 2004 and Maas 2014.

The committee was surprised by the inconsistency in the investment banks simulated calculations on risk-weighted assets. There were follow-up site visits to reveal the most likely sources of the inconsistency, and in particular to examine the relative importance of supervisory personal judgment versus mathematical modeling. The RCAP simulations were also prolonged observations with additional analysis to determine how to tweak reporting frameworks and how to prescribe and proscribe calculation protocols in order to narrow modeling choices for the investment banks. The Basel Committee on Banking Supervision intends to use the latter to counter an individual bank's use of optimizing models that minimize the value of their risk-weighted assets in order to minimize the capital they need to set aside to meet Basel III stipulations.[17]

As with the RAND LSL simulations, the aims of the RCAP's iterative simulations have been to measure inconsistencies and bottlenecks to achieving effective implementation of decision rules and develop specific reporting/decision protocols that entrain desired implementation with low variation in the outcomes. Simulation monitors at both institutions also observed the gaming of the system. They studied ways to ensure that optimization at the system level (e.g. minimizing USAF costs or minimizing risk of a financial crisis) trumped the rational self-interests of individual air bases or investment banks. Implementation rationality at this level was in some ways analogous to avoiding a Nash equilibrium in the prisoner's dilemma by

[17] The most obvious evidence of such a practice has come from internal bank email messages revealed in the US Senate investigation of the J.P. Morgan's $6 billion "London Whale" loss. These show that quantitative analysts at J.P. Morgan's Chief Investment Office were explicitly "optimizing regulatory capital" to minimize the reported value of capital subject to regulation and to reduce the calculated Value-at-Risk of trades the London office persisted in making. The *Financial Times* and Matt Levine at the dealbreaker blog had good synopses of the RCAP simulations, and its relevance to the London Whale incident (see for example, http://dealbreaker.com/2013/01/banks-risk-measurements-rarely-off-by-much-more-than-a-factor-of-ten/, http://www.ft.com/intl/cms/s/0/6eae8382-6bab-11e2-8c62-00144feab49a.html , http://ftalphaville.ft.com/2013/04/09/1450202/ten-times-on-the-board-i-will-not-put-optimizing-regulatory-capital-in-the-subject-line-of-an-email/)

creating a reporting/deciding framework for maximizing benefits for the collective of participants. In both cases the simulations were an iterative, adaptive process with the aim of taming optimizing models, achieving "good-enough" operational rules, and maximizing the effectiveness of the regulations through perfecting data-reporting interfaces and narrowing supervisory personal judgment or modeling choices. Both were attempts to *define* a system.

The RAND Logistics Systems Laboratory and the Basel Committee on Banking Supervision's RCAP simulations occurred in contexts of regulatory or command-and-control systems. It may well be that part of the problem of people gaming a system is a product of the system trying to control the individual. The more compelling story is about the resolution to naturally conflicting optimizations. In some situations, the micro and macro fail to mesh unless a regulatory system with effective information channels is cultivated. The evolution of iterative modeling and solving for rules of action at the LSL and in the RCAP also highlights the advantages of lawmakers giving flexibility to the regulators doing the implementation. The end goals of an efficiently adaptable, stable system as well as the schema of the information monitoring network are often embodied in the command and control legislation. These experiments in simulation suggest, however, that the explicit narrowing of modeling choices that bind the rationality of the individual units may be best iterated through a process that takes into account the human factor.

Economists at the RAND Logistics Systems Laboratory were searching for a way to implement the optimal policies that matched the organizational objective functions of maximizing alert readiness given resource constraints or minimizing the budget given the operational program. In joining psychology with economics, the RAND LSL came to the conclusion that they had to analyze and synthesize the group as a single organism rather than an aggregation of individuals. A key to growing the organism was to create effective information processing channels, including feedback loops. Researchers had to allow for learning and adaptation in both the subjects of the experiments and the academic economists and psychologists running the simulations. Interactions with experimental psychologists took RAND economists to another level of detail and complexity. A door opened to non-standard modeling and an iterative, heuristic specification of economizing rules of action that had a greater chance of implementation.

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