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USE OF MATHEMATICAL MODELS  
FOR LOGISTICAL PLANNING

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### SUMMARY

This paper gives a definition of machine models and their uses in logistic planning and experimentation. As examples, a general description is given of "Laboratory Project 1," a man-machine model, and of the Missile Support Model, a machine model used in "Laboratory Project 2." This description covers such areas as:

1. The purpose of these models.
2. The general procedure used in creating the models.
3. The trouble areas found in this creative period.
4. The results obtained from the running of the models.
5. The trouble areas found in the running of the models.
6. Other possible uses of models, such as a means of training on a managerial level.

## USE OF MATHEMATICAL MODELS FOR LOGISTICAL PLANNING

Let me begin by giving a definition of the words model, simulate, and system. Webster's definition of these three words are: 1. A model is a miniature representation of a thing. 2. To simulate is to assume the appearance of, without reality, and 3. A system is an organized whole. We are all familiar with certain kinds of models, such as an airplane model or an architect's model of a building, etc., but today, I am going to talk of a relatively new kind of model—the machine, or computer model and its uses in logistic planning and experimentation. A machine model is also a miniature representation of a thing—the thing in our case is a system, such as a logistic system. This model is really a mathematical or logical representation of the system programmed for a computer—or, if you like, a simulation of the system by use of mathematics and logic. My use of "simulate" is slightly different from Webster's definition, for the model assumes the functions of the system rather than the appearance, and though the model is unreal in physical make-up, we hope and strive for a great deal of reality in the execution of the assumed functions.

I am going to talk about two kinds of models—a machine model and a man-machine model. A machine model is of the type where the computer does not necessarily need any human intervention to complete a problem, and the man-machine model is the type where people must interact with the computer in order

to complete a problem.

I will talk later, in some detail, about each of these types, but first, I would like to explain the uses of machine models. Let's look at a few of the more conventional, well-known models and explore their usefulness. For instance, a model airplane of the type built by the aircraft industry for wind tunnel testing. Usually, a model of this type is built because it is the fulfillment of a new design and the engineers have found that by testing the model you can, in many ways, test this design. By use of a wind tunnel, the engineers can subject the model to a variety of stresses in a short period of time and gather much data on its performance. They hope that analysis of this data will say much about the feasibility of the new design. Certainly, this is also cheaper than actually building the airplane and testing it. It is also much quicker. To run the gamut of conditions simulated by the wind tunnel would probably take many years. Another gain from using models is the educational benefits derived by the engineers and designers. It is also much easier for the designer to alter and test designs in this stage than in any other. These, then, are the uses of a conventional model: 1. Educational. 2. Inexpensive experimentation, where experimentation covers techniques, design, etc.

Now the model airplane isn't the only example I could use—for instance, the architect's model building or the sculptor's model statue performs the same function. To sort of sum

up--you build a miniature representation of a thing; you simulate the conditions to which the real thing will be subjected, and apply these simulated conditions to your model. From the results of these two steps, in turn, you make changes in the model and its environment. If you have been "real" in your simulation, you can then apply these changes and results to the model's real-life counterpart.

Now, strangely enough, these are exactly the steps and aims of a machine model. To apply this to logistics, for the moment, consider the aims of a model, called LP-1, created for the RAND Logistics Department. Several members of this department had some definite ideas on how to improve present-day supply in the Air Force. Obviously, it would be nice to somehow test these ideas and policies without changing present-day supply policy, and then possibly finding you had goofed. These people initiated the creation of two models--one, based on present-day supply policies, and the second, a like model that incorporated their ideas. They then ran the two models simultaneously in an effort to compare one against the other. I intend to take up this model in more detail later, but I think this shows one of the uses of a model.

LP-1 is, then, an example of a model used by RAND's Logistic Department. Another example is the "Missile Support Model," which is the first step in LP-2. Both of these models contain models. For instance, LP-1 contained a "Base Maintenance Model," a "Parts Repair Depot Model," a model of the

Storage Site, etc. Just the names are indicative of this department's usage of models.

