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Computer Simulation and Gaming in Logistics Research

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Computer Simulation and Gaming in Logistics Research

by
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PROBLEM

To determine the present state of the art in logistics gaming and computer simulation, and to evaluate the usefulness of these methods for research on US Army logistics and management systems problems.

FACTS

There is a great deal of discussion in the Army Staff, as well as in research circles, about the potential of gaming and/or simulation in logistics research. Numerous proposals for use of such methods are now or soon will be under consideration, some of them involving substantial long-term commitments of resources.

At the same time, this is not an established research methodology, and recourse cannot be had to authoritative publications defining conditions for its use.

In this situation it seemed worth while to make a systematic review of work accomplished in logistics gaming and simulation. The present study is the result.

DISCUSSION

One result of this study was recognition that very little work in either gaming or computer simulation in Army logistics areas has ever been completed. Even related work, such as that done on Air Force or Marine Corps problems, is scanty. These methods are in an early stage of development.

Accordingly, the temptation to generalize was resisted, and the paper discusses most of the relevant games and simulations individually. In fact Chapters 2, 3, and 4 of this paper together with the list of references may be used as a critical bibliography and descriptive directory of logistics gaming and computer simulation. The final chapter contains an appreciation of the Army requirement for application of these methods and an outline of conditions for their use.

SUMMARY

PRINCIPAL CONCLUSIONS

1. Gaming methods for research in US Army logistics are still in the early experimental stages.

2. Computer simulation methods for Army logistics research are in a more advanced stage of development than gaming methods, but it is still an early stage.

3. Gaming, computer simulation, and certain related mathematical methods are complementary methods; the successful application of any one of them today implies the capability to use all of them, separately or in appropriate combination.

4. The use of both computer simulation and gaming methods for military logistics research has been increasing, although slowly, over the last 10 years.

5. Free use of both methods has been impeded by unsolved technical problems. One of these, centering around excessive time requirements for programming computer simulations, appears to be on the verge of solution.

6. The distinction between tactical and logistical gaming seems to have been incorrectly drawn and is hindering rather than helping work in both areas.

7. Sufficient evidence shows the existence of a requirement for vigorous application of gaming and simulation methods to the unsolved problems of Army logistics.

**COMPUTER SIMULATION AND GAMING
IN LOGISTICS RESEARCH**

ABBREVIATIONS

ADC	Air Defense Command	NWL	Naval Weapons Laboratory
AIDS	Air Development Simulator	NWP	Naval Warfare Publication
ALC	Advance Logistics Command	NWRC	Naval Warfare Research Center
AORE	British Army Operational Research Establishment	ONR	Office of Naval Research
AORG	Army Operational Research Group	ORO	Operations Research Office
ARDC	Air Research and Development Command	OSA	overseas supply agency
ASC	Army Support Command	POL	petroleum, oils, and lubricants
BLC	Base Logistics Command	PRC	Planning Research Corp.
C ₁	contract copy 1	P&P	plans and programs
C ₂	contract copy 2	R	requisition
CAORE	Canadian Army Operational Research Establishment	RAC	Research Analysis Corp.
CDEC	Combat Developments Experimental Center	RARDE	Royal Armament Research and Development Establishment
CNO	Chief of Naval Operations	RLT/MAG	Regimental Landing Team/ Marine Aircraft Group
CONUS	continental United States	R&D	research and development
CORG	Combat Operations Research Group	SAC	Strategic Air Command
DASL	Department of the Army Strategic Logistics (Study)	SD	shipping document
DCSOPS	Deputy Chief of Staff for Military Operations	S/IR	stock and issue analysis report
EDC	electronic data-processing center	SRI	Stanford Research Institute
EIP	Economic Inventory Policy	STAG	United States Army Strategy and Tactics Analysis Group
GWU-LRP	George Washington University-Logistics Research Project	TAC	Tactical Air Command
HH	Harbridge House	TDY	temporary duty
LOC	lines of communication	TEMPO	General Electric Technical Military Planning Operation
LP	Laboratory Problem	TLC	Theater Logistics Command
LSL	Logistics Systems Laboratory	TMM	Multibase Transport and Maintenance Model
MATS	Military Air Transport Service	TOE	tables of organization and equipment
MIT	Massachusetts Institute of Technology	USALMC	United States Army Logistics Management Center
MTMA	Military Traffic Management Agency	USCONARC	United States Continental Army Command
NCEL	Naval Civil Engineering Laboratory	USMC	United States Marine Corps
NICP	national inventory control point	WADC	Wright Air Development Center
		ZI	zone of interior

Chapter 1

INTRODUCTION, DEFINITIONS, AND REVIEW OF ACCOMPLISHMENTS

INTRODUCTION

The original plan of this study called for a systematic examination of gaming and simulation methods as applied in logistics research; assessment of the usefulness, special properties, and limitations of each; appreciation of the requirements, if there proved to be any, for application of gaming and simulation methods to US Army problems; and finally, based on the findings, determination of conditions for successful application of these methods. This plan has been carried out and the results are presented in this paper.

The study led to recognition of a basic fact that had not been apparent when the plan was made but determines the general character of the results. It was assumed that a relatively large body of gaming and simulation experience exists and that its examination would result in reasonably conclusive generalizations about the efficacy and proper use of these methods. The facts are otherwise. Only a small volume of work in logistics gaming and simulation has ever been completed.

Hence, instead of being able to summarize definitive data and results and apply the resulting generalizations to US Army problems in a comprehensive way, it is necessary to proceed with caution, resting the few, tentative generalizations that now seem possible largely on step-by-step discussion of individual cases. There are hundreds of logistics problems to which gaming, or simulation, ought to be applicable in the opinion of qualified research people, or to which their application has been proposed, suggested, recommended, requested, or planned, but actual, complete, fully reported applications are few in number.

After some preliminary definitions this statement is documented in Chap. 1. Then in following sections existing examples of simulation (Chap. 2) and gaming (Chap. 3) considered most relevant to Army problems are enumerated and described in sufficient detail to permit assessment of the use and limitations of these methods. Next a central problem peculiar to US Army logistics gaming is examined, and evidence bearing on it is reviewed (Chap. 4). Finally, in the last section, the Army's requirements for logistics gaming and simulation are discussed, and conditions for successful work in this field are formulated (Chap. 5).

DEFINITIONS

Terminology in the research community as a whole has not been settled, but for the purposes of this paper the following usages are adhered to:

computer simulation. A representation of a real system, or situation, programmed for a computer.*

game. A representation by human players, or participants, of a real system or situation; this includes two-player games, the traditional war game, and one-player games. Also included are computer-assisted games, where the computer assistance may range from simple bookkeeping or "housekeeping" functions up to involved calculations (e.g., damage assessment). Games may be supported by computer simulations, such as simulations of subsystems in the system being gamed, or simulations of conditions on the "boundary" of the game.†

Clearly one object of this terminology is to distinguish between methods depending primarily on humans in their decision-making roles and those consisting of computer programs. These do represent two main methodological lines in evaluating which separate discussions frequently will prove necessary.

SUMMARY REVIEW OF WORK IN THE FIELD

Gaming

Development of methods of logistics gaming for military operations research, in any substantial volume, has been done mainly in these agencies:‡ RAC/ORO (for US Army), the British Army Operational Research Establishment (AORE) (formerly "Group") (for British Army),§ and the RAND Corp. (for US Air Force).

Overwhelmingly the greatest volume of such gaming as measured by dollars and man-years or by published results has been done by RAND. The list of references reflects this situation.

In every instance except one, logistics games have borrowed methodology or adapted it from older and more extensive work in tactical military gaming. This has been a natural approach, but whether it is the best has not been established. It is suggestive that the exception, RAND's Logistics Systems Laboratory, has been in several respects the most successful logistics gaming activity.

*That is, a digital or an analog computer; however, important cases of the use of analog computers in logistics research as discussed here were not encountered, and the reference in this paper is to digital computer simulation.

†The main alternative terminology to be found in the literature is the use of "computer simulation" as above, "game" to mean the 3-room (Red, Blue, and Control) tactical or strategic war game, and "simulation" for all other games. Neither alternative satisfies everybody.

‡Experimental naval logistics gaming was tried by the Naval War College assisted by the Logistics Research Project, George Washington University, in 1956-1958.

§The Canadian Army Operational Research Establishment (CAORE) is currently considering undertaking such gaming.

Another source of methodology now exists. Beginning approximately in 1957, operations analysts, and later economists, etc., began applying the methods of both tactical and logistical gaming to develop business management games, marketing games, and the like for industrial and commercial studies. This work has already generated a larger and more diverse literature than the literature of logistics gaming; hence, it now constitutes a source of methodology and technique for adaptation to logistics gaming; it is not, however, a source that has proved especially valuable to date.

Useful recent bibliographies of literature on business games and catalogs of the work done are available and will be referenced to complete the present discussion. The Harvard Business School report, with annotated bibliography,¹ was published in 1959, the bibliographies by Deacon,² Malcolm,³ and Shubik⁴ in 1960, and the bibliography and "Directory of Management Games" by Kibbee, et al.,⁵ in 1961.

Surveys of military logistics gaming as such have not been made, but the 1962 United States Army Strategy and Tactics Analysis Group (STAG) directory⁶ lists 18 organizations "engaged or interested in" logistics gaming. All these have been taken into consideration in preparing this paper.

Simulation

The use of computer simulation in logistics research has a somewhat different history. The first Systems Simulation Symposium⁷ was held in 1957. The symposium was limited to 20 participants, each of whom was supposed to have completed work in simulation either of a business or of a military system, but in fact this requirement proved impossible to satisfy in 1957, so that several of the participants had simply designed but not yet executed simulations. Indeed the earliest simulations of military logistics or related systems date from 1954-1955. Among these are the RAND air base supply simulation,⁸ the ORO simulation of Quartermaster supply control,⁹ and United Air Lines' simulation of a commercial air terminal operation.¹⁰ Relatively few simulations in military logistics have been completed in the 7 years since, but the work is more extensive than that in logistics gaming nonetheless.

As with gaming, a large body of literature on computer simulations in business has grown up and constitutes a possible source of methodology. Generally speaking, sharp distinctions between games and computer simulations are not drawn in this literature; the references cited previously¹⁻⁵ for games also serve as guides to business simulations. The comparison with gaming breaks off here, however. The basic point of difference is that, quite unlike gaming, computer simulation and the closely related monte carlo method of analysis have been accepted scientific tools in physics since early in WWII and in nearly every major field of science and engineering for up to a decade. The body of literature on computer simulation in science is already large (compared with that of gaming). It tends to be of higher quality technically, and it is difficult of access because it is distributed in parallel compartments representing the computer simulation studies of meteorologists, physical chemists, biophysicists, geophysicists, and more recently sociologists, economists, and biologists, not to mention the numerous engineering and engineering physics

applications, e.g., in aeronautical, electrical, civil, and chemical engineering.* Of course a study of this literature was not attempted in preparing this paper, and the above statements are based on cursory sampling. A good recent example from biology (ecology) is given by Barnett¹¹ and one from the social sciences by Orcutt¹². An illuminating example from engineering is the comprehensive report¹³ of the work of the Harvard Water Program, Harvard Graduate School of Public Administration, recently published, from which the following is taken:

... Prior to ... 1954, no major river development had been simulated on a digital computer. Perhaps the first enterprise of this kind was the simulation of the Nile Valley plan in 1955 ... In the United States, large-scale simulation experiments were begun by the Corps of Engineers in 1953 for reservoir management on the main stem of the Missouri River ... A trial translation of this approach to the more complex Columbia River Basin proved to be beyond the capacity of the computers then available ... No one ... has yet completed simulation of a large and complex river-basin system on ... [700-series] computers for purposes of system design.

So far as dates are concerned the parallelism with the history of logistics simulation here is evident, and it seems probable that similar histories could be compiled for meteorology, electronics, and many other scientific or engineering fields such as those listed previously.

The development of computer simulations in logistics research (as in most scientific and engineering research) has been determined in part by two essentially mechanical factors: the state of development of computers and the capabilities of the particular research institution in computer programming and its possession of or access to a computer.

Thus, with regard to the first factor, the first generally available large digital computer was the Univac in 1953, and the first simulations are found to have been completed in 1954-1955 (ORO's 1103 computer was installed in 1955). With regard to the second factor, the number, size, and quality of computer simulations completed might be expected to be a function of the size of the research institution; and indeed RAND has completed most, RAC/ORO next most, and the Combat Operations Research Group (CORG)† least among those three institutions.

As with gaming, there is no survey of computer simulations in logistics as such. Morgenthaler's survey article¹⁴ covers the whole subject of computer simulation, however, including military applications, and offers another useful bibliography. Cline's University of Michigan survey¹⁵ is directed specifically to weapons system evaluation applications but includes some logistics simulations;‡ also Cline's classification of games and simulations is of interest.§ His survey includes 4 instances of games and 41 of computer simulations, which is another rough indication of the relative development of the two methods.

