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# CONTINUOUS SIMULATION OF AIR BASE ASSETS (CSAA) "INTEGRATING LOGISTICS SUPPORT OPERATIONS" A PROPOSED METHODOLOGY

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## ABSTRACT

A unique approach is developed for analyzing the balance between supply versus demand in evaluating logistics requirements of the armed forces of the United States. With this approach new ways of measuring combat readiness and logistics support are proposed and available to ensure that the armed forces remain ready to fight during the projected defense draw down beyond the year 2000.

The development of this analysis methodology was established as an alternative approach to existing studies to answer the never ending question of whether or not the Air Force can maintain logistics to support strategies of force as claimed during the recent Deep Attack Weapons Mix Study (DAWMS).

The contribution of this research is a prescribed method for the strategic analyst to develop flow diagrams which can be used to analyze logistics requirements to project and evaluate force sustainment.

Additionally important to this modeling effort is a prescribed method to evaluate the steady-state logistics flow of fuel and ammunition through time. This will allow the analyst to evaluate various resource strategies, constantly evaluating bottlenecks, and inconsistencies with the logistics flow process.

This modeling effort serves as a Simulator to model steady-state logistics flow and as an Output Processor to evaluate and verify TACWAR results.

## 1 INTRODUCTION

The Deep Attack Weapons Mix Study (DAWMS) is an ongoing analysis exposing service rifts and rivalries that came to the fore in 1995 when the independent Commission on Roles and Missions of the Armed Forces looked at how the services should divvy up fighting responsibilities.

At the center of the controversy is the computer model, TACWAR, used to depict how the U.S. military can best win a war in Southwest Asia and in Korea at nearly the same time.

TACWAR is a discrete event, simulation model which fights the two wars in 12-hour increments. Such combat simulations provide insight to commanders as to how the battles will unfold using different force combinations. Projections can range into the years 2006, and 2014.

At the heart of this study is the Air Force's projections in deploying large numbers of aircraft to the projected theater, and a capability to sustain large numbers of sorties (flights) per day.

The underlying assumption here is that the number of sorties can and will be supported logistically while performing all types of missions, such as close-air-support (CAS), reconnaissance, and interdiction.

The assumed logistics support to these missions is that inter-theater and intra-theater logistics flow can and will be maintained equal to the rate of expenditure of the fighter wing equivalent's (FWE) missions. Examples of variables in question may be; numbers of aircraft by location, pre positioned stocks, sortie rates, munitions loads, and fuel consumption per sortie.

This paper proposes a solution to this dynamic dilemma by integrating system dynamics and combined simulation. The result is a more suitable methodology to adequately predict and control a proper balance between competing logistics requirements; identifying shortfalls and helping to plan or schedule the necessary assets to support the logistics base for future operations.

## 2 SOLUTIONS THROUGH INTEGRATION

The objective of system dynamics, as utilized in this paper, is to study the causal relationships bearing on the combat logistics domain, and effectively identify the variables which will effect the force structure balance (Parker 1994).

The application of system dynamics to problem solving entails several important features not usually found in standard open loop simulation architecture.

First, such problems are looked at as being dynamic, involving quantities which continually change over time. Next-event simulation alone may not accurately portray the constantly changing variables or quantities under investigation (Pritsker 1986). Such quantities are expressed in terms of graphs of variables over time. The oscillating levels of various military specialties, units, equipment, etc., over a projected time period are non-linear and dynamic. Logistics flow is a dynamic problem, continually anticipating a future threat, based on past experience, coupled with additional complications such as new equipment, changing strategies, and arms reduction. This situation is further complicated when confrontation escalates, requiring quick commitment of large resources. Typical static approaches, such as linear programming, to solving such allocation problems often cannot be used where the problem scenario changes continuously through time.

For example, it may be advantageous to model an increase in demand, (a sudden increased need for fuel and ammunition), in order to determine how quickly the logistics inventory levels return to steady state, particularly in a dual Major Regional Contingency (MRC) as previously described. This was clearly evident with the activation of the Ready Reserve Force for the invasion of Kuwait. The activation effort severely strained the resources of the Ready Reserve as well as the commercial industry in the United States (Ott 1992).

