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USER NEED SATISFACTION AS A BASIS FOR EVALUATING CARGO AIRCRAFT SCHEDULING

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ABSTRACT

The primary emphasis of this study was to develop a measure of effectiveness for cargo airlift scheduling, based on satisfying the needs of the end user of the supplies. A detailed cargo airlift resupply network using Simulation Language for Alternative Modeling is developed and used to analyze the effects of applying different scheduling heuristics and alternative importance multiplier policies during the scheduling process. A modified worth assessment technique was used to estimate the relative worth of each supply category to the end user. These values are incorporated with the supply category levels attained to prioritize the user requirements. Airlift missions are scheduled to satisfy the highest priority requirements first. An airlift score is developed to reflect the effectiveness of the supply effort.

INTRODUCTION

This paper reviews the use of simulation techniques to compare measures for evaluating the effectiveness of scheduling cargo aircraft. Traditional effectiveness measures for scheduling aircraft have concentrated on a single goal, such as maximizing the percentage of on-time takeoffs, maximizing the average flying time per aircraft, maximizing the number of tons of cargo moved per mile flown, etc. Such measures are appropriate when the daily cargo delivery requirements are predictable and similiar flight schedules are employed on a daily basis (such as the schedules for passenger airlines). However, these measures are not considered appropriate when the daily cargo delivery requirements are dynamic in nature. In such cases, the driving force for scheduling aircraft should be the daily cargo requirements of the user. Hence, the effectiveness of the schedule should be measured with respect to satisfying user needs.

Attempting to schedule cargo deliveries that satisfy fluctuating requirements is not an easy task. It involves satisfying multiple goals that may conflict with one another. For example, it may not be possible to mix certain types of cargo that the user has requested. If a limited number of aircraft are available, the user may be required to specify an ordinal ranking of the requirements. The scheduling process then proceeds by satisfying the higher priority goals as best as possible prior to progressing to the lower priority goals. Since all goals may not be realized exactly, the scheduling process attempts to minimize the deviations from these goals with consideration given to the hierarchy of stated priorities.

The remainder of this paper will discuss the methodologies applied to set up and solve this multiple goal problem. First, a hypothetical, yet realistic, scenario will be described. Within this scenario, the individual preferences of experts are assessed and combined to form numerical preference values for various supply categories, which represent the user needs. The consumption rates for certain supply categories are allow to vary dynamically across four states of nature. Given the user needs and the expected consumption rates, heuristics are applied to schedule the delivery of cargo to the users. An experiment is designed to analyze the effects of changing scheduling policies on the satisfaction of user needs. The results of the experiment are analyzed using both analysis of variance and multiple ranking procedures. Finally, conclusions and recommendations are presented.

SCENARIO

The hypothetical scenario used in this study is based on the delivery of supplies to combat forces engaged in varying levels of conflict. There are limitations on the number of aircraft available to deliver supplies and on the size and availability of airfields to support delivery operations. Additionally, the scenario considers the effects of cancellations of scheduled sorties due to maintenance problems and non-availability of aircrews.

The situation assumes an invasion of Iran by Soviet forces from the northeast.[1] The Soviets are moving south toward the Persian Gulf. The United States has introduced a force of three divisions into Iran, with divisions headquartered adjacent to three Iranian airfields -- Arak, Khatami, and Yazd (see Figure 1). The division bases are approximately twenty-five kilometers behind the forward edge of the battle area (FEBA) and are accessible by major roads.

Tactical resupply of the U.S. forces will be accomplished by both surface transportation and airlift. All supplies enter the theater of operations at ports of debarkation (PODs), either the seaport of Bushehr or the airport at Shiraz. Since surface transportation is severely limited by long distances and by desolate, mountainous terrain, the supplies are delivered to the division bases predominantly by airlift. In addition to resupply, casualties are airlifted from the division bases to Shiraz for evacuation from the theater.

Nine squadrons of sixteen C-130 aircraft each have been assigned to support these airlift operations. These aircraft are based at Riyadh and Dhahran in Saudi Arabia and at the international airport at Bahrain. Standard deployments of such aircraft include all support personnel, with a ratio of two aircrews per aircraft.