* When considering the literature of the physical sciences a further difficulty lies in the necessity of distinguishing examples of the monte carlo method in the strictest sense from simulations. This distinction is not insisted on here because it rarely if ever becomes an issue in logistics research.

† Research group for Technical Operations, Inc., operated at HQ United States Continental Army Command (USCONARC) under Dept of Army contract.

‡ Specifically Nos. 8, 23, 27, 32, 34, and 37.

§ Cline's category II agrees with our "games" and his IV with our "computer simulations."

Application of Gaming and Simulation to Army Logistics Problems

The open problems in US Army logistics^{16,17} may be classified in a practical way by echelon within broad functional categories; this permits examination of work accomplished in gaming and simulation to date, superimposed on the

TABLE 1
SUPERPOSITION: RESEARCH ACCOMPLISHMENTS ON PROBLEMS

Logistics problem	Gaming	Computer simulation
Combat army:		
S4: battalion and forward	Tacapiel (RAC)	ROAM (RAC) Medical platoon (SRI) ^a
G4: division and forward	Theaterspiel (RAC) Map exercise (CORG 57-2)	POL ^b supply (CORG 57-2) Amphibious logistics (SRI) Ship-to-shore (Navy Weapons Laboratory)
Technical and management systems:		
Theater	Multilevel game (RAC) LP-II (RAND) ^c LP-IV (RAND) ^d	Air base supply control (RAND) Air base inventory (RAND) Air base maintenance operations (RAND) Minuteman maintenance (RAND) All-computer LP-IV (RAND)
CONUS and intertheater	Multilevel game (RAC) Wholesale-level game (RAC) LP-I (RAND) LP-III (RAND) SAFE (RAND) LOC logistics game (AORG)	QM supply control (RAC) Air deployment (SRI) Multibase transport and maintenance (RAND) Cargo airlift (RAND) Heath Facility (RAND) Army inventory policies (HH) ^e Ordnance inventory (CAORE) Depot system simulator (MIT)
Planning:		
Strategic	Computer-assisted strategic logistic planning (RAC)	Amphibious logistics (SRI)
Operational	Computer-assisted operational logistic planning (PRC) ^f	Ship-to-shore model (Navy)

^aSRI, Stanford Research Institute.

^bPOL, petroleum, oils, and lubricants.

^cLP, Laboratory Problem.

^dNot yet completed.

^eHH, Harbridge House.

^fPRC, Planning Research Corp.

classification. This is the scheme of Table 1 where the logistics below division level, which would normally be the concern of the company, battalion, or brigade officer designated S4, are classified S4; similarly Army and division logistics are classified G4; and the titles of the remaining echelons, as well as of the three functional categories within which the echelons fit, are self-explanatory.

Some general comments on Table 1 are in order. All the Army gaming shown (as distinguished from Air Force) is in the trial or feasibility-testing stage, or perhaps at most just leaving that stage, with the exception of the British AORE Logistics Game (which, however, is no longer in use). This is not true of most of the computer simulations.

The table reveals fairly clearly the paucity of past work that can be related to Army problems. The relation of the Air Force (RAND) work to Army problems is somewhat indirect. Also two primarily tactical games have been included, which are thought to be applicable to the study of logistics problems, but the whole question of the relation of tactical to logistics gaming is postponed for separate discussion in Chap. 4. Work strictly in Army logistics can be surveyed by deleting these two categories from the table.

A mildly surprising result of the superposition is the uniformity of coverage. No area has been neglected. One area in which coverage is light is application of computer simulation to Army theater problems, and it is interesting that CORG has issued a proposal for such a simulation.¹⁸

Table 1 documents the assertion in the "Introduction" that assessment of these methods for Army logistics research and the development of criteria for their application must rest mainly on discussion of individual cases. The computer simulations will be discussed in Chap. 2, and the games, except primarily tactical games, in Chap. 3.

Chapter 2

COMPUTER SIMULATION FOR LOGISTICS RESEARCH

Computer simulation, as a method for logistics research, is in a transition state at present. Some key technical problems have been impeding progress, and these will be summarized at the end of this section. In the present state of the art, computer simulations tend to be to some extent personal creations in which the individual methods and ideas of the responsible analyst play a large role. In any event it is exceptionally difficult to extract a clear idea of technique from the literature on simulation—much more difficult than in the case of gaming, for example. It usually seems to be true at present that the best way to gain understanding of a simulation, short of rewriting it, is to discuss it with the author.

In the right-hand column of Table 1, computer simulations were grouped according to an echelon concept. In Table 2 the same simulations are grouped by problem categories, a method that proved helpful for describing simulations in detail, as will be done in this chapter. Some of the listed simulations have been reported in the literature and references are given; others have not been reported. In most cases the description is based on discussion with the author(s). In some cases, descriptions have been restricted by security considerations.

The computer used for each simulation is identified by its commonly used manufacturer's designation, one of the following: IBM NORC, Whirlwind, 650, 701, 704, 705, or 7090; Remington-Rand 1103 and 1103-A; Burroughs 220; Royal-McBee LPG-30; and Engineering Research Associates Logistics Research Computer. No further characterization of these machines will be attempted here since descriptions of all of them are readily available from their manufacturers or in standard sources.

The type of simulation is defined in each instance as being "critical event" or "time-slice." An "event-store" or critical-event type of simulation is one in which the events of interest are examined in some appropriate sequence, the results of each event being stored until needed. A time-slice type of simulation is one in which the state of the system under study is calculated at definite, usually equal, time intervals.

Descriptions of the simulations follow, grouped in the problem categories of Table 2. A few generalizations and findings of the study are given after completion of the individual descriptions.

Medical Logistics

Medical Platoon (SRI). This simulation was designed and programmed in the first 3 months of 1960, with a double purpose. It was intended to assist in

design and evaluation of a special medical field experiment at the Combat Developments Experimental Center (CDEC), Ft Ord, Calif.; and it was expected to help in developing criteria for evaluation of the medical platoon.

TABLE 2
ACCOMPLISHMENTS IN FUNCTIONAL AREAS

Functional problem area	Computer simulations
Medical logistics	Medical platoon (SRI)
Amphibious logistics	Amphibious logistics (SRI) Ship-to-shore (Navy Weapons Laboratory)
Theater transportation	POL supply (CORG)
Intertheater lift	Air deployment (SRI) Multibase transport and maintenance (RAND) Cargo airlift (RAND)
Maintenance	Armored battalion maintenance (RAC/ORO) Air base maintenance operations (RAND) Minuteman maintenance (RAND) Heath Facility (RAND) All-computer LP-IV (RAND)
Supply control	QM supply control (RAC/ORO)
Inventory control	Army inventory policies (HH) Air base supply: 1 (RAND) Air base supply: 2 (RAND) Ordnance inventory (CAORE) Depot system simulator (MIT) ^a

^aMIT, Massachusetts Institute of Technology.

The model included an aid station, related military positions, and appropriate personnel (such as doctors) and equipment (such as ambulances). The generation of casualties and their evacuation, sorting, and treatment are simulated. Certain variable parameters are fixed for each set of computer runs, e.g., distribution and rate of occurrence of casualties within each tactical platoon by class of casualty. Other elements of the situation are treated as random variables, e.g., type of casualty (which in turn determines the distributions of other random variables, such as field treatment time). Finally, ambulance travel time between the various locations considered in the simulation includes a deterministic and a random part. The output of the simulation summarizes criteria of performance of the simulated platoon.

The simulation is a critical-event, stochastic type, programmed for the Burroughs 220. It has not been reported.

Amphibious Logistics

Amphibious Logistics (SRI).¹⁸ This is a simulation designed and programmed by SRI's Naval Warfare Research Center primarily as a tool for use by the Naval Civil Engineering Laboratory (NCEL). This is a simulation of great interest from the Army point of view and from the point of view of logistics, since it represents the situation of amphibious assault by the US Marine Corps (USMC) and is designed to measure logistical factors in this tactical context. Also this model has significance in relation to strategic planning. In conjunction with the US Naval Weapons Laboratory (NWL) simulation described next this represents work that it is most important to study and apply to Army problems.

An original version of the amphibious logistics simulation was programmed for the LGP-30 in 1959. The current version was programmed in 1960-1961 for the 705 and is a critical-event, deterministic type of simulation.

Ship-to-Shore Model (US NWL).²⁰ This is the first in a sequence of detailed simulations that will represent all phases of amphibious operations. Programming of the second, the "embarkation model,"²¹ will be attempted this year.*

The model keeps track of the ship-to-shore phase including both over-the-beach and vertical envelopment techniques in great detail, down to individual boatloads in many instances. It is a critical-event type of simulation, stochastic with respect to attrition and times for loading and unloading landing craft. It has the input capacity to represent the ship-to-shore means for landing a brigade Regimental Landing Team/Marine Aircraft Group (RLT/MAG) or smaller force. The transport organization consists of up to 30 ships and 400 landing craft, operating in an area 50 NM square.

Internally every ship, craft, helicopter, beach, serial† and supply dump is represented by a table. The "events" consist in analysis of given situations from the tables and other data such as logistic usage, calculated by the model every 24 hr of simulated action; or attrition probabilities (determined as input up to a distribution), decision (in accordance with doctrine), and consequent updating of all tables affected by the decision.

One feature of interest, from the methodological point of view, is the technique used to determine the times to call unscheduled serials to shore following or coincident with the scheduled waves. In reality such times would be determined by the progress of the action ashore, which is not included in this simulation. The technique adopted is to determine call times and places by manual gaming of the action in the USMC gaming center at Quantico, Va.

The output that the simulation is basically designed to produce is the on-shore buildup rate and landing craft utilization‡ for each individual craft involved in the operation. However, the built-in capability to print any of the tables at any time in the simulated operation creates flexibility; thus from the

* It has recently been decided, however, to program a very much aggregated, comprehensive simulation of amphibious operations before proceeding to the third of the detailed phases.

† "Serial" is a USMC technical term meaning either one, or several "components"; a component is a boat/helicopter load of personnel, wheeled or tracked vehicles, other equipment, or supplies; supplies, in turn, in this model, are broken down into 22 categories separately accounted for.

‡ That is, a detailed percentage breakdown by several standard categories of the utilization of the craft over the whole time of operation.

raw tabular output can be developed " . . . the actual rate of build-up ashore of a particular type of supply as compared with the desired build-up rate, the distribution of ships and craft at specific times during the operation, the numbers of craft and helicopters out-of-action at given times, the backlog of craft waiting to unload at a beach at certain times, comparisons of the effects of using one type of equipment as opposed to another, etc. . . ."²⁰ The use of display equipment to exhibit graphic output is contemplated.

As mentioned above, simulated decisions proceed in accord with USMC doctrine, specifically, that contained in Advance Change 5 to Naval Warfare Publication (NWP) 22.²² It follows that the simulation is not designed to test doctrine; instead its primary purpose is, taking doctrine as given, to investigate the effects of proposed equipment changes, for example, or the ability of specific shipping to support various levels of troop action ashore. A second function of the simulation is to test contingency plans. It has already served this purpose, under directive of the Chief of Naval Operations (CNO), and currently it is in use to support research on mobility being conducted at the Landing Force Development Center.

The technique used in testing a plan is to take "snapshots" of the action at various points by the print-out of tabular material as described above, thus providing the materials for a detailed quantitative and critical review of the plan.

It was found that translation of a typical contingency plan to computer input was a major task requiring the efforts of a team of officers for several weeks. A second model of this simulation is now being programmed with the aim of reducing this delay. The original model was partly programmed and coded for the NORC then recoded for the 7090. The new one is being done for the 7090. Runs take from approximately 1.5 to 4.5 hr on the 7090, but these times include delays involved in printing tabular status reports as needed.

Theater Transportation

POL Supply (CORG).^{23,24} This simulation was programmed in 1959-1960 with the object of comparing the effectiveness of different methods of transporting POL in an active theater of war. An attempt to gain the same end by means of a map exercise was made, and, this proving inadequate, computer simulation was chosen as the most promising tool.

The simulation was programmed for the 650 computer. Four sets of runs were made for a total of 64 runs; i.e., each set represented a choice of parameter values corresponding to a particular military situation. The main reference is confidential;²³ an earlier, partial report on the same study is unclassified.²⁴ A new CORG project this year is undertaking a simulation of the POL distribution system forward of division. This will provide results in the S4 area of Table 1.