These and similar questions can only be answered efficiently with a simulation method which can cope with delays, flows of information, and material, obviously lending itself to the study of transient phenomena.

When such a simulation model is developed, the state variables are continuously changing and their time variation may depend on other state variables, both discrete and continuous. The dynamic behavior of these variables describes the real system and their computational relationship is critical to achieving reliable results.

A second feature, and the most critical, to solving force structure problems to which the system dynamics perspective applies involves the notion of feedback. Essentially, feedback is the transmission and return of information. A feedback loop is a closed sequence of causes and effects. A series of interconnected sets of feedback loops is a feedback system. Logistics support to tactical aircraft is an example of a large scale strategic feedback system.

The delay of information feedback combined with the delay or time to produce the required assets is an area of great concern. Thus, understanding of the behavior of feedback systems is a goal of the system dynamics approach (Forrester 1961).

## 3 MODEL DEVELOPMENT

Figure 1 is a basic flow diagram of the physical accumulations and flows regarding the Air Force scenario previously described. A complete model of the system would also include the mathematical relationships describing how the accumulations and flows are calculated (Parker 1994).

This system is characterized in its most simplistic form to better understand the relationships to support much larger modeling initiatives. To insure no relation to actual data which could be classified, the quantities in this example are purely hypothetical and are in no way related to actual requirements.

The focus of the model is the level described as "Distribution POD 1" consisting of two resources, fuel and ammunition. The levels represent the values of the variables under study through time. The level symbol is depicted as a rectangle.

The amount contained in a level is calculated as an equation, represented by the symbol is:

$$x_{i,t} = x_{i,t-1} + DT \times \left( \sum_{j=1}^{M} rate.in_{ji,t-1} - \sum_{k=1}^{N} rate.out_{ik,t-1} \right)$$

where

$x_{i,t}$ = state variable level $i$ at time $t$
$x_{i,t-1}$ = state variable level $i$ at time $t$-1
$DT$ = delta time interval
$rate.in_{ji,t-1}$ = flow rate $j$ into level $i$ at time $t$-1
where $j$=1,...,$M$ and $M$ is Integer
$rate.out_{ik,t-1}$ = flow rate $k$ out of level $i$ at time $t$-1.
where $k$=1,...,$N$ and $N$ is Integer.

Levels are calculated at each of the closely spaced solution delta time intervals, DT. The equation for the level symbol states that $x_{i,t}$, the present value of $x_i$ at time $t$ (time now), is equal to the previously computed value $x_{i,t-1}$ (time last), plus the difference between the inflow rate, *rate.in*, during the last time interval and the outflow rate, *rate.out*, the difference in rates multiplied by the length of time DT during which the rates persisted.