The study assumes a sustained resupply scenario -- the situation has developed such that supply requirements for the initial deployment are no longer a factor. Adequate and uninterupted strategic airlift and sealift are assumed, with needed supplies always available at the PODs. We also assume that

[1]The scenario presented is intended to create a valid test environment for evaluating cargo airlift scheduling policies. It is not intended to be representative of any existing or anticipated war plans.

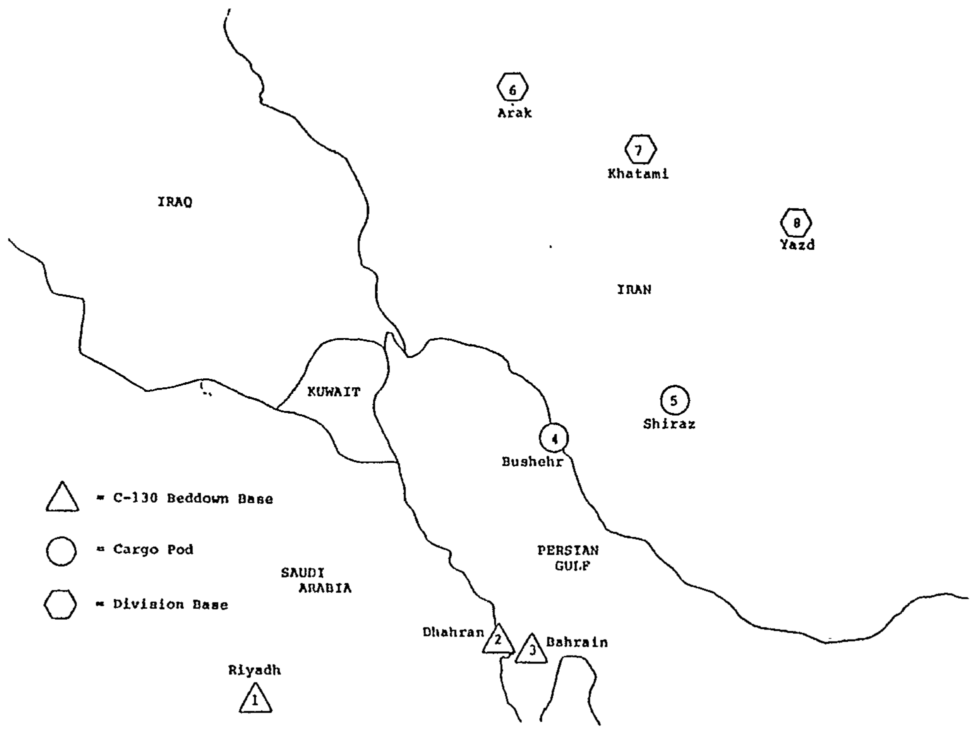

Figure 1. Geographical Situation

the location of all facilities will remain constant for the period of the study, and none of these facilities receive damage that would adversely impact the tactical airlift process for delivering cargo to the divisions.

An airlift schedule is published every twelve hours. The missions are scheduled based on priorities established at the three division bases, considering importance and the supply quantities on-hand. The missions are assigned to the three home bases for the aircraft. Those missions with the highest priorities are scheduled to depart first, and all departures and arrivals throughout the scheduling period can be deconflicted to avoid saturation of the capabilities of any base at any time.

All airlift missions originate from and terminate at the aircrafts' home base. At the completion of each sortie, a check of the remaining crew duty time is made (crew duty can not exceed 18 hours). If delays result in the aircrew exceeding the maximum crew duty length, any incompleted missions are cancelled and the aircraft and crew remain overnight at the point where the delay occurs. When the aircraft returns to its home base, the aircrew enters crew rest for a minimum of twelve hours, and the aircraft maintenance status is assessed. Once the required maintenance and servicing functions are performed on the aircraft, another crew is alerted to fly the next mission.

Within this scenario, the development of a measure of scheduling effectiveness based on satisfaction of user needs required that the term "cargo" be broken down into sub-categories. To account for supplies and to aid in the calculation of supply requirements, the Department of the Army categorizes supplies into nine classes (see Table 1). A certain desired quantity of supplies must be established by the user for each of these classes. The degree to which the needs of the user in each class are met is used as the basis for measuring the effectiveness of the supply effort and defines the term "satisfaction of user needs."