Intertheater Lift

Two simulations of deployment of military units by air were found; a third simulation deals with routine airlift of resupply in peacetime. One of these simulations is deterministic and designed to assist formal Air Force planning procedures, as well as being intended for analysis; the other two are

stochastic and designed for analysis. All three of the simulations were written primarily for use on Air Force problems. A surface lift simulation is now being written by one of the groups (SRI).

Air Deployment Simulator (AIDS) (SRI).²⁵⁻²⁶ This is a simulation of strategic deployment by air either of Air Force or of Army units. There was some emphasis in the design on Air Force since the prime users of AIDS were visualized as being the Air Research and Development Command (ARDC), the Tactical Air Command (TAC) and HQ 19th Air Force; however, a procedure was worked out for handling the special characteristics of Army units.

AIDS was designed to assist in comparative evaluation of weapons systems in the research and development (R&D) cycle or as a planning tool in several different applications. Considerable flexibility was therefore built into the design; e.g., the program will accept tables of organization and equipment (TOE) detailed down to individual men or will aggregate a TOE to a number of tons. The output listings are carefully designed to suit Air Force procedural requirements, and the work is exceptionally well documented in the four documents referenced. Indeed the Computer Techniques Division of the former Wright Air Development Center (WADC) was able to write a working duplicate of the program from "AIDS System"²⁷ without any consultation with the authors.

The simulation is of critical-event type and is deterministic because investigation of the stochastic elements, e.g., weather or queuing, showed that available data were so poor that it was unreasonable to specify more than the mean values of the distributions. It is programmed for the 650 because it was designed for use by Air Force commands that were expected to be limited to 650's. The work on AIDS was done and the reports published in 1959. The group is now undertaking a simulation of surface deployment for the USMC.

Multibase Transport and Maintenance Model (TMM) (RAND). RAND's TMM is also a simulation of strategic air deployment; however, its application to tactical air support problems is theoretically possible and has recently been considered. An earlier, simpler version exists, which has been described in a published report,²⁹ although the TMM itself has not been.

This simulation differs from SRI's AIDS in several respects. It is in some aspects an adaptation of the Rainey-Levine base-maintenance-operations model³³ and considers in great detail stochastic and other effects of maintenance operations of all bases and for all aircraft types involved in a given lift. For example, random delays in parts supply at bases are considered; and a maximum number of maintenance personnel that can work simultaneously on a given aircraft type is enforced. On the other hand the problems of loading TOEs on specific aircraft are not considered in detail as they are in AIDS, nor is the program designed, as is AIDS, to produce output required in formal Air Force planning procedures.

The earlier model was designed in 1959, and the TMM itself was programmed for the 7090 in 1960-1961. It is of stochastic time-slice type and will print for every time interval and base, or for specific intervals and classes of bases as instructed, the arrivals since last report and current count available and ready for flying of each aircraft type involved in the lift.

Routine Cargo Airlift (RAND).³⁰ This simulation represents one element in a larger RAND study of military air transportation. It is directed to analysis of routine airlift of cargo in general support of " . . . military forces not engaged

in emergency activities"³⁰ It considers the interactions between port procedures, e.g., priorities, and contract arrangements (the complex of policies constituting the airlift system) and pipeline times. It " . . . was designed to assess the varying impact of these interactions, with particular regard to system size and pipeline times."³⁰ In the author's opinion, this simulation " . . . is limited in application to more or less standardized, repetitive cargo flows, but is not at all limited to air movements. On the contrary, it may be even more profitable for investigating the movement of packaged freight on trains, trucks, or ships."³⁰

The simulation fills cargo terminal warehouses using relative frequency distributions developed from punched-card data on all Military Air Transport Service (MATS) cargo airlifted in 1959 for the Army, Navy, Air Force, and other US government agencies; day of arrival, route, priority, weight, and volume are considered. In the second stage a simulated loading procedure determines the number of aircraft loads required per day, and eventually per year, to move such cargo out. The output is designed to permit evaluation of the efficiency of various combinations of transport aircraft, as well as of the effect of various system policies.

This simulation was programmed for the 7090 in 1961-1962, and the results of 85 runs are summarized by Pascal.³⁰ It is a time-slice, stochastic type with interval of one day.

Maintenance

Three of the five maintenance simulations considered attempt to evaluate some operational characteristics of a military organization, or installation, as a function of maintenance—whether a missile wing, an air base, or an armored battalion. The fourth simulation is intended to assist in layout of a new Air Force test and diagnostic facility. The fifth deals with management systems (and management information systems) for maintenance.

Armored Battalion Maintenance (RAC/ORO).^{31,32} This is a simulation of the march of an armored battalion, designed to analyze the operational mobility of such a unit as a function of maintenance. Unit mobility is affected by reliability of tanks and other equipment of the battalion; but it is affected also by the type and number of maintenance personnel traveling with the unit and by the urgency of the mission, which determines time available for maintenance tasks. This situation was adjudged difficult, probably impossible, to represent with a closed analytic model. Analysis by field experiments would be extremely costly; also, one object of the study was to estimate the unit mobility attainable with hypothetical future tank designs, and field experiment would probably be a poor method for making such estimates. The emphasis was on mechanical factors and times rather than on management systems, so that a game did not seem to be indicated. Hence a computer simulation was decided on.

The simulation took approximately 6 man-years to design and program for the 1103-A computer and ran to 10,000 program instructions (machine language). The main part of the work was done in 1958-1960. The simulation is of the critical-event, stochastic type.

Air Base Maintenance Operations (RAND).³³⁻³⁵ This simulation, programmed originally for the 704, was designed as a research tool for studying the

interactions of aircraft operations and direct maintenance at base level, with some related elements of base logistics (such as maintenance equipment supply).

Given a flying program and a set of parameter values such as the ground-abort rate the model computes from stochastic malfunctions the base maintenance personnel shortages that may develop, by type of specialist personnel, maintenance equipment shortages, and status of planes (e.g., fully operationally ready on the ground; airborne; noncombat; ready and awaiting parts; etc.), all per time interval. By design the simulation is suited to study a variety of base operations as affected by maintenance. For example, its authors consider that it would serve for "work on the logistics of the chemically-fueled long-endurance bomber . . .," to make "Predictions of F-108 fighter-interceptor capabilities . . .," or to estimate ". . . utilization rates and capabilities of various MATS transport aircraft."³³ The simulation has in fact been applied to a number of practical Air Force problems with results that may be reviewed in several references.³⁶⁻³⁹

The authors of this simulation stated that whenever possible ". . . the model is first tried out in a simulation of operations as they actually occur; this test verifies the model's applicability . . ." Various such tests have been made as applications occurred; in one of them ". . . the key output . . . the average number of aircraft which the simulation reported operationally ready—came within two-tenths of an airplane (out of a squadron of 25) of the average actually tabulated in the [field] test. The other aircraft status outputs were almost as close to the reported [field] test results."³³

Actually, two simulation models were developed, as is often the case in this work: an earlier and simpler model in late 1957 and the main model, described here, in the following year. This is a time-slice, stochastic simulation determining malfunctions and some other factors from binomial distributions, and the times for completion of maintenance tasks from empirical distributions. It is designed to simulate 2 weeks of 1/2-hr intervals per run, repeating 10 to 30 times with random variation to develop an adequate sample. Two types of aircraft are considered—indeed the capability to consider two types simultaneously is one of the main improvements made in the second model; e.g., maintenance support may be provided by the same (simulated) organization to both combat aircraft and tankers.

Alternative methods of investigation were considered. Gaming is one way of studying maintenance operations. LP-II and LP-IV, discussed next, both do so. Both these games, however, are supported by complex computer models and hence cannot be considered precisely alternatives. It is difficult to conceive of analyzing maintenance with a manual game. The true alternative seems to be an analytical model, and there were basically four reasons why simulation in this case was chosen instead.³⁵

(a) Transient states are the states of interest in this problem, and analytical models sometimes can be solved only for the steady state.

(b) Analytical models sometimes force use of particular distributions, e.g., the negative exponential in queuing models.

(c) Analytical models tend to be both more simplified and more rigid than a monte carlo model of the same situation; the latter has desirable flexibility, e.g., details may be included simply with the thought that they may turn out later to be of interest.

(d) It is easier in a simulation to localize the cause of an incorrect prediction, e.g., whether it is due to a poor model, bad data, or flaws in the underlying theory being modeled.

Of course these reasons are not thought to be conclusive; choice of simulation as against analytical methods remains a matter of judgment and taste in present conditions.

Minuteman Maintenance (Boeing-RAND). RAND's computer-assisted game, LP-II, discussed below, studied maintenance support for a missile organization. Application of LP-II results to the case of Minuteman was desired by the Air Force, and it was felt this could be accomplished by a computer simulation without going to a full-scale game. But before designing such a simulation RAND analysts found that the Boeing Airplane Co. at Renton, Wash., had programmed one (in early 1961). RAND then programmed an adaptation of the Boeing model for the 7090, and this adaptation is the one considered here. A simpler RAND model of the same general subject matter exists, programmed prior to LP-II.⁴⁰

Descriptive details of the model are classified; it will be treated in a RAND report on Minuteman logistics now in preparation. The same general problem is discussed by Steger and Winestone.⁴⁰ It is a critical-event, stochastic type simulation; the time for one run varies from 15 min to 2 hr, depending on certain parameters.

Heath Facility (RAND). The Air Force's Heath Facility will in the future test and maintain missile guidance systems according to a concept of computer-controlled diagnostic equipment still in the design stages with Air Force contractors. The object of this simulation is to help determine effective test and maintenance policies for use of the simulated equipment and hence to contribute to decisions on design and layout of the facility.

A first model of the simulation has been programmed this year and is incidentally the first operational program written in SIMSCRIPT.* This model is in effect a feasibility test of the method and guide to the precise engineering data that will be required in the second model. The plan later would be to turn both the simulation and the SIMSCRIPT language over to the Heath Facility as a tool for continuing use.

The simulation is critical-event, stochastic in type, programmed for the 7090. A report has not yet been written.

All-Computer Model, LP-IV (RAND). RAND's LP-IV "Laboratory Problem IV," is a game that will be described in the next chapter. Its primary purpose is to develop maintenance management and information systems for SAC multiweapon bases. The all-computer model of LP-IV is a computer simulation, under design in the summer of 1962, which will attempt to cover the same ground as the game to the extent this proves possible. This effort is of considerable theoretical importance and should provide new information about the relations between gaming and simulation methods, their complementary use, and the limitations and advantages of each. The first version of this simulation, for the 7090, is also one of the first to be written in RAND's newly developed language, SIMSCRIPT.

*Also see the section "Technical Problems."

Supply Control

QM Supply Control (RAC/ORO).^{9,7} This simulation, of which actually four versions were programmed for the 1103 computer in 1955-1956, represents that segment of the Army supply control system dealing with sized clothing items. The emphasis is on requirements determination and long-term balance of total depot system stocks, not on stock control or inventory procedures. Demand and the distribution of demand over many sizes are assumed to be estimated with random error, and demand is itself a random variable as is the production lead time.

The simulation is time-slice, stochastic in type, considering approximately 100 quarterly periods (i.e., 100 quarters in one version, 115 in another, etc.) of operation of the system. The simulated operating results were compared with actual Quartermaster accounts, the reasons for differences determined, and either new runs made or a new version programmed. Thus the use of the simulation was as a research tool (a substitute for field experiment) to aid in determining the causes of objectionable behavior of sized-item stocks and to assist in designing new procedures for their control.

Inventory Control

Generally an economic inventory policy is a rule determining order quantities thought to be near optimum (in some economic sense), as a function of certain cost and demand estimates. Simulations in this field commonly are designed to compare the effects of different rules, operating in the same conditions of random demand, random delays in delivery of new stock to inventory, etc. The five that are listed include three specifically designed to represent Army situations (one Canadian, two US) and two others dealing with very similar situations in the Air Force.

Army Inventory Policies (Harbridge House). In developing inventory control policies for the Army, Harbridge House has used the sequence: theoretical study, simulation of recommended system, field test of recommended system, and implementation; this has been done twice, once at the level of post, camp, and station inventories, and once at the national-depot-system level. The station level model,⁴¹ programmed for the 650, permitted comparison of simulated operating results of the Army's Field Stock Control System with those of the contractor's "Economic Inventory Policy," under random demand. The national level model⁴² similarly compared results of operating under AR 710-45⁴³ with those obtained from using "economic order quantity" rules and "statistical safety levels."

Air Base Supply System (RAND).⁴⁴ This simulation, programmed in 1954, was probably the first logistics simulation. It is an idealization of base supply support operations in the sense that it is a model of the supply procedures in Air Force Manual 67-1⁴⁵ and assumes these procedures to be followed to the letter. Its purpose is to determine the effect on supply support costs of varying safety level and requisitioning policies in the face of random demand.