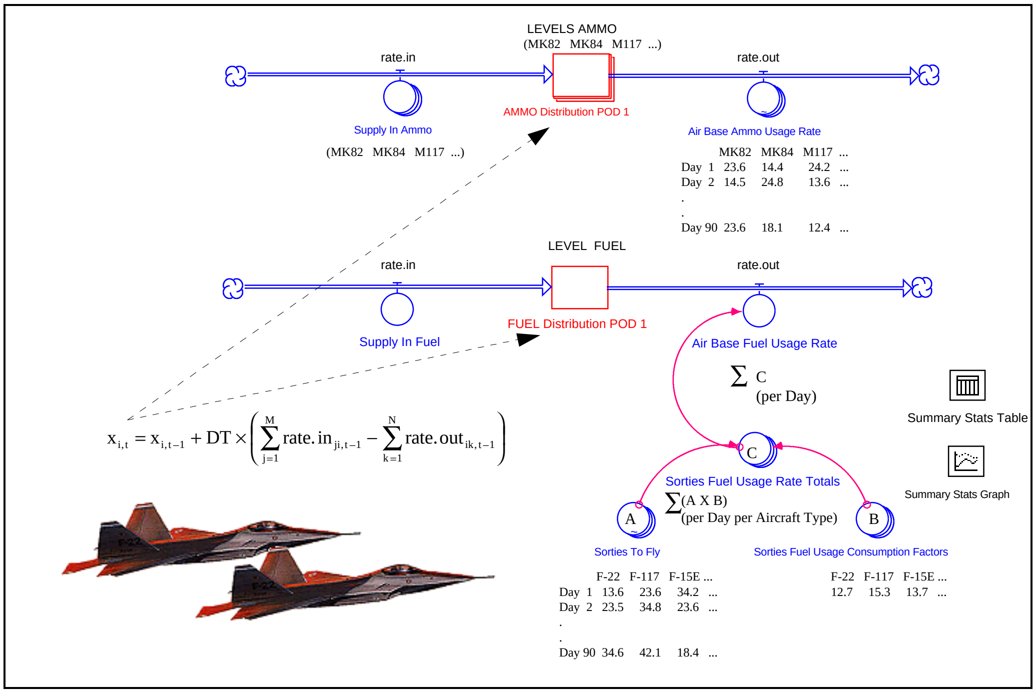


Figure 1: Network Model Simulator of Logistics Support and Usage of Air Assets

This level equation's initial conditions depicting the "Fuel" and "Ammunition" levels at each air base at time zero are determined by the analyst.

This level receives resources or commodities from the input rate "Supply In". The rate symbol is used to depict the rate of flow. The rate equations are of great importance in that the changes to all the levels in the model are attributed to some form of the rate equation. The rate equations associated with this symbol are usually found either entering or leaving a level node. The flow rate may be a function of several variables. Flows into a level node are positive (+) and flows out of a level node are negative (-).

The understanding of the relationships of equations previously described is important for model development (Parker 1994). The building of this particular model was enhanced with the aid of the commercial simulation package, "Stella" (HPS 1996). An important feature of this simulation language is the ability to model multiple commodities, levels and rates, as arrays. In figure 1, notice the separation of the levels and rates for the levels AMMO and FUEL. Each level represents a stockage associated with an air base, dependent upon the rate of flow into the level, and the demand or usage placed on the level. The "Air Base Fuel Usage Rate" draws upon TACWAR output for a 90 day evaluation, reflecting all "Sorties To Fly" each day, all aircraft types (40 total), and the associated "Sorties Fuel Usage Consumption Factors" associated with each aircraft type. Similarly, the ammunition levels include the matrix depicting the 90 day usage of all munitions types (45 total), as scheduled for use by TACWAR. The total number of equations for each theater, North East Asia (NEA), and South West Asia (SWA), are approximately 5000.

As previously stated, the example for this paper has been simplified returning the reader to the initial conditions as defined in figure 1. For example purposes, the remainder of this paper will focus on the aspects associated with fuel.

The goal of this model is to accurately portray the levels and rates supportive of each air bases mission(s), and identify the overages and shortfalls as the time line varies according to the simulation. Ultimately the analyst will be able to evaluate, from a system perspective, the stability of the dual theater scenario.

# 4 ANALYSIS

## 4.1 Base Case

The first simulation run is portrayed in several outputs or responses as viewed in Figure 2. Three variables are evaluated: "FUEL Distribution", "Fuel Demand Rate", and "Air Base Fuel Usage Rate". The variable "FUEL Distribution" is the level or the amount of fuel located at that particular air base. At time zero the initial level begins at 18,000 tons and depletes to zero at