Although all nine classes of supply are important, Army doctrine considers petroleum, oil and lubricants (POL); ammunition; and repair parts and components (Classes III, V, and IX) to be critical supplies vital to the support of operations. Army Field Manual 100-10 asserts that adequate fuel for force movement, adequate ammunition to engage enemy targets, and repair capability to keep weapons systems operating are the essentials which provide the force with its fighting capability. These critical supplies must have priority over other classes of supply.

However, to consider only these three classes would be to neglect special needs represented by the other classes. Thus, a relative worth of all supply classes was required to quantify the level of need satisfaction attained by the specific scheduling policies employed.

ESTABLISHING USER PREFERENCES

Worth assessment techniques were used to assign realistic numerical values to the supply classes, based on their relative value to the Army.[2] Multiple objectives exist within the resupply scenario presented. Specifically, the desire to maintain optimal or near optimal levels in each supply category. Since all of these objectives may not be satisfied, it becomes necessary to distinguish which supply categories are most important.

[2]Worth assessment provides a formal procedure that may be applied to establish an ordinal preference relationship between qualitative factors (see Sage).

Class I	Subsistence
Class II	Individual Equipment Clothing, etc.
Class III	Petroleum, Oil and Lubricants
Class IV	Construction Materials
Class V	Ammunition
Class VI	Personal Demand Items
Class VII	Major End Items Combinations of Products Ready for Intended Use Such as Tanks and Vehicles
Class VIII	Medical Materials
Class IX	Repair Parts and Components

Table 1: Supply Classes

Class	Description	Numerical Value
IX	Repair Parts and Components	12.8
III	POL	12.7
V	Ammunition	11.0
VIII	Medical Supplies	9.0
I	Subsistence	7.0
IV	Construction Materials	4.0
II	Clothing and Equipment	1.0
VI	Personal Demand Items	0.5

Table 2: Consensus Preference

By using a modified version of the worth assessment technique, the opinions of three experienced Army officers were used to establish individual preference weightings of all supply categories from least to most valuable. The individual assessments showed complete agreement as to the relative ranking of the five least valuable classes. However, there was some disagreement on the ranking of the three classes considered most critical to sustaining combat operations.

The individual preferences were combined to obtain a single weight which reflects the relative value of each supply class. Although the final weights reflected only one of the three officer's preferences exactly, the other two officers agreed that they could accept these weightings as representative of the relative valve they would place on each supply class given the scenario described. These consensus weightings are depicted in Table 2, and are presumed to represent the general worth to the Army of each supply class within the scenario used in the study.

DYNAMIC CONSUMPTION RATES

Although supply consumption rates in most supply classes are constant according to division type, consumption of POL and ammunition supplies (classes III and V) are a function of the intensity of combat experienced at a point in time. Within the scenario, a combat unit which defends a position for several days or weeks may launch an offensive, or another unit may come under siege. As a result, the rates of supply consumption for POL and ammunition will increase or decrease with the changing combat conditions.

Four levels of combat are considered in this study -- intense, moderate, light, and reserve. To model these changing combat conditions, a one-step transition matrix was developed to predict the situation which will exist at the beginning of the twelve hour scheduling period given the overall situation at the end of the previous scheduling period. According to expert opinion, the overall rate of consumption for this scenario should be the rate associated with a moderate level of conflict. Thus, the transition matrix was established to yield steady state probabilities which reflect a moderate level of combat. The one-step transition matrix and the steady state probabilities are depicted in Table 3.

Combat Level	Intense	Moderate	Light	Reserve	Steady State
Intense	0.4	0.5	0.1	0.0	0.231
Moderate	0.2	0.5	0.2	0.1	0.500
Light	0.2	0.5	0.2	0.1	0.192
Reserve	0.0	0.5	0.4	0.1	0.077

Table 3. One-Step Combat Level Transition Matrix (With Steady-State Probabilities)

SCHEDULING HEURISTICS

Heuristics are used to schedule cargo deliveries. This involves three processes: (1) determining the consumption of supplies and generation of casualities for the preceding twelve-hour period, (2) scheduling cargo deliveries for the current period from calculated priorities based on the updated status, and (3) deconflicting the schedule to minimize congestion at the various airfields and configuration changes to the aircraft.