The simulation, programmed for the 701 computer, is of the time-slice type, stochastic (in demand, assumed Poisson), and considers a 1-month time interval in runs of 200 intervals (after running through the effects of initial conditions).

Air Base Inventory Control (RAND).⁴⁶ This is an extension and refinement of the Air Base Supply System simulation. The capability for base repair in certain cases is included; resupply times as well as demand are stochastic, and up to 10 different and arbitrary demand distributions may be programmed in advance to enter any one run. The time period is arbitrary (although $\frac{1}{2}$ week was used), and a run may comprise up to 9999 of them.

The simulation is time-slice, stochastic in type, and was programmed in 1958 for the 704.

Ordnance Inventory (CAORE).⁴⁷ This is a simulation programmed for the 650, which reproduces the history of one spare part at Spare Parts Stores Section level at each run. It is of time-slice type, stochastic with respect to lead time and demand. The Wilson reorder rules, familiar in inventory theory, and present Canadian procedures are simulated for comparison of results.

Depot System Simulator (MIT).⁴⁸ This is a 704 program, an earlier version (due to M. Simond) having been programmed for the Whirlwind computer. It reflects some aspects of the stock control problem faced by the former US Army Ordnance Corps. Specifically simulated is the operation of " . . . a geographical complex of cooperating depots stocking a given item of supply for a captive demand." This involves representation of post, camp, and station level demand on each depot for the item, filling or extracting (i.e., forwarding the requisition through established channels to another depot) demand, interdepot transfer shipments, and replenishment of stocks through Army manufacture or commercial procurement. The simulation is stochastic with respect to period demand on the depot. Its purpose is to analyze effects on stock quantities and costs of operation of changes in stock control and inventory policies.

Comparison of Computer Simulations

Computer simulations include so many mechanical features that the temptation to try to compare them mechanically becomes irresistible, and one sees statements such as the following: "Simulation A has 10,000 program instructions while B has more than 15,000."* But from another aspect, simulations are collections of algorithms, i.e., they are mathematical models, and mechanical comparisons are like saying, "Mathematical Model A has 125 equations; B has only 50."

The present review encouraged a belief that systematic study of specific simulations can lead to improvements in technique but that most comparisons of simulations, at least in the present state of the art, are not very productive. This holds, for the most part, even for simulations dealing with ostensibly the same topics. Inventory control is perhaps an exception, and point-by-point comparison of simulations might conceivably yield results of interest to specialists in that field.

There are several reasons for this conclusion. In design of a simulation one seeks economy and speed on the one hand, power (in problem-solving) on the other. These objectives conflict to some extent, or are likely to conflict. Thus a superficial simulation of a supply system might run through 100 years of simulated operation in 2 min on a low-cost computer and print out all the

*Since the number of machine-language program instructions for a program written in one or more of the new languages is often not available, such statements are becoming less frequent.

results in 10 lines, apparently representing speed and economy; yet if the results tell little beyond what is obvious, such simulation would be considered to lack power.

The opposite case has occurred in practice more than once in recent years. That is, a simulation of extreme complexity is programmed, which requires so many hours for input preparation, running time on a high-cost computer, and analysis of the voluminous output, that considerations of economy and timeliness limit the use of the putative power inherent in the model.

It comes down to the fact that general criteria for this methodology, such as would provide a basis for intelligent comparison of simulations, have not yet been developed; there are just too few cases of completed work on which to found such criteria.

Testing Simulations

No attempt will be made here to say anything definitive about the vexed question of "validating" simulations. This section is simply to record observations that tend to support the conclusion in the preceding section and that may be of independent interest.

An effort was made to determine, for each of the simulations listed above, whether or not its output had been tested by comparison with reality. But it proved that this could not be determined with any real precision, and hence the determinations that were made have not been reported. The reasons for this give further insight into the state of the art.

First of all it appears that authors of simulations have not made, generally speaking, any systematic effort to assure a test of output. In other words, testing in any definite sense has not usually been recognized as a formal requirement to be satisfied in the design of a simulation. (It is notable in the literature that some work that pays close attention to statistical rigor, control of variance, etc., pays little or no attention to tests in the sense of comparison of output with reality.) There are exceptions. For instance RAND's Rainey and Levine evidently made explicit provision in the design stage of their base-maintenance-operations simulation for comparison of the output with actual maintenance operations.³³ And several simulations get a test of sorts by reason of their objectives. Thus RAC/ORO's QM supply simulation was designed to produce stockage records for comparison with actual records then under study;⁹ and the Harbridge House inventory simulations embodied policies that were given service tests at the next stage in a prearranged testing and implementation procedure.^{41,42}

The main difficulty lies in formulating precisely what is meant by "comparison with reality." It seems that the author of almost any logistics simulation could claim that his work had received a test, in some sense (e.g., a manual computation using queuing tables yielded numbers with which certain outputs of RAND's Minuteman maintenance model were compared); on the other hand it is questionable whether any of the tests and comparisons cited in the literature would completely satisfy a rigorous standard. One conclusion is that drafting at least a tentative procedure for comparison of simulation results with observables would be worth while at this stage for any research group making much use of this method.

GENERALIZATIONS

As promised, a few generalizations on the state of the art in computer simulation (in logistics) will be attempted here, based on the 19 simulations dealing with 7 different logistics problem areas that have been described in some detail.

Reporting

Poor reporting of work in this field is notable. The main evidence of it that appears in the preceding pages is the number of simulations for which no published reports yet exist (3 out of 17, omitting two simulations on which work is still in progress). More conclusive evidence is obtained by reading the reports cited; the reader who undertakes this will find a great diversity of ideas on what ought to be included in the report of a simulation. A few authors^{25,27} give enough detail so that the program could be reproduced from the report, but from others it would be impossible to draw even a general block diagram. Statistical details are very commonly omitted (the CAORE Report 107⁴⁷ is an exception). Mechanical facts such as the designation of the computer, the size of the program by some suitable measure, the number of man-years to design, code, and check the program, and the date when design began and when the program became operational, are commonly either omitted or presented in helter-skelter, incomplete fashion. In short the literature is not at all comparable either with that of experimental science or that of applied mathematics. This may constitute indirect evidence for the conclusion that this methodology is in a stage too early for criteria of adequacy to have been developed.

Complementarity of Methods

It is suggested by the evidence assembled in this section, and confirmed by that in the next, that good current practice treats computer simulation, gaming, computer-assisted gaming, certain types of related mathematical analysis, and experiment as complementary methods. The art consists precisely in their harmonious application to solve problems. Thus cases exist of simulations used to assist in design and conduct of field experiment (e.g., SRI, Medical platoon), in place of field experiments (e.g., RAC/ORO, QM Supply Control), as preliminary to a field test (e.g., Harbridge House, inventory control), in place of mathematical analysis (e.g., RAC/ORO, battalion maintenance, and RAND, base maintenance), in place of an unsuccessful map exercise (e.g., CORG, POL), to extend results of a large-scale computer-assisted game (e.g., RAND, Minute-man maintenance), and in conjunction with a large-scale game (e.g., RAND, all-computer model of LP-IV).

The use of related mathematical methods was mentioned above. This refers to the use of algorithms or procedures complex enough to require the support of a big computer but not categorized as simulations. Although in practice these methods tend to be employed by the same people as use simulations, and on the same or similar problems, they are not conveniently discussed in papers on simulation, a fact that may have given a misleading impression. Good examples of such methods are a graph-theoretic method of analysis of large transportation networks developed by RAC/ORO's Logistics

Gaming Group,⁴⁸ a very similar procedure used by the GWU-LRP,⁵⁰ and a linear programming procedure used by the Mobility Project in RAND's Logistics Dept⁵¹ to study the intertheater airlift problem for which simulations (discussed above) are also used. Actually, in the latter case, both methods have been tried on the same problem, and the linear programming routine is the preferred tool, at least for the time being. All three of these computational procedures have been programmed for the 7090.

Purposes of Simulations

It should be noted, although it is perhaps not especially surprising, that the purposes to which simulations are being put in logistics research are diverse; simulation is, in this sense, a general-purpose tool. Previous discussion has shown this by exhibiting existing simulations, first against the echelons of Army logistics (Table 1) and next against a list of functional problem areas (Table 2).^{*} From still another point of view, simulations are found in use for analysis of equipment characteristics (e.g., SRI, amphibious logistics), of transportation systems (e.g., the strategic airlift models of RAND and SRI, and RAND's model of cargo lift), of management systems (e.g., RAND's all-computer LP-IV), of shop layout and procedure (e.g., RAND's Heath Facility simulation), and as a military planner's tool (e.g., SRI's AIDS and NWL's ship-to-shore model).

Increased Use of the Method

The results of this study indicate that the use of computer simulation in logistics research has increased monotonically every year since 1957.[†] Notes on projected simulations and discussions with working research people suggest that this trend will continue, although such indications cannot always be relied on. The important facts here are that increased use of the method has been recorded despite formidable technical problems, and that at least one of these problems seems now to be on the verge of solution, as discussed below.

Technical Problems

A series of difficult technical problems continues to face the authors of computer simulations. One is the problem of validation or testing, mentioned above, for which a clear-cut solution is not yet in sight.

A second problem, or rather complex of problems, has to do with statistical characteristics of design and output of simulations. This includes questions of sample size, significance, and procedure for analysis of results. In particular, Charles E. Clark, at Systems Development Corp., is conducting research on the difficult and central problem of control of the volume of computation required to produce significant results from simulations; only an early stage of this work has so far been reported.⁵²

A third problem that may now be on the verge of solution is, as expressed by H. Markowitz of RAND, that "Simulation has suffered . . . from the fact that it usually takes several times as long to develop the computer program as it

^{*} Although the list in Table 2 is not exhaustive, those familiar with Army logistics will recognize that it represents quite broad coverage in view of the small number of simulations that have been completed.

[†] The monotonic property depends to some extent on the year to which simulations programmed over 2- or 3-year periods are assigned. In any event the trend is up.

does to formulate the simulation model.⁵³ The burdensome, excessively time-consuming process of programming simulations has had two effects over the past 5 years: It has discouraged creative workers not primarily interested in computer programming from using this method, and it has limited the willingness of research management to budget for simulations.

Markowitz has developed SIMSCRIPT, a " . . . programming system and source language that is specially adapted to the problems of writing simulation programs."⁵³ If the encouraging preliminary results already obtained by RAND analysts with SIMSCRIPT* are confirmed, it may well prove that this problem has been solved. In addition to RAND's effort, simulation languages are being produced by others, i.e.: SIMPAC by Systems Development Corp.;⁵⁴ CL I and II by Project OMEGA of Technical Operations, Inc.;^{55,56} and MILITRAN by Systems Research Group, Inc., under contract to the Office of Naval Research,⁵⁷ the last being designed especially for weapons systems simulations. Note incidentally that all these languages are written primarily for the 7090.

NAVAL SIMULATIONS

More detailed consideration has been accorded in this paper to simulations of Air Force problems than to those of naval problems, for reasons more or less obvious in light of the Army orientation of the paper as a whole. Air Force logistics problems can be fitted conceptually into an Army scheme, as in Table 1; but this would be difficult or impossible to do in a meaningful way with naval problems. However, a number of computer simulations of US Navy logistics exist, to which an interested reader may wish to refer for methodological details. For example, a simulation programmed for the 650 by the General Electric Technical Military Planning Operation (TEMPO)⁵⁸ is designed to evaluate operational availability of the Polaris guidance system as a function of maintenance, an objective similar in principle to that of three of the maintenance simulations discussed above. A second simulation by TEMPO, indirectly for the Navy,[†] represents maintenance and related logistic activities at the Fleet Ballistic Missile tender, together with relevant activities of submarines alongside.^{59,60} Specifically studied are the movements of modules or repair parts from failure on the submarine, through various test and repair channels, to storage or reinstallation, with queuing at each channel and stochastic service times. The program is for the 704.

A second group of simulations deals with the Navy's "allowance list" problem, i.e., the problem of determining which items to stock aboard ship and in what quantities. One example, designed by the Navy's Logistics Research Project at George Washington University for the Office of Naval Research (ONR) Logistic Computer, compares the effect of various allowance policies over several simulated years as measured by shortages, amount of reordering, etc., and more importantly, with respect to the estimated influence on military effectiveness.⁶¹ This work was later extended at Navy request in an application to the Polaris program.⁶²

*See previous descriptions of the Heath Facility and LP-IV all-computer models.

†It was done directly for General Electric's Ordnance Dept as one element in a series of studies of support requirements of the Fleet Ballistic Missile system.

Finally there has been a series of simulations designed to test or investigate inventory-control rules, in the usual sense, for the Bureau of Supplies & Accounts of the Navy. These have been done largely by SRI and PRC and are similar in principle to the Army inventory simulations described above.