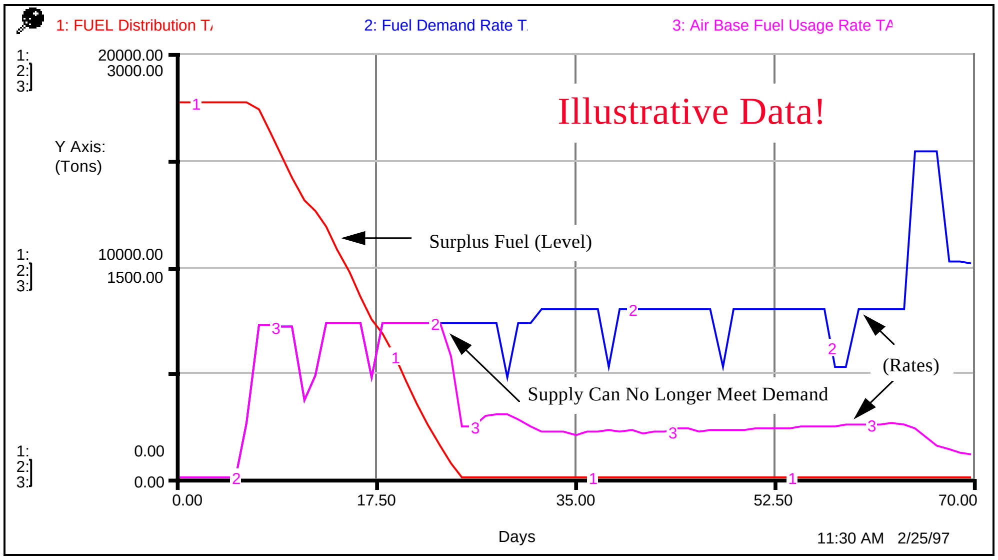


Figure 2: Individual Air Base Fuel Consumption

approximately day 20. This depletion is the direct result of the difference from the input flow "Supply In" of each commodity minus the sum of the usage or flows out of the same commodities as they relate to the missions flown for that air base. The level is the surplus amount at the storage facility. Once the storage capacity is at level zero, fuel still enters the air base through the inputs. However, the analyst sees that the demand on the air base exceeds the fuel capacity. Thus, sorties continue to fly, but cannot meet demand. Note the jagged demand curve.

Next, draw attention to Figure 3 which focuses particularly on the fuel flow rates for "Total Sorties Flown for All Platforms" again referencing the supply and demand dilemma. This graph summarizes the total of all sorties flown inclusive for the entire theater. Again, pay particular attention to the unavailability of fuel to support the TACWAR demands for the simulation run.

## 4.2 Sensitivity Analysis

Sensitivity analysis is used to adequately predict the effects associated with a change in the input or output flow rates as modeled under the current scenario majors.

Figure 4 represents the sensitivity analysis to test a sudden catastrophic loss of the fuel associated with the input source. In particular, the harbor under consideration was temporarily destroyed by enemy special operations forces. The harbor was unable to provide fuel to three air bases. The result was a total loss of sorties flown during the period from day thirty to day forty seven.

## 4.3 Modeling As A Simulator

The previous model runs provided insight into new modeling capabilities regarding the use of level and rate equations particularly as an output processor for TACWAR. Simulation additionally offers the opportunity to incorporate dynamic characteristics associated with data analysis. By modeling the TACWAR output associated with each air base, distributions can be modeled. By modeling distributions of the sortie generation, the analyst can thus use this modeling effort to simulate logistics scenarios without reading TACWAR output.

The benefit of this capability is the ability to use the model as a logistics simulator. The analyst can vary a wide variety of initial conditions, various strategies, unknown event, etc., and determine whether or not the logistics in each theater can support such efforts.

Figure 5 is an example of determining the distribution of an air base sortie generation using TACWAR. First, the actual sortie generation data is plotted. Next, by using a statistical function, e.g. a moving average function, we see the data is now plotted to reflect the average of the data. Next, this data is analyzed with a distribution test, e.g. chi-square goodness-of-fit test, to determine the sampling distribution. Notice the visual fit in figure 5.

These results provide a basis to run simulation excursions to support future war game scenarios, as seen from a logistics perspective. Thus, the phases associated with the tactical aspects of the scenario can be easily adjusted or modified. The simulation will sample from the appropriate distributions, as they are previously