Updating Consumption

The initial action is to update the combat states at the three divisions using the one-step transition matrix (depicted in Table 3). Next, the supply status of each division is updated to reflect the effects of the preceding twelve hours of combat. This consumption is deterministic for all classes except POL and ammunition.

Schedule Cargo Deliveries

Airlift scheduling is based on meeting the needs of the airlift user. This is accomplished through a priority system in which the base with the greatest need for resupply is ranked highest on a list of scheduling priorities. Weighted priorities are derived from a linear function which weights the level of supply in each class at each base by the importance of the supply class. Unweighted priorities are calculated by dividing the desired fifteen-day supply level (computed using the moderate rate of consumption) by the current on-hand supply level. Weighted priorities are derived by multiplying the unweighted priorities by the importance weight for that particular category. For example, the relative priority for item type i, with corresponding importance factor W(i), at division location j would be:

$$P_{ij} = W_i \times \frac{(15 \text{ day supply of } i)}{(\text{on-hand supply of } i \text{ at } j)}$$

The goal of the resupply effort is to maintain supply levels at each base as near the desired fifteen-day level as possible. The heuristic first schedules a cargo delivery to the base with the highest calculated priority, and updates the status of that base to reflect the planned delivery. The priorities for the supply category at that base are then recalculated, and the process repeated until all available cargo deliveries are scheduled for the current period.[3]

[3] Certain constraints are imposed on this scheduling process. The two main constraints are that partial onloads and offloads are not allowed, nor are aircraft allowed to reconfigure once they have departed their home bases. These constraints cause deviations from the objective to schedule higher priority deliveries first.