Chapter 3

LOGISTICS GAMING AT RAND AND RAC

The RAC/CRO games are the only examples of gaming specifically designed for the study of US Army logistics and management systems. But only two have been tested, and one of those only in a training context. The only examples of logistics gaming thoroughly tried in research on problems sufficiently analogous to US Army problems to justify their close examination are the RAND Air Force games and the British Army Logistics Game.⁶³

Although the latter has not been in use for some years and deals with a highly specific situation, it is a unique example of methodology and must be included in any complete study of the subject. It will not be discussed any further here because of its classification, but an adequate description will be found in the reference cited. The conclusions of this paper must rest primarily on the RAC and RAND games discussed in this section and in the following section, which deals with tactical games having a logistical element.

LOGISTICS GAMING AT RAND

The Logistics Systems Laboratory (LSL) is the scene of logistics gaming at RAND. The principal facility is a 50- by 50-ft room with a central, glassed-in, overlooking balcony equipped for monitoring phone conversations. The room is fitted with desks, phones, office equipment, temporary partitions, and a digital computer close at hand. Thus a team of managers, or more than one team, may be installed in the room in conditions approximating those in the Air Force logistics system. The computer may be programmed to generate the operating results of a simulated military establishment, which are reported to the managers and provide a basis for their decisions. The managers are normally provided with clerical support, and the computer also may do bookkeeping and computational chores for them. Managerial activities may continue in this setting for several weeks or months, possibly with rotation of personnel on temporary duty (TDY) from regular assignments in the Air Force.

In the terminology established for this paper, this activity constitutes a computer-assisted logistics research game, supported at times by one or more computer simulations of related systems or subsystems. RAND conducted the first and second "Tooling-Up Exercises"^{64,65} for its Logistics Systems Laboratory between October 1956, the date of activation of the laboratory, and March 1957. Since then three games have been completed—LPs I, II, and III. LP IV is currently under design.

LP-I,⁶⁶⁻⁶⁸ designed and run in 1957, considered the Air Force Logistics System as modified by three major policy changes that had been developed in RAND's Economics Division. Comparison of the modified system with the existing one was attempted. The same set of simulated operations was managed by a team using the modified system and occupying one-half the laboratory room and by a second team using the existing Air Force system and occupying the other half. Both were monitored from the balcony, and the cost and effectiveness of their operations were compared.

The three policy modifications were deferred procurement of high-value parts; theoretically more economical procurement, distribution, and repair of low-value parts; and automatic resupply of low-value parts, together with use of an electronic data-processing center (EDC).*

Each of the two systems comprised 10 Air Defense Command bases (as their lowest echelons) and 10 base managers were assigned on TDY. The next higher echelon, Logistics System Managers, had five specialists from the Air Materiel Command. Hence, 30 Air Force personnel were assigned to the game; there were 20 clerks, including programmers and machine operators; and the RAND professional staff in the Laboratory totaled 30. The computer simulation of the physical system being managed, as programmed for the 704, comprised more than 25,000 program instructions.

LP-II,^{69,70} designed and run in 1957-1958, considered a (future) missile squadron with launch complex and support unit, with the objective of developing an effective management system for support. There were 10 managers and 14 lower-level assisting Air Force personnel on TDY, clerical and computer-operator support, and more than 30 on the professional staff.

The first step in this study was a computer simulation of the missile squadron on the 704. This was then supplanted by the game itself with supporting simulations (e.g., a missile malfunction generator). Finally an analytic model of the support system, including a stochastic queuing model, was programmed for the computer, together with a costing function.

The complementary use of these three tools is characteristic of some recent work and its objectives are worth examining. The original computer simulation was used, with experience gained through repeated trials, to indicate a preferred size of squadron organization. Several operations research studies of similar problems have stopped at this point. The hypotheses of the computer model were, however, relatively crude compared with those used in constructing the game itself; e.g., 100 components were used to describe the missile and associated equipment in the simulation, 1500 in the game.

The object of the entire exercise, it should be borne in mind, was to develop, really to invent, a support system better for its future purpose than any known system. The game, exploiting the resourcefulness of experienced managers and the creative ingenuity of analysts associated with the laboratory, proved a more effective tool for doing this than did the computer simulation.

The game on the other hand, partly because the number of replications of any game is so severely limited, did not prove a good method for sensitivity analysis of results. The original computer simulation had some capability in

*Of course, this is a simplified statement; each policy improvement includes many detailed features not mentioned here. For a full discussion see pertinent references.⁶⁶⁻⁶⁸

this direction but, as mentioned above, had not been constructed from the same relations and data as used in the game. Hence an analytical model was developed, simplified in some respects as compared with the game, but employing the same data and relations (e.g., 1500 components described the missile); its output was directly comparable with that of the game and it was used to carry out a sensitivity analysis. The analytical model, including among other things the stochastic queuing model, involved very lengthy computational procedures. Hence the analytical model, together with a costing function, was programmed for the 7090 computer.

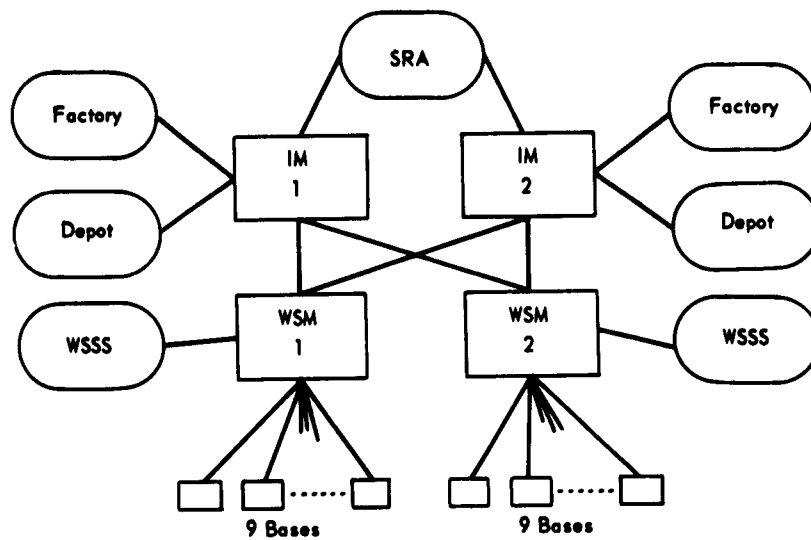
LP-III⁷¹ was designed in 1959-1960 and the 17 plays of this game (called "runs" by RAND) were completed during 1961. The object of the game was quite different from that of LP-II; it was aimed at improvement of the Air Force "supply support" system (a term that appears to be equivalent to "supply control" in Army usage).

Motivation of the study in which this game was the major method was RAND's appreciation of two facts: (a) More is likely to be demanded of the USAF supply support system in the coming decade; and (b) a new potential for improvement in management of supply support has been or is being created by introduction of transceivers and computers, by reduction of transportation times based on increased airlift, and by introduction of computer-assisted scientific inventory control procedures.

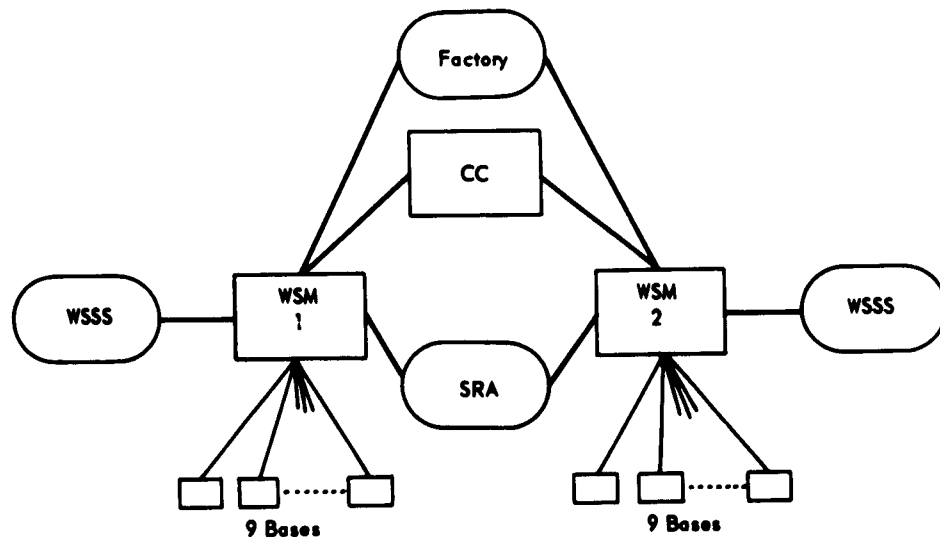
It was assumed that an integrated support system, which the Air Force does not now have, could take maximum advantage of the potential in new management tools. The principal goal of LP-III was to define the general structure of such a system and to examine it "... to determine the nature of the problems involved in its implementation, operation, and control." Specifically the game was designed to answer the following three questions: (a) How can the support system be integrated? (b) How responsive should the system be? and (c) How should an integrated and responsive system be organized?

Two organizational cases were taken in LP-III for alternative use in successive plays. These are shown in Fig. 1. As in RAC's multilevel game some, but not all, functions in the real system are aggregated in player stations such as Inventory Manager, Weapon System Manager, and a Supply Manager for each of 18 bases. The simulated system with which the managers could work to accomplish their support mission included a depot-repair facility, a production source (factory) for new procurement, a transportation system, and a data flow system. The military establishment, the operations of which were simulated, and which the system managers were required to support, consisted of two weapon systems, both missile systems "... with 210 missiles per weapon at full program . . . , " and both deployed over nine base complexes. Supply support, for purposes of these gaming experiments, was restricted to 64 costly (i.e., category I and II-R) spare parts, highly repairable and common to more than one weapon.* Clearly then, LP-III does not belong to the class of comprehensive games designed to reproduce an entire military system in its

* This may sound like a restricted number of parts. But RAC/ORO experience of logistics gaming indicates that although depth and richness of the experimental situation increase with number of items managed, technical control and feasibility become harder to maintain; 64 items can be a very large number, depending on game structure. (See the later section in this chapter, "Number of Supply Items Managed.")



a. Case I



b. Case II

Fig. 1—LP-III: The Two Organizational Cases

SRA, Specialized Repair Activity
 IM, Inventory Manager
 WSSS, Weapon System Storage Site
 WSM, Weapon System Manager
 CC, Commodity Coordinator

combat environment but is designed like a laboratory experiment to investigate specific characteristics of a system and the interactions of certain of its parts.*

A fundamental restriction was embodied in the game design, which was aimed at study of the short-term relations only. That is, each play covered 7 to 9 months of game time; and since procurement lead times in the military systems are generally longer than this, procurement and other long-term factors had only slight effects on management results.

In its general technical characteristics, LP-III resembled its predecessors LP-I and LP-II. The Air Force supplied 42 technical specialists from AF Logistics Command who rotated in and out for 1- or 2-month tours as managers of the LP-III system during simulated operations. The game was computer-assisted in a sense similar to that in which the Army's LOGSIM-WC is said to be computer-assisted (see the later section in this chapter, "Experiment in Computer-Assisted Technique"); e.g., requirements computation was mechanized

Weapon system	Case I		Case II	
	1	2	1	2
Property Class 1	9 Bases 64 Parts per base	9 Bases 64 Parts per base	9 Bases 64 Parts per base	9 Bases 64 Parts per base
Property Class 2	9 Bases 64 Parts per base	9 Bases 64 Parts per base	9 Bases 64 Parts per base	9 Bases 64 Parts per base

Fig. 2—LP-III: Basis of Factorial Design

in LP-III (as it is in LOGSIM-WC) so that managers or their clerks do not have to spend time computing requirements manually. As contrasted with LP-I, a trend toward firmer experimental design is perhaps observable in LP-III; e.g., although two organizational cases were considered in LP-III, they were not simply compared: 17 successive plays were conducted in which not only the organizational case but length, stress (on the system), and several system characteristics were varied. More specifically, plays were scheduled in accordance with a factorial experimental design of 19 variables and more than 1000 interactions, according to the scheme sketched in Fig. 2.

*The costly item categories studied in LP-III are estimated to represent 11 percent of line items in the Air Force inventory and 65 percent of inventory cost. In this and in its concentration on short-term effects the LP-III problem resembles the one attacked by the Army, first in "Project 170" of the US Army Ordnance Corps and later in the Deputy Chief of Staff for Logistics' "Project MASS."

LP-IV, is an exercise whose object, like that of LP-II, is to develop ab initio management systems and information systems for a future operating organization while obtaining some estimates of feasibility. Specifically a multi-weapon base will be studied, including perhaps several aircraft weapon systems and air-to-ground and ballistic missiles. Development of maintenance management systems, including policies for scheduling and allocation of resources, new data-processing systems, and automation of certain management procedures will be undertaken with the aim of maximizing operational capability per support dollar under various conditions. The gaming and computer support techniques will be similar to those described above except that an increasing level of technical sophistication may be expected; e.g., the 1401 computer will perform functions handled in earlier games by a staff of clerks. The plan is for a mock-up trial of the exercise in the summer and floor runs for usable results in the fall of 1962.