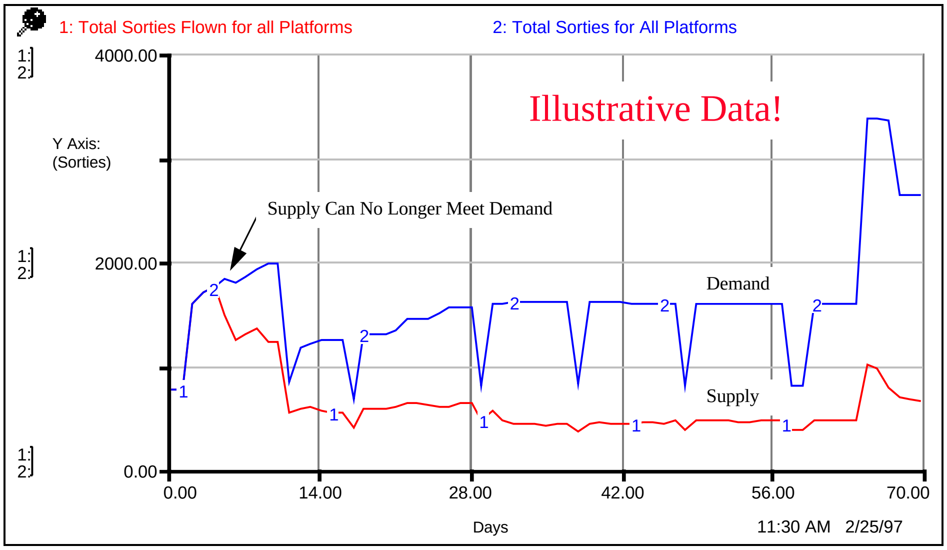


Figure 3: Output Of All Sorties Flown For The Theater

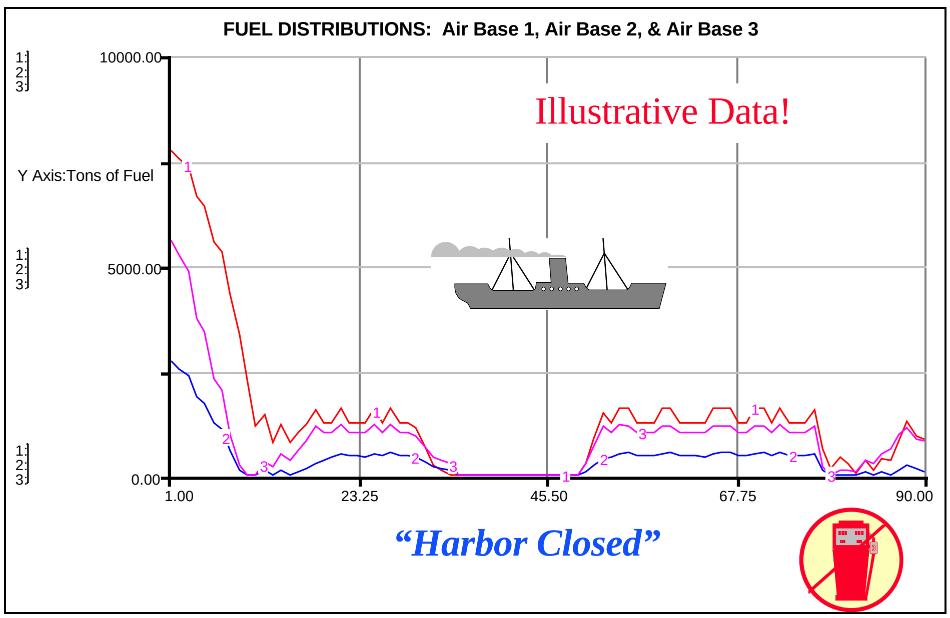


Figure 4: Exploring "What-If and Why-Not Scenarios"

defined, and provide output similar to that as if the model was an output processor to a specific simulator, such as TACWAR, or CEM.

## 5 SUMMARY

There are several major contributions which stem from this research.

First, a result of this research is a prescribed method for the strategic analyst to develop a logistics flow diagram which can be used to simulate and analyze logistics requirements to project and evaluate force capabilities. As part of the method, a symbolic network representative language was implemented which combines the continuous variable features of system dynamics and the discrete event features of conventional simulation techniques.

Secondly, as a simulator to evaluate the steady-state logistics flow of fuel and ammunition through time. This will allow the analyst to evaluate various queuing or commodity bottlenecks and inconsistencies within the support system.