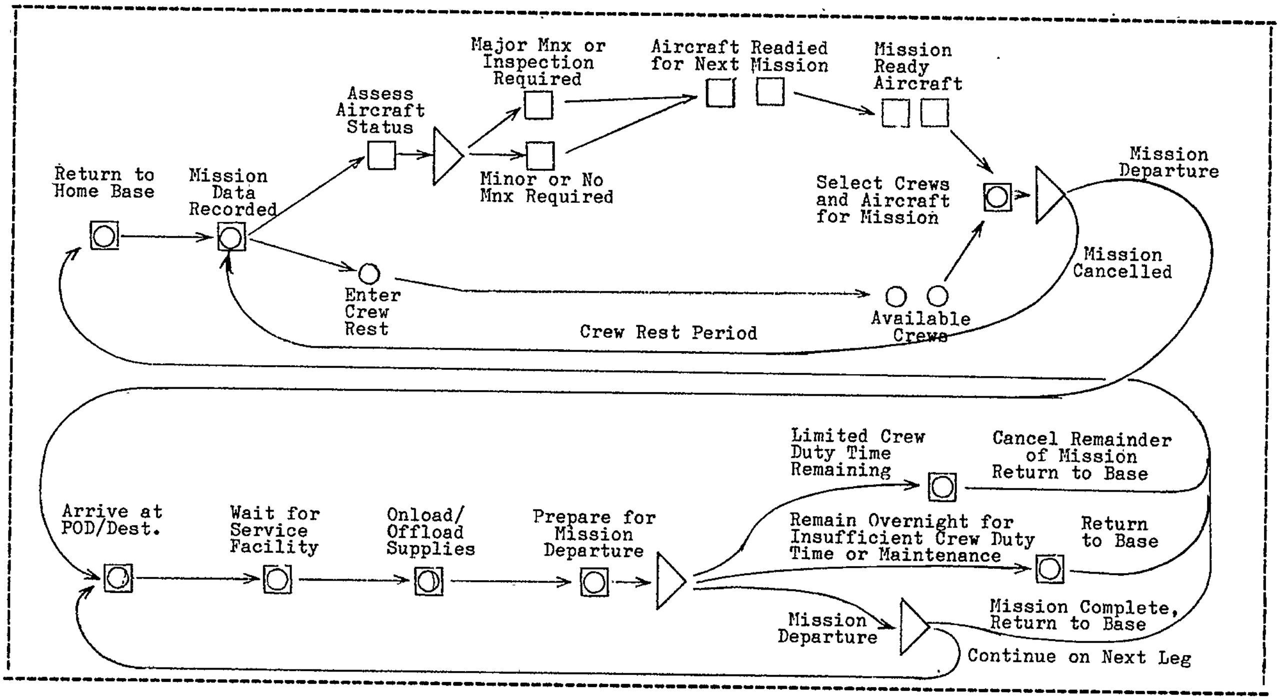

Figure 2. Pre-mission, Mission, and Post-mission Activities

Deconflicting Deliveries

This heuristic attempts to deconflict the scheduled deliveries to minimize congestion at the various delivery locations and to minimize configuration changes to the aircraft. As each scheduled delivery is sequenced, conflicts with higher priority deliveries already sequenced are identified and resolved where possible. This includes spacing departure times from the home bases and ensuring that adequate ramp space is available at the destinations for offload and onload activities. If an unacceptable conflict does occur, rescheduling is attempted through a series of switches between the current scheduled delivery and lower priority scheduled deliveries that have not yet been sequenced. Once a scheduled delivery is sequuenced, it is not altered to accommodate a lower priority mission. In the event deconfliction is not possible, the scheduled delivery is cancelled.

SIMULATION MODEL

A simulation model was constructed using the Simulation Language for Alternative Modeling (SLAM). SLAM is particularly well suited to this purpose because it allows for the movement of aircraft through the airlift system by the passage of entities through an interconnected network of nodes. The flow of aircraft through the system is conducted in three phases: pre-mission activities at the home base, mission activities at depot and division bases, and post-mission activities. After presenting each phase, model design considerations, as well as verification and validation will be discussed.

Pre-mission Activities

Pre-mission activities are depicted in the upper right-hand corner of Figure 2. The process begins with the assignment of a crew to an aircraft. The aircraft and crew are then given two cargo delivery missions from the prioritized delivery schedule. If no maintenance problems are encountered, the airlift mission departs at its scheduled departure time. If maintenance problems are encountered, yet can be corrected within four hours of the scheduled departure time, the airlift mission departs after the problems are corrected. If the mission cannot depart within four hours of its scheduled departure time, it is cancelled and the crew returns to crew rest.

Mission Activities

Mission activities are depicted in portion of Figure 2. After arrival at any base, the aircraft proceeds to the proper service area based on its configuration and is onloaded or offloaded as required. Prior to departure on the next segment of the mission, there is again the possibility of maintenance delays. If maintenance and queuing delays (waiting for service) leave the aircrew only enough crew duty time to return to the base station, the remainder of its mission is cancelled and the aircraft returns to home base. If the crew has insufficient crew duty time to return to home base, or if the aircraft requires extensive maintenance, the aircraft remains overnight at its present location and the aircrew enters crew rest. Otherwise, the aircraft and crew continue on the scheduled delivery mission.

Post-mission Activities

Post-mission activities are depicted in the upper left corner of Figure 2. Basically, the aircrew enters the twelve-hour crew rest period and the aircraft receives maintenance and servicing.

Model Design Considerations

Combined network and discrete event simulation techniques were used. The model was designed to be scenario-independent. Thus, at the beginning of each simulation run, variables must be initialized to reflect the actual scenario begin modeled. Since the scenario assumes that the supply system is in steady state, supply levels at each division were initialized with realistic quantities on-hand.

The model events were synchronized such that critical events occurred in the same sequence each time the model was run with a particular random number stream. This technique insures that any variation in the model output between two runs with common random number streams can be attributed to the effect of the policy. Bias in the model output resulting from this technique should be consistent as long as common random number streams are applied. Thus, the resulting effect should be negligible as long as policy alternatives are evaluated on a comparative basis. The combination of applying synchronization and common random number stream techniques also leads to reduced variance between the system measures obtained from implementing alternative policies.

Verification and Validation

Model verification was an iterative process which ran concurrently during the development of the model from its simplest to its final form. The five verification techniques listed by Law and Kelton (pp. 334-337) were each followed.

Validation of the model was difficult since tactical airlift scheduling is not currently based on the satisfaction of user needs. Thus, the model's representativeness of a real world system could not be established. As a result, the opinions of experts within the Army and the Air Force