General Purposes of Logistics Systems Laboratory

As the descriptions just completed suggest, RAND's logistics gaming activity in the LSL represents one of the major efforts in logistics and management systems research; indeed, the budget for this work has run from \$1 million to \$1.5 million per year for the whole period from its inception in November 1956 to date, not including the salaries of Air Force personnel on TDY. This budget has been from 5 to 10 times the budget for RAC's Logistics Gaming Group over the period November 1957 to date.

RAND has pursued certain fundamental aims in organizing and continuing the LSL and has from time to time drawn conclusions from experience with it. These are relevant and will be discussed here to the extent that they tend to clarify functions peculiar to gaming, results obtained by gaming that are not obtainable otherwise, and limitations of gaming.

One of the main aims of gaming in the LSL, as viewed at the time of its founding, was to bridge the gap between research solutions to logistics problems and implementation of the solutions, neither the Air Force nor RAND having been satisfied with progress in implementation of results obtained by RAND's Logistics Dept, then 3 years old (see Geisler⁶⁷). This aim does not appear to have been fully realized yet, but progress toward it seems to have been made. For example, it was recognized in the design of LP-III that answers to research questions would be subject to considerations of administrative feasibility. It was anticipated that the game would introduce a large fraction of the administrative interactions explicitly and hence help to settle the question; this was found to be so. Moreover the design of the game subjects administrative characteristics of the system to trial and critical judgment by a relatively large number (42 in this case) of Air Force professionals. In consequence of these facts RAND was able on completion of LP-III to "... draw the provisional conclusion that it would be administratively feasible to operate an integrated support system like LP-III in the Air Force support environment."⁷¹

This is a notable conclusion. The question how to assess administrative feasibility of solutions to logistics problems obtained from theoretical economic analysis, mathematical analysis, or computer simulation, has been largely a closed book. Frequently the question has been ignored by the research group

and left to the client to settle. Hence even a provisional conclusion about administrative feasibility has importance.

Of course an attempt to judge administrative feasibility by tests in service or pilot installations is possible. RAC/ORO's experience with this method is inconclusive. Harbridge House, on the other hand, which has conducted continuing studies for improvement of Army inventory and procurement policies, considers that their experience "... has demonstrated the great usefulness and reliability of inventory simulations,* both as a method of research and of pretesting new inventory applications."† They consider that study, pretest by computer simulation, service test, and finally implementation monitored by the research group have "... proved thus far in the EIP [i.e., Economic Inventory Policy] program to be the best guarantees of successful application of novel research ideas."⁷²

RAND on the other hand considers (and some RAC/ORO experience tends to confirm) that "... service tests are not always able to isolate the influence of the novel policies and procedures, and so they do not often demonstrate conclusively the value of a proposed innovation." This view entered into RAND's decision to carry on the gaming activities in the LSL, as did their opinion that service tests are costly and tend to disrupt operations. It is RAND's belief that proper use of gaming may obviate the need for service test prior to implementation. Finally, RAND considers that in research for the military, proposed new policies should be subjected to some simulated wartime stresses such as are possible in a game.⁷³

Of course in research to develop a system for future use in a situation that does not yet exist a service test is not a promising method. In the case studied in LP-II, not even a pilot installation would have been feasible. The game in effect took the place of a pilot installation; the objective of the game "... was to integrate the physical system, the human organization, and the information system into an efficient and consistent overall working system."⁶⁹

It is worth emphasizing that supporting research, together with long periods for game design and analysis of game results, has been a feature of RAND's method from the start; "... gaming of this kind must be an adjunct of a larger research effort that also uses traditional means of research ... For a few months of enactment on the floor, there is perhaps a year of preparation."⁷³ At least the latter part of this statement, written at the time of LP-I, has been reinforced by experience since then. The current aim of RAND staff experienced in gaming is to arrive at a cyclical schedule keeping one game in the design stage, one in operation, and one in the analysis stage at all times.

Those who have attempted computer-assisted gaming recognize that this is a little-understood technique, exceptionally difficult to handle. Certainly one of the notable things about the LP series of games is the technical experience in computer-assisted gaming that they represent. The support of the LSL

*This means computer simulations as defined in this paper.

†Note, however, that as discussed above in the section on simulations, inventory simulations are a highly special case.

by RAND's Computer Sciences Dept has without doubt been an important element in the development of the series.

Air Force vs Army Logistics Problems

A RAND author has pointed out that LP-I "... simulated, with people and computers, a very considerable part of the Air Force supply system."⁷³ LP-I represented (see the earlier section on the LP-I) 10 Air Defense Command (ADC) bases and 5 Logistics System Managers at the next higher echelon. It is evident to anyone familiar with Army logistics that a comparable structure could simulate at most only a small fraction of the Army supply system. At the time of LP-I, for instance, Army supply alone (forgetting other logistics functions) was managed through seven technical channels, each in turn controlling from one to five or more national inventory control points (NICPs). Under each of these NICPs came a complex of depots, or sections in Army general depots, with their satellite depots. Finally, for support of overseas theaters (the main task of Army supply in wartime) a series of separate agencies entered the system: overseas supply agency (OSA), Military Traffic Management Agency (MTMA), and several terminal commands. In any overseas theater another self-contained and in some respects more complicated logistics system takes over; or more precisely, there are two such systems, one for the communications zone and one for the combat zone. Of course the Army logistics system supports the Air Force, wholly or in large part, in the theater of operations.

Although the Army system has changed, and is changing in detail (most recently under the Army reorganization of 1962), it remains large and complex. It comprises a multiplicity of separate systems and of levels within systems, such that ideas of overall integration are probably not meaningful beyond a certain point (taking an example at random, it is probably not meaningful to speak of integrating supply of tactical atomic weapons, treatment and evacuation of casualties, and distribution of storage batteries, when each is a very large-scale operation).

With the Air Force, of course, a comprehensive, integrated concept of logistics is difficult to construct, but it can be done. The RAND author just quoted has attempted this, as follows:

The Air Force is in the business of keeping aircraft in commission (particularly important in the case of SAC [Strategic Air Command] bombers and ADC interceptors) and generating flying hours (primarily for training). These two "outputs," which to some extent are economic alternatives, require various inputs. The most important ... are maintenance personnel, maintenance facilities, and spare parts.⁷³

The Army's logistical "business" is inherently more complicated, and this is a fundamental fact to be kept in mind when comparing research methods and results. RAND's gaming seems to have profited from resting on at least a tentative comprehensive view of the whole system, with appropriate selection of key problems, of severely limited scope, for study. In comparable research by Army contractors there has been a tendency either to pick out limited problems on almost an arbitrary basis or to try to attack a large, ill-defined complex of problems, e.g., to try to "solve" the "problem" of "logistics in the theater," or of "logistics in the field army."

LOGISTICS GAMING AT RAC/ORO

Logistics gaming at RAC and its predecessor organization was carried on by the Logistics Gaming Group (Project 24.1) from its activation in November 1957 until the establishment of a Division (Logistics Simulation Division) for this and related purposes in May 1962. Since the group comprised five or at most six professionals during this time it is clear that the scale of effort is not comparable with that at RAND.

The approach adopted was one that seemed appropriate with respect to the size of the group. It was decided to proceed by completing work in series on specific problems, each possessing a definite potentiality of payoff for the Army, and chosen in addition for relevance to the development of gaming methodology. At the same time it was necessary to rule out procedures involving large permanent facilities such as the LSL.

It would be difficult to justify this approach over the long run, but it was possible to accomplish a certain amount by means of it over the 5-year period 1958-1962 using a number of expedients. For example, the Wholesale-Level Game, described next, was extended to a good-sized training exercise using Army personnel working with the Group on a temporary task basis. Army facilities were provided, of course, for the training exercise itself; and later it was extended to computer-assisted form under a contract funded directly by the Army (with IBM Federal Systems Division).

Essentially four distinct study results have been accomplished by the Group in the 5 years 1958-1962 (the last is currently approaching completion, scheduled for December 1962) as follows:

The Wholesale-Level Game⁷⁴

This is a one-echelon game dealing with the Army equivalent of the Air Force problem area studied in RAND's three-echelon game LP-III, Case 1. On the other hand the functions within the single echelon are broken out and studied in greater detail than apparently is the case in RAND's game.

This game, under the above title and as a research game, has not been carried beyond the design stage, or rather the first phase of the design stage, at RAC. However, in the summer and fall of 1958 a joint Army-ORO team developed this tentative design into a completely detailed training exercise,^{75,76} which the US Army Logistics Management Center (USALMC) then implemented. Considered strictly as a training game this is not of interest here, and the training aspects will not be discussed. Considered as a "laboratory" for the study of gaming technique, however, the training exercise has been found to be of substantial and continuing value to the research group; and, in fact, it has provided a basic methodological capability to proceed quickly to the study of large-scale Army management systems problems. Some specific respects in which this has proved true are as follows:

Testing by Faculty and Several Generations of Students. The training game, called LOGSIM-W(holesale), sustained a series of faculty tests and revisions at USALMC in 1958. Since then approximately 2000 officers and civilian logistics managers from the Army system have participated in the exercise, with critical postmortems following each class. This has provided a made-to-order

test-bed for determining realism of game features, relation to organizational attitudes, and a complex of related questions, e.g., the difficult question whether or not the game structure permits a satisfactory scope for the exercise of professional judgment. Of course, a number of technical improvements have been found since 1958. It remains to exploit the results of this critical testing in research applications.

Development of a Scoring System. The immediate object of this development was to permit seven or more teams of officers and civilian managers to play against the same scenario* in parallel while being scored in such manner as to permit a final comparison of their relative success. While developing the scoring system, and later helping to adjust it, the research team gained insight into the deeper problem of developing cost and effectiveness measures for this game. Further, monitoring the practical administration of the scoring system since 1958 has yielded useful information on techniques of cost and effectiveness measurement in the game. The scoring system reflects, first, effectiveness of managers in meeting demands on the system, weighted by the military importance of the item, which furthermore may vary with the changing military situation; second, variable costs of operation; and, third, degree of conformity with control regulations.

Number of Supply Items Managed. This question, which sounds trivial at first, seems to be both difficult to answer correctly and crucial to success of a logistics game at this level. Again, experiments with the training game have supplied useful information on this factor. It was found that after LOGSIM-W had been brought to the level of realism and complexity considered satisfactory by both groups (school faculty and research team), three supply items were all that could profitably be handled by a six-man team; to put it more precisely, four or five items would have made the game much less satisfactory administratively, without adding much to the scope; dropping to two items, on the other hand, would have greatly reduced the scope. Later it was hoped that in the computer-assisted game, LOGSIM-WC, 100 or even up to 500 items could be managed; but experience led to the conclusion that 25 was approximately the correct number. As noted elsewhere, RAND managed 64 in their LP-III.

Development of Forms. This is a technical problem—a sort of nuisance parameter—in all logistics games of this sort.† Generally a special study of forms in use in the real system has to be made by the research staff and modifications developed, which then often fail to satisfy professional managers in the Service logistics system. In the close working team of faculty and research staff that developed LOGSIM-W, agreement was reached on a basic set of forms (reproduced in full in ORO-SP-106⁷⁵) that fully satisfied both parties, and which, with later improvements, provides a solid starting point for adaptations of the game to research in wholesale logistics systems.

Experiment in Computer-Assisted Technique. Development of LOGSIM-W to the computer-assisted form called LOGSIM-WC by the Army and its contractor, answered a series of technical questions and raised a new series that had not been foreseen. LOGSIM-WC demonstrated, to the satisfaction of those concerned, that properly engineered computer assistance can greatly increase

*Thirty-six months of peace, cold war, war, peace, etc. (see ORO-SP-107⁷⁶).

†See Nelson and Peterson (Ref 71, pp 51, 67) for the discussion of USAF Form 326.

both scope and depth of such a game.* For example, completion of a 40-line Supply Control Study by participants in LOGSIM-W was one factor that restricted the feasible number of items to three. This form was completed by the computer in LOGSIM-WC; 25 items were managed, and this permitted inclusion of principal items in addition to minor secondary items. This inclusion introduced a whole new category of management problems more closely depending on actual deployments of the Army in the field; hence this had a deepening as well as broadening effect on the game.

The Multilevel Game⁷⁷

This game design adapts the traditional three-room formal structure of the war game to logistics research. Instead of a Blue team, a Red team, and Control, the multilevel game comprises a Blue team, Control, and a so-called Situation team.