However, before I go into detail about these models, I want to talk a little of some of the troubles you can encounter in the building of models. Let's look first at the formulation stage. You essentially need three types of people to formulate a model: Person or persons, 1. who know what the problem is, 2. who know the real-life system to be modeled, 3. who know the capabilities of the computer to be used for the model. In the formulation of LP-1, it was the members of the Logistics Department who wanted a model which would test their new supply policies. In order to better ensure a realistic model, they called upon civilian personnel from the field for information and advice regarding present day supply policies, and finally, to this group were added programmers from RAND's Numerical Analysis Department. Thus, conferences were held—the civilians explaining supply in real life, the programmers doing their best to translate this into a machine model. Often, compromises had to be made, for space limitations of the machine or anticipated machine running time places a definite limitation on the size of the model. It is ridiculous to even think of a model which takes, say eight hours of machine time, and yet represents only one hour of supply experience. Finally, when all these parties have come to that armed truce, signifying agreement on the machine representation, the programmers begin programming. After the model has been programmed, it must be

checked out by trial runs to eliminate programming errors. Often, during this stage, compromises are again made. This is actually sort of the second stage. The third step is the actual running of the problem and the fourth step is the analysis of results. The fourth step often leads to changes, and we then repeat steps two, three, and four. In these four steps are many trouble areas, for compromise is not an easy thing to come by. It takes careful and intelligent planning, and a little luck, to reduce a system to a machine model. You dare not oversimplify for fear of trivial results, and yet, if you overcomplicate, analysis can become impossible.

Overcomplication will also result in more machine hours consumed in the running of the job, and in more programming time to ready the job for the machine. These two items are expensive and should not be wasted. Even when this set of problems is overcome, you may still have trouble. Here, I refer to the machine making errors. Machine errors, if caught, cause delay; if not caught, they cause errors in results. This is a problem that must be considered all the time, and is usually countered somewhat effectively by continual supervision.

I will now give you a description of LP-1; what it is, why it was done, and some of the results of this model.

"Laboratory Project 1" was a man-machine model created to study two different philosophies of aircraft spares support. One philosophy was incorporated in Weapon System 1, which was a supply model based on current Air Force supply policies; and

the second philosophy was incorporated in Weapon System 2, which was a model based on policies proposed by members of the RAND Logistics Department.

In general, the problem of supply is (1) procurement, which asks the question: "When and how many spares do I buy?", and (2) distribution, which asks: "Where do I put the spares I have bought?" The two weapon systems were run simultaneously with the hope that by comparison, Weapon System 2 would emerge more efficient and less costly.

The weapon systems consisted of bases (10 in each system), IRAN (1 in each system) where IRAN means "Inspect and Repair as Necessary", Parts Repair Depot (1 in each system), Storage Site (1 in each system), Factory (1 in each system), and Transportation (1 for both systems).

A base consists of 3 major functions: (1) operations, which fly the aircraft, acquire failures, fix airplanes to make them combat ready, send failures to maintenance; (2) maintenance, which repairs failures or sends failures to Parts Repair Depot, returns repaired items to supply; and (3) supply, which provides parts to both operations and maintenance, and receives parts from the storage site. The base was part of the machine model, and consisted approximately of 5,000 instructions. The major difference between a base in Weapon System 1 and Weapon System 2, was in the requisitioning of parts. Supply at a Weapon System 1 base requested parts from the storage site when stocks were low. It requested a specific number of a specific part. A

Weapon System 2 base never ordered stock—instead, it supplied daily information to the storage site. This information consisted of things like the number condemned, the number of repairables, etc. The result of these two courses of action will be discussed when I talk about the storage sites. Each base had a base manager who had some control over the machine base.

The two major actions available to the base manager were (1) ordering his base to cannibalize a part from one downed aircraft and put it on another aircraft, and (2) ordering his base to fill a hole on the aircraft, by using the next higher assembly. Some of the other activities of a base manager were (1) allowing maintenance to work overtime in order to repair more failures, and (2) changing the priorities by which maintenance scheduled its repairs. The base manager received daily outputs from his base and it was the study of this information which triggered all of his actions.

When a plane on any base logged a given number of hours, it was sent to IRAN for an overhaul. IRAN corresponds directly with operations at the base level. It flew planes, acquired failures, fixed planes, and sent the failures to the parts repair depot. The major difference between IRAN in Weapon System 1, and IRAN in Weapon System 2 was the ordering of stock—IRAN, in Weapon System 1, ordered stock, but the IRAN in Weapon System 2 never actually ordered—rather, it sent daily information to its storage site. IRAN was also a part of the machine model and consisted of approximately 5,000 instructions. The IRAN

manager had the same functions as a base manager, except all activities pertaining to maintenance, since IRAN maintenance functions were accomplished by the parts repair depot. The manager received daily outputs to facilitate his decisions.