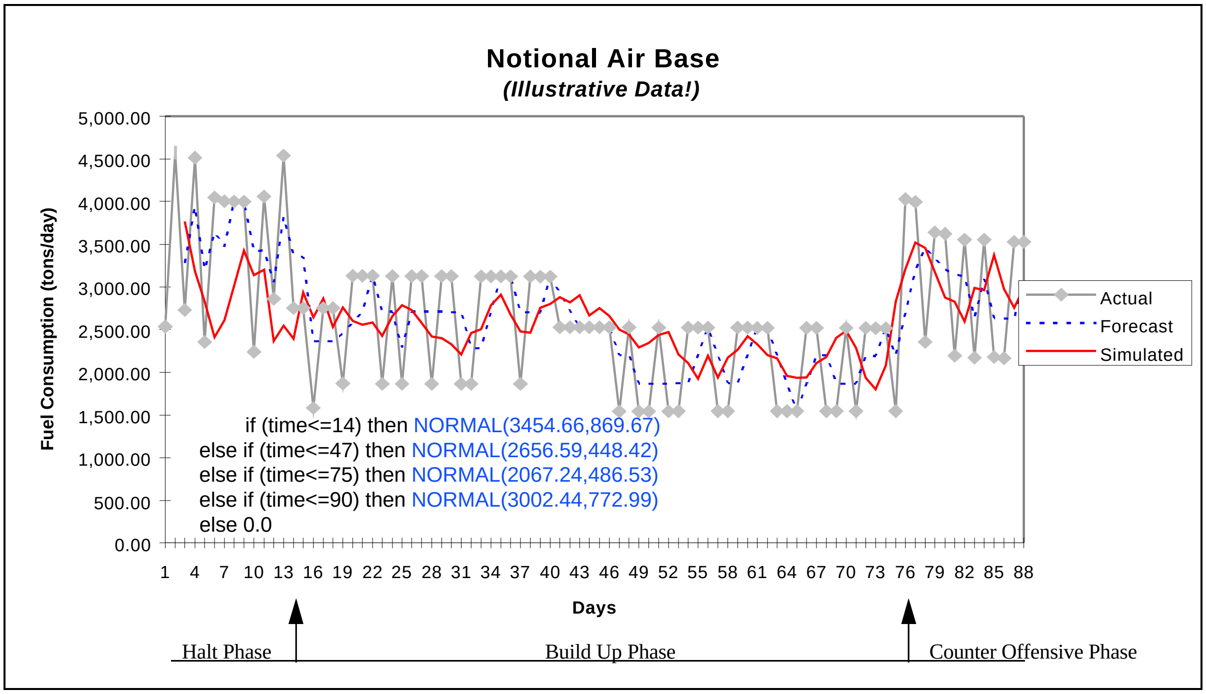


Figure 5: Modeling Sustainability of Various Fuel Policies as Viewed by the POD

This will provide an opportunity to evaluate the logistics flow of materials throughout the battle space to insure all participants are coordinated.

Third, as an output processor to evaluate TACWAR results. Typically, TACWAR does not facilitate the use of control measures to let the simulator know when resources are depleting below acceptable levels and where the source of such problems may exist so that resource allocation can be evaluated.

Such system analysis will provide decision makers the capability to balance the flow of support resources to equal the combat simulation results of high resolution as well as aggregated modeling efforts. These results insure that logistics and resources needed to support future operations are adequate and well planned.

## REFERENCES

Coyle, R. G. 1977. *Management Systems Dynamics*. New York: John Wiley & Sons.

Forrester, J. W. 1961. *Industrial Dynamics*. New York: John Wiley & Sons.

High Performance Systems (HPS), Inc., *Stella*, Hanover, NH, 1996.

Ott, A. A. 1992. Ready Reserve Fleet Activations: The View from the Deckplates, *Naval Engineers Journal*, September, pp. 27-38.

Parker, S. R. 1994. Military Force Structure and Realignment "Sharpening the Edge" Through Dynamic Simulation, DYNASIM, unpublished Ph.D. Dissertation, Purdue University, West Lafayette, Indiana.

Pritsker, A. A. B. 1986. *Introduction to Simulation and SLAM II*. 3d ed. New York: Halsted Press.

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