The game is designed either to test proposed logistics systems or to develop a logistics system to suit a given situation. In the testing case the Blue team operates the proposed system while the Situation team conspires to make it break down; thus the concept of the Situation team is simply an extension and amplification of a function performed either by the scenario or by the Control team in all war games. In accordance with its function, and depending on the system being tested, the Situation team may include specialists in meteorology and terrain, in civil affairs and military government, in refugee movements, in logistics administration, or in tactics. Of course, interference by Situation with Blue operations is subject to the Umpire's decisions.

This game was designed and a series of trial plays at theater level were conducted at ORO in 1958 using as scenario plans of campaign produced by the Army Deputy Chief of Staff for Military Operations (DCSOPS). These trials were not for research purposes but to complete the design. It was then agreed with USALMC, Research and Doctrine Division, to use the game for testing the Army's proposed scheduled supply system, on an arrangement whereby the Army would supply 20 active-duty field-grade officers for two plays of the game. This research had to be suspended at Army request, however, to permit the Logistics Gaming Group to work on the higher priority tasks described next.

It may be useful to compare this game briefly with LP-III, the two having been designed quite independently. A very similar structural principle is used in setting up the stations for the system managers in the two games as shown by comparison of Fig. 1 with Figs. 3 and 4. Of course the complications involved in passing from the zone of interior (ZI) to the theater of operations in the Army system are missing from the Air Force game, and the complications involved in managing item inventories on the one hand and major weapon systems on the other are missing from the Army game. The pressure applied to the system managers by the Situation team in the multilevel game is applied largely through a stochastic computer simulation in LP-III. The comparison cannot be carried much further since LP-III was designed for the specific problem of managing a certain category of spare parts, but the multilevel game is a more general design studying tonnage logistics of classes I, II, III, IV, and V supply

*This is apparently taken for granted by RAND, or was proved by them long ago within the framework of their Air Force studies; the question is not regarded as settled in Army circles, however.

and other Army logistics problem areas in the ZI, the theater, or the inter-theater situations.

Computer-Assisted Transportation Planning⁷⁸ and Strategic Logistics Planning

The two final tasks of the Logistics Gaming Group listed in the heading are discussed together since the study listed first was extended to the second after the adoption of its results by the Army.

The established procedure for making Army plans to support strategic objectives is a species of one-player war game with emphasis on logistics. Campaign plans are written in accordance with objectives. For each such plan so-called Department of the Army Strategic Logistic (Studies) (DASLs) are made. "The DA-SL's develop a plan for logistic support for each campaign visualized . . . , measure the logistic costs in manpower and materiel and identify situations and problems which are likely to arise in support of the campaign."⁷⁹ The purpose of this planning cycle, or one of its primary purposes, is to determine requirements for support of objectives, which in turn influence the Army materiel procurement and troop programs.

Detailed logistic support requirements for a campaign are worked up in seven technical areas corresponding to the seven former Army Technical Services: medical, ordnance, signal, chemical, transportation, engineer, and quartermaster. The two studies under discussion involved development of computer-assisted procedures for doing strategic logistic planning first in the transportation area alone, next in all technical areas. These studies fitted the plan of the Logistics Gaming Group for two reasons: they called for development of methods and techniques of computer-assisted gaming and some related mathematical methods of representation of military situations on a computer; they involved familiarization with the details of technical logistical support in all areas, details that have up to now proved especially difficult to introduce in games and simulations with adequate realism and validity. Experience gained on the two studies, the second of which will be completed this year, is considered to provide the necessary basic know-how for conduct of games and simulations, both for planning and study of systems in the problem areas important to the US Army. The studies will not be further described here since adequate coverage is provided by the referenced report.⁷⁸

GENERALIZATIONS

It does not seem possible to generalize from the record of logistics gaming, even to the extent done previously in this paper from that of computer simulation. Essentially, all US Army logistics research gaming is in the experimental or feasibility testing stage. And RAND's gaming for the Air Force includes only three completed research games, although these were relatively large-scale activities.

The main generalization from RAND's methodological results is that gaming, simulation, and mathematical procedures programmed for the computer are complementary, and this is confirmed by RAC/ORO's experience in (a) computer-assisted strategic planning and (b) design of a logistics game for training purposes.

Chapter 4

RELATION BETWEEN TACTICAL AND LOGISTICAL GAMES

In the opinion of some experts the distinctions frequently drawn between "tactical" and "logistical" games, although plausible, actually hide the real issues. This school feels that, in a comprehensive gaming representation of the battlefield, logistics, intelligence, tactics, and all other military functions ought to enter in a harmonious way, and that a serious defect of so-called "tactical" games designed to date is the failure to represent properly these other elements.

A more essential distinction seems to be the one separating the following two classes of research games: (a) comprehensive games designed to represent realistically the whole situation on the battlefield; and (b) games focused for scientific study of specific, more narrowly defined problems.

Of course the distinction is not absolute. A sufficiently broad military problem may be said to require the whole battlefield as context for study; while even the narrowest systems problem in CONUS conceivably requires some assumption about the status of conflict. The distinction is best supported and studied through a series of examples.

Comprehensive Games

Generally Class a of comprehensive games has been considered so interesting and important, and is so closely related in principle to the big map maneuvers and command post exercises used for training purposes or for testing operational plans, that Class b has been relatively neglected. But for example, a Class b game might perfectly well be designed and used to study the question whether tanks of a certain type can deploy in given territory according to a given doctrine without being observed by the enemy.* Again, such a game might be used to study the interaction between control centers in a proposed theater movement control system. The problem and the game might fairly be described as strictly tactical in the first case and as strictly logistical in the second. Probably no necessary or useful relation exists between two such games; they just represent two different experiments in two different specialized laboratories.

Take for a second example the British Army Operational Research Group (AORG) game for study of vulnerability of intertheater lines of communication

*Actually a simple game of this kind is now being conducted by SRI at CDEC in support of a field experiment.

(LOC) and feasibility of support.⁸³ This was called "a logistics game." The emphasis was on logistics. Nevertheless the game clearly must include tactical elements. But there seems no extraordinary requirement for relation of this game to a tactically focused game—the traditional practice of exchange between scientists working in different laboratories on slightly overlapping topics seems to cover the case.⁸⁰

Take RAC's wholesale-level game: this is designed to study management systems for control of supply and maintenance at the highest CONUS level. Again the need for strategic and tactical assumptions is obvious, but there is no special need to coordinate them with tactical games as such.

A third example is provided by RAND's LSL on the one hand and their Sierra-Redwood games⁸¹ on the other. These are two whole series of games, the former focused on logistics and the latter on tactics; no need for coordination between them, or for special relations, has been recognized. On the other hand the Sierra series itself, verging on the Class a or comprehensive type, has the need for a strong logistic component.

From the point of view of good scientific practice there certainly seems to be merit in building up the specialized knowledge and techniques of a center for experimental (i.e., gaming) study of logistics and of another for study of tactics, or better, more than one of each.

The problem therefore emerges not so much as that of constructing relations between Class b games but as that of determining appropriate conditions for the design and conduct of Class a games of comprehensive character.

Battlefield games can be designed with minimum attention to intelligence and almost none to logistics. Yet both these omissions are coming to be regarded as serious defects; attention here will be directed to the second, in keeping with the purpose of this paper.

The two most determined efforts to correct defective logistical aspects have been those in the Syntac game* between 1959 and 1962 and those in RAC's Tacspiel in 1961–1962.† Experience in both cases reveals a set of major problems that await solution.

Syntac experience brings out two major considerations.

(a) Design of a game to evaluate tactical effectiveness tends to concentrate action in periods of intensive combat, i.e., periods when logistics activities really may be quiescent; hence the interaction of tactics and logistics and the extent to which it is to be studied need to be considered thoroughly in the earliest design stage (even this, however, would not necessarily meet the issue; see comments below relative to Tacspiel and the British experience).

(b) In the present state of the art the attainable ratio of real time to game time (r.g. ratio‡), which is 28 for Syntac (25 for Tacspiel), makes the study of many logistics problems, or introduction of some realistic logistical constraints, impossible. That is, physical and research conditions dictate that a play of a

*For example, USCONARC's evaluative war game. See Pamphlets 71 to 80^{82,83} for recent examples of the output of this game and a good picture of its characteristics.

†Tacspiel, and the work referred to, have not yet been reported.

‡By "real time" here is meant the time by which the world works; by "game time" is meant the time hypothetically elapsed in the hypothetical world of the game. A game that takes one 8-hr working day to play and represents ½ hr of hypothetical combat would have an r.g. ratio of 16. This explanation is given because it was found during preparation of this paper that there are four schools of thought on this subject among analysts: the second school uses the terms as above but prefers the reciprocal of our r.g. ratio, the third means by "real" what we mean by "game," and the fourth uses the reciprocal of the ratio preferred by the third.

game run not much more than 3 months, but 3 months permits study of only 18 hr of combat at the Syntac rate or 20 hr at the Tacspiel rate.

Recent Tacspiel experience based on consideration of logistics in the design stage suggests that in the present state of the art the attempt to represent logistics with some completeness will make r.g. ratios substantially worse, and they are already at the tolerable limits. A British comment on the subject is the following:

There is a serious difficulty in attempting to play a single game as a means of studying both logistics and tactics. For the game to be realistic the logistic requirements for all types of stores must be related to the tactical situation of the troops concerned; and equally the tactical freedom of fighting units must be limited in accordance with any logistic difficulties that may exist. Unfortunately however, the tactical aspects seem best studied in short 3-day actions, taken in 1-hr steps, whereas this period is too short for logistic factors to make themselves fully felt. Some form of compromise seems necessary if a tactical-cum-logistic game is to be played with benefit to both sides.⁶⁴

The Problem of Resolution

Further discussion of the question at hand requires introducing several matters connected with game resolution.

The lowest echelon represented in a game will be called the unit of resolution, or simply, the unit. This determines the level of the game as a practical matter.* Thus the company is the unit in Tacspiel, so that Tacspiel is a division-level game with battalion, brigade, or regiment the level at which play centers and at which useful results can be obtained.⁶⁵ Generally speaking, resolution down to the company as unit, in present conditions, implies a corps-level game at most, with most results centering below division.

It is possible that company resolution is at present the correct approach to comprehensive Army research gaming. Company is the unit, roughly speaking, in the present AORE, USMC, and CONARC games, and in Tacspiel.† However, an attempt in the Tripartite organization to legislate the question of resolution was adjudged inadvisable by the Ad Hoc Working Group;⁶⁶ and no known theoretical principle favors company, battalion, or any one particular level.

Gaming at resolution lower than company is being studied,‡ but the main concern in this paper is with games designed for a higher-echelon unit. RAC's Theaterspiel,§ and the earlier FAME games at ORO,⁶⁶ which use division as the unit, constitute the main examples. Here too introduction of an adequate logistics component is a major problem, but it is a different kind of problem from the one discussed above in connection with Tacspiel and Syntac, since the logistics involved, in the communications zone for example, differ in kind from that forward of division.

RAC's multilevel game probably should be identified as a Class b game, though one of the largest scope. It is designed to study specific problems of

*It is understood in this section that all such statements are made relative to the present state of the art; i.e., nothing in principle prevents a theater-level game from using the squad as unit of resolution, but no one has designed such a game.

†"Roughly speaking" because the USMC game is considered a variable-resolution game in which units below company may be at times considered in play; and some of the others, e.g., Syntac, are not absolutely rigid on the point.

‡At Royal Armament Research and Development Establishment (RARDE) and CAORE.

§A general description of this game has not yet been published.

technical logistics but will accept a rather broad range of such problems running from management problems in the ZI to intertheater problems in cases involving several active theaters of operations, down to intratheater problems extending forward to Army. When used in the latter situation the problem of generating a correct tactical environment becomes important.

Two Types of Games

From the standpoint of gaming technique a distinction may be drawn between the representation of some human system under laboratory conditions and the map exercise or map maneuver. The first has a scientific genesis, the second has its origins in military science, especially in the Command and General Staff College at Ft Leavenworth, Kans., so far as the US Army is concerned.

The technique of the map maneuver has been typically used in tactical gaming and is almost necessarily associated with the Class a comprehensive games. These involve Red and Blue teams and Control and depend on the use of maps and overlays essentially as taught in the professional schools of military science. The Syntac game and Theaterspiel mentioned above are examples.

A technique of map maneuver for research, deriving directly from the original AORG tactical game⁸⁷ uses a horizontal relief map with counters to represent units and seems to be yielding good results. Tacspiel, derived from the AORG game, via the ORO intelligence game, INDIGO,⁸⁸ is of this class, as is the new USMC game, derived from INDIGO. Still more recently a horizontal-type game board of novel design has been established at CDEC by SRI for advance gaming of field experiments. The AORG, USMC, and SRI games are tactical; but Tacspiel, by attempting to complete its logistic component, has gained the capability to study logistic problems in the forward area and is doing so.