The parts repair depot is the counterpart of maintenance at a base, for it fixed failures sent there by all the bases, plus IRAN. In this model, all repaired items were sent to the storage site for distribution, rather than back to the activity where it originally failed. The parts repair depot was also a part of the machine model, and thereby also had a manager. The manager's two major functions were (1) to schedule the work to be done, and (2) change priorities which governed the maintenance. He could also instigate overtime work if he felt the need. Again, a daily output facilitated his decisions. The difference in the parts repair depot for the two weapon systems was again the ordering of stock.

The storage sites were comparable to supply at the base level, except on a larger scale, for their primary function was to distribute stock to the bases, IRAN and the Parts Repair Depot. The storage site for Weapon System 1, was fairly simple for it merely acted upon the requests sent by the bases, IRAN or Parts Repair Depot. It filled the orders as stock levels permitted, and kept records such as back orders, and ordered from the factory when its own levels warranted. The storage site for Weapon System 2 was far more complex, for it was here that the new policy proposals were incorporated. Each day it

received information, decided what to ship, where to ship, or to ask for more information. This storage site also ordered from the factory when the need arose. These storage sites were also a part of the machine model—2,000 words for Weapon System 1, and 6,000 words for Weapon System 2. It was this activity which caused Weapon System 2 to take up to twice the machine time as Weapon System 1.

Each storage site had a manager, who, with the help of daily output, kept track of stockage levels. It was in his power to up priorities of orders from the factory if the situation warranted. In general, managers in Weapon System 2 had less control over the machine than did their colleagues in Weapon System 1, the reason being, that some of the decisions allowed managers in Weapon System 1 had been incorporated into Weapon Systems 2 machine models.

The factory, a manual activity, did not vary in the two-weapon systems. Its function was to manufacture requested stock and send these items to the appropriate storage site. The manufacturing was merely the computing of a realistic delay, along with costing the order. The machine activities, by the way, also computed costs for such things as stock used.

The other manual activity was called transportation. All shipments of material and requests for material in Weapon System 1 were via punched cards. The transportation people saw to it that the proper cards were input to the proper activity on the proper day.

These two manual activities, the factory and transportation, would have been made a part of the machine model had time and space permitted. The machine models took about 9 months to do—this represents 45 man-months of programming time. Much of this time was spent in conference with supply people, defining operations, maintenance, supply, etc. The managers were Air Force personnel

It took approximately 10 to 15 minutes to run the machine part of Weapon System 1 for 1 day, while it took 15 to 20 minutes to run Weapon System 2. At the end of the machine runs, the output was given to the managers who then had 20 minutes in which to make decisions before the next daily run took place. Thus, one real day was compressed into approximately one hour. For purposes of study, a month was considered to have only 10 days. The experiment ran for 5 years compressed time—5 years of 120 days a year. At the end of each month and quarter, special reports were made to the weapon system managers. These reports were machine programs also. There was a weapon system manager for each system, and his functions were:

1. Responsibility for the efficient running of his system.
2. Central clearing house of information for the other managers.
3. He could have a base ship parts to another base.

Many problems were encountered in the running of this experiment. One trouble area was the 704, since downtime

disrupted the compressed day. The managers, sometimes, instead of getting the next day's output in 40 minutes, waited hours. We had our fair share of tape trouble, and since we were using 4 tape units for the job, it caused some grief. Another trouble area centered around bad input cards. Many things were checked internally in the machine, but not nearly enough. Again, I attribute this to the time allowed for the completion of the job. Also, many of the managers were confused as to just what the machine was doing. This indicates that the indoctrination was incomplete and that the system was too complicated.

The managers, during the course of the run, were observed through one-way glass while performing their duties, were asked to fill out questionnaires, were personally interviewed, and had all their telephone calls recorded. From this source of data the Logistics people compiled a list of the managers' criticisms, along with some suggestions. I will give you a few of these, along with my comments:

1. They wanted more and different kinds of information, such as a warning of impending maintenance trouble to be able to start overtime work earlier.

Comment: These types of suggestions are very helpful in the formulation of new models.

2. They wanted more automatic error detection and correction of inputs and possibly bad decisions.

Comment: So did everybody else.

3. They were unhappy about some of the limitations of the machine in size—wanted to put in many more interrogations.

Comment: Managers were allowed to ask, via input cards, a great deal of questions concerning stock levels, maintenance priorities, etc. We possibly slipped up by not allowing more in a given day, but I doubt it.

4. They disagreed with some policies.

Comment: These were legal with respect to Weapon System 1, since this system attempted to simulate present-day policies. Many of these disagreements were things we had compromised on for one reason or another. For instance, a more realistic repair routine could have been set up if we had had more time and machine space.

Many of these people thought Weapon System 2 policies to be very good, but were sure it would require that supply personnel have a higher experience level.

5. Too easy to communicate with other bases.
6. Problems pin-pointed too fast.
7. Reports too accurate—not real.
8. Downtime on 704 allowed managers extra time for work—not a real situation.

Comment: These are sets of complaints about the non-reality of the models and all valid ones.

9. Rapid passing of the compressed days allowed managers to remember from one day to the next much better than normal.

10. Parts repair depot too efficient.

The second model I want to talk about is the "Missile Support Model," which marks the beginning of LP-2. This is a very recent model; in fact, it was ready for production runs the middle of March. I said this marked the beginning of LP-2, and herein lies a different usage of modeling. Since there exists little information on exactly how missile bases are to be run, the problem of support is somewhat vague. It was decided that since we could not build a realistic model for missile support at the present time, we would build a model to investigate the problem. In this model we included many alternatives which could be eliminated easily. For instance, we included (1) base maintenance (beyond take off and put on, of so-called black boxes) which hinged upon personnel specialists, (2) cannibalization, (3) shipping between bases, as well as from some central support organization, etc. We intend to make runs with combinations of these alternatives in order that we might determine their effectiveness on the system. It is by no means apparent whether a base should have maintenance or not, and similar doubts were expressed about all these alternatives. We hope, by making runs, to determine how much stress will be placed on these alternatives in real life so that we may create a more realistic, larger "Missile Support Model."

Let me give you a brief description of this model. It has six "points," where a point is similar to a base. Each point has up to ten missiles, two launch consoles, and two guidance stations. The point tests missiles, finds failures, replaces failures, repairs failures, and requests new stock, and can cannibalize. The maintenance and cannibalization, among others, were programmed so as to be easily excluded on any run. Supporting these six points was a "Central Support Organization," which sent stock to the point, fixed failures sent to it by the points, and requested stock from the factory. The factory, for this model, was really only a delay--orders were always filled after N hours.

The point took approximately 6,000 machine instructions, and the Central Support Organization about 4,000 instructions. The problem runs a month of supply experience in approximately one hour of machine time. The job, from the start to the finish, took about two months. The formulation period for this model was much shorter than LP-1 for several reasons: (1) simpler job (maintenance easier), (2) we eliminated the group comparable to the civilian personnel (since no counterpart for missiles existed; also, we had LP-1 experience to draw on).

We see, then, that this model was created to use as a guide to a bigger and better model. This model is also an example of a machine model as versus LP-1 which was a man-machine model. You can supply this model with its initial stock, etc., and turn it loose--it will run, output at whatever

intervals you wanted, for instance, every month, and then stop at the end of X months. However, if one desired, changes could be made in stock, etc., between runs. The point is, that it was not necessary for anyone to make a change in order to run a complete problem. You will remember that in LP-1, base managers made daily decision.

This model is one of the "Monte Carlo" type, and presented certain added difficulties in checkout. In the Monte Carlo models a failure probability ranging from 0 to 1 is determined for each piece of stock. For each time period, a random number is drawn, for each part, and compared to the failure probability for that part, and action within the model is generated according to whether the failure probability is greater or less than the random number. Since the frequency and type of action occurring in the model is determined in a random fashion, one sees readily the difficulty in the tracing of these actions. Yet, it is necessary to determine that the model operates correctly. As a matter of interest, I will briefly discuss three ways you can attack this problem.

1. Start checking out the model with a small sample size. A few **pieces** of stock are easier to trace through the model than a few hundred **pieces**.
2. Attach fictional failure probabilities to the stock. Obviously these numbers should be designed to make the job easier.

3. Use statistical methods to analyze your answers. And finally, I want to point out one other important possible use of a man-machine model like LP-1. This is the training which you can give on a managerial level -- because of fast runs and quick analysis of the results of the manager's actions.

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