The original use of the other technique, that of laboratory representation, was by RAND, for logistics and management systems gaming, to which indeed it seems naturally suited. LOGSIM-W, the USALMC training game, is of this class (of course in its training version it lacks provision for observation and monitoring of calls).

RAC's multilevel game includes elements of both kinds. The Blue team is a representation of a real logistics system with its offices, forms, and procedures similar to the laboratory type of gaming; but there is a Control team and a team opposing Blue, and maps and overlays may be extensively used in the theater phase of the game.

Map Exercise for Logistics Gaming

Systematic study reveals the interesting fact that a third type of research game, which ought to exist, is missing: this would be a game deriving from the school map exercise, as distinguished from the school map maneuver. Typically a map exercise differs from a map maneuver in being quicker and less costly (in man-hours and facilities) and yet relying on the same basic professional skills; generally in a map exercise only one side is actively played.

One or two unsuccessful attempts to apply this technique to logistics problems are known to the author. On the other hand they could not be classed precisely as failures. On the whole the history is inconclusive.

One conclusion of the present study is that both the research gaming techniques now in use require a substantial investment of time, manpower, and physical facilities to have reasonable chances of success, and that this investment has frequently been underestimated, resulting in unsatisfactory results.

It appears that development of an austere technique for investigating forward logistics problems derived from the map exercise should be attempted.

Chapter 5

REQUIREMENTS FOR GAMING AND SIMULATION— CONDITIONS FOR SUCCESSFUL APPLICATION

In this section after an appreciation of the US Army requirement for gaming and simulation, conditions for their successful application are outlined.

APPRECIATION OF THE ARMY REQUIREMENT FOR GAMING AND SIMULATION

The major open problems in Army logistics center around operation and control of large, extremely complex systems in which elements of uncertainty enter at many points. Here complexity is defined in terms of the sheer number of alternatives confronting the decision maker and the number of different technical or scientific disciplines involved in these alternatives (it is believed that both these numbers have increased exponentially since WWII). Uncertainty, or random variation, enters for two reasons: first, because many of the problems concern future contingencies; second, because many of the logistic factors are inherently variable, e.g., loading times, consumption rates, failure rates, and weather.

The main evidence that a requirement for application of gaming and simulation to US Army logistics problems exists rests on the character of the open problems, on the fact that they do not yield to classical* methods, and on the actual examples (most of which have been reviewed here) of application of these methods to Army problems or to roughly comparable problems in other services.

A reading of the reports referenced in Chap. 2 will show that in instance after instance among the cases reviewed the factors of complexity and uncertainty, and the special capabilities of simulation for coping with these, determined the methodology. The first examples coming to hand are the following:

CAORE: "The decision to construct a simulation model was based primarily on . . . characteristics of the problem which complicate the relationships among the various economic factors. . . ."47

RAND: "Two considerations led to the development of this . . . random sampling simulation (or Monte Carlo) model . . . First, purely analytical techniques make difficult the inclusion of real world complexities. . . Second, there is a class of problems of great practical interest which are not . . . amenable to analytical methods."48

*By "classical" methods is meant, on the service side, the method of the estimate of the situation and subsequent analysis; and on the research side, the methods of economic or mathematical analysis.

Naval Warfare Research Center (NWRC), SRI: "An amphibious assault operation is one of the most complex of all military operations . . . The Naval Civil Engineering Laboratory (NCEL) . . . established a requirement . . . for models [which] would permit the various parts of . . . [an amphibious cargo] transfer system to be analyzed in terms of their influence on the integrated operation of the over-all system . . . Specifically, it was decided that NWRC would develop an amphibious logistic simulation model and computer program for the NCEL."¹⁹

Computer simulation methods have been specifically designed by scientists and engineers to grapple with problems having the properties of complexity and random variation: and although the promising results obtained in physics, meteorology, or civil engineering cannot be directly extrapolated to the military situation, they reinforce the hope of success when taken together with the work actually accomplished and reviewed in Chap. 2.

Gaming lacks the scientific background of computer simulation but compensates for this to an extent by its military origin. It is a method genetically adapted to consideration of military problems.

Results of the present study indicate that, at least in logistics research, the military requirement for gaming stems from the same sources as that for simulation, with an added recognition that gaming can supply certain capabilities missing in simulation. These can be summed up by saying that gaming can introduce the human factor. Thus, as RAND has pointed out,⁷¹ a game can test the operational feasibility of a new system as it works in military hands. Further, exploiting the capabilities of the human mind, a game can deal with situations still more complex, in a dynamic sense, than those representable in a computer simulation. Finally the art and experience of war of the seasoned military man can be applied to analysis of future contingencies in a game.

As previous discussion has indicated, gaming and simulation are emerging as complementary methods in current logistics research practice, and the requirement for the one probably cannot be disentangled from that for the other.

Essentially all the direct evidence for the usefulness of gaming in military logistics research as distinct from computer simulation, however, must be drawn from an evaluation of RAND's games and AORG's game, and so far as the US Army is concerned, even this evidence remains indirect. There are also two or three items of evidence of a different character that should be included. The Army's considerable investment of time, energy, and computer rental in the STAG establishment shows that the Army Staff considers that a well-defined requirement for gaming and simulation as a means for solving complex operational problems exists.⁸⁹ And there is no reason to think these methods are more easily applied, or more usefully applied, to tactical than to logistical problems; in fact, the contrary can be argued.

Finally the changes in technology and increasing complexity of systems, taken together with changes in Department of Defense organization and approach, are creating a recognizable requirement for processing large masses of data, arraying it, and supporting the Army position in a way meaningful to higher echelons of authority—this in order that the Army's efforts to improve its defense posture will reflect the Army's true position at all times and in a comprehensive form. Existing completed work seems to show that gaming, especially when computer-assisted and supported by computer simulations, has a capability to assist in this task.

In summary then it appears that a sufficient body of experience and accomplishment now exists to indicate that gaming and simulation methods, followed up with some vigor, can provide the Army staff with materials for solving some of the more complex decision problems in logistics and management systems. Not enough direct evidence now exists to prove that these methods will succeed on Army problems, and the only promising way to get such proof now seems to be by an attack directly on these problems. Existing experience and results, however, certainly can be exploited to assure that such an attack be carried out in the way most likely to prove effective. The indicated way is outlined in the concluding sections.

CONDITIONS FOR SUCCESSFUL USE OF SIMULATION

Facts reviewed in earlier sections point to the following two conclusions:

1. Computer simulation is an established method for scientific investigation of complex problems that include important stochastic elements.
2. Success in such investigations depends on building a staff with strong technical competence in mathematics and computer programming, and of course on having access to a computer.

Computer simulation is not particularly well established as a method for investigating Army logistics and management problems. To see this, it is sufficient to review Table 1, distinguishing Air Force from Army examples. An explanation for this may be found in the attempts that have been made to bypass the requirement for strong specialist support and proper technical development.

In view of these circumstances it seems worthwhile to define the requirement for specialist support in more detail.

What is needed is a mathematical apparatus rather than simply a given number of mathematicians, i.e., an organized and balanced group including mathematicians at different educational levels, with different and complementary fields of specialization, and with varying orientations toward the computer. For example, in a small group there might perhaps be one senior research mathematician, one well-trained mathematical statistician, a specialist in simulations and monte carlo, and a senior and junior specialist in computer programming. Educationally this group of five might include two Ph.D.'s, two M.A.'s (or one Ph.D. and three M.A.'s), and a B.S. (or two). Among the early additions to the group should be mathematicians and programmers with experience in mathematical programming and graph theory and a man experienced in experimental design. Generally the group would be headed, not necessarily by the most senior man in the mathematical sense, but by a good organizer with general operations research experience in addition to mathematics.

Given at least the nucleus of such a support apparatus and access to a good computer, it appears that a systematic program of applications could develop simulation as a powerful and disciplined method for reduction of Army logistics problems. Such a program is visualized as proceeding in phases, the first to occupy 24 to 30 months. The aim of phase 1 is the production of complete simulations of reasonable scope with major emphasis resting on discipline

and technique; no special effort at sophistication would be made until technical proficiency had been established.

In the first phase the following criteria would be satisfied for each simulation undertaken:

(a) Limited scope. Only problems of feasible size (number of program instructions), complexity (of program design), and technical requirements should be undertaken, feasibility being determined by the size, background, and continuity of experience of the available staff.

(b) Well-defined objective. The objective of the simulation and the specific contribution it is expected to make to solution of an Army problem should be well-defined before undertaking the simulation.

(c) Due dates. Each simulation will be undertaken subject to a due date that will be met.

(d) Definite technical objectives. The complete work plan by each simulation task group should include at least a tentative statement of statistical characteristics and estimated computer time costs for the simulation.

Thus provisions a and b eliminate the possibility of undertaking the big, open-ended simulation designs; provision c, as will be apparent to the experienced reader, carries the implication that both partial and negative results (down to and including failures) will be closed out and reported on time.

Provision d is technical and goes to the heart of the reasons for inadequate results obtained from simulations in logistics to date. If a big simulation (e.g., 15,000 program instructions) is being put together, under present conditions the satisfaction of provision d calls for statistical talent of the first rank, such as is frequently not available to the study group. On the other hand the discipline of satisfying this provision, in at least the formal sense, for smaller, limited-objective simulations is quite feasible (always supposing the collaboration of at least the minimum mathematical and programming apparatus described above). By the time phase 1 of the program has been completed, with appropriate employment of consultants, a technical level can be attained that is essentially impossible, or prohibitively costly, to reach in a single leap.

Conditions for Successful Gaming of Logistics and Management Systems

As shown in this paper, experience of logistics gaming is scanty. And there is no theory of gaming sufficiently well established to use as the foundation of a program. The following list of conditions then could not hope to be definitive; it is thought to represent the best judgment available at this date.

(1) Experienced Cadre. Since gaming has the character of a laboratory method, its success depends in part on good practice and good technique. This can be taught fairly quickly if a cadre of experienced and well-motivated people is built and maintained.

(2) Choice of Personnel. This requirement is closely related to the first. The distinction between gaming and much other operations research is similar to the distinction between experimental and theoretical work in science. Recognition of this fact is essential to the proper staffing of groups as teams to do gaming.

(3) Military Professionals for Active Posts in the Game. This requirement may be self-evident but it has been overlooked, or scanted, with poor results. Although obvious, it is quite difficult to satisfy. Two preferred methods of doing so have emerged: the first is to use recently retired military on a consultant basis in the game posts; the second, which demands a good deal of advance planning and cooperation with the client, is employment of active-duty personnel on TDY.

(4) Well-designed Facilities and Support. The basic requisites are a large (20- to 30-man) space, adjacent to or near the computer, with movable partitions, phones, and similar operating equipment; provision for overseeing and monitoring; and clerical support.

(5) Scientific Backup. This can be met by the sort of mathematical group discussed above in connection with requirements for computer simulation. In other words the one group will meet both requirements, and joint use of this group is also indicated by the complementary character of gaming and simulation.

(6) Correct Relation between Gaming and other Operations Research Groups. In logistics and management systems successful gaming requires supporting theoretical studies in economics, costing, and systems analysis. The RAND experience demonstrates this rather well. Equally the gaming program should include work in support of regular operations research projects, ensuring realism and the acquisition of "hard" data. Correctly balanced relations of this kind are evidently quite important to success.

(7) Correct Relation between Gaming and Other Research Methods. In this may lie the key to effective employment of gaming. Certainly this relation is being carefully studied by those doing successful advanced work in the field. Two examples are provided by the RAND games, especially LP-II, and in an entirely different context, the work of SRI's Weapons Systems Laboratory. In LP-II (see previous section concerning LP-II) computer simulation provided an abstract indication of the solution to the problem: a game, computer-assisted and supported by computer simulations, extended, deepened, and improved this, while to some extent checking its administrative feasibility; finally a mathematical analysis, depending on the computer because of its complexity, checked the sensitivity of the quantitative aspects of the solution. In the Weapons Systems Laboratory's studies at CDEC the plan was to use a game to pretest field experiments and a computer simulation to extend the quantitative results of the field experiments; in practice there is some indication that the game is also useful for analysis of the experimental results. Thus it may prove that gaming will fulfill its original promise in logistics research through controlled employment in conjunction with these other tools, simulation especially.

Integrated Capability

Although gaming and computer simulation have been discussed separately above for clarity, the aim is of course an integrated capability. This follows in particular from what has been said about the complementary character of gaming, simulation, and related mathematical methods. In the present state of the art the capability to apply any one of these methods successfully in logistics research implies the capability to use all the others in appropriate combinations depending on the problem and the available resources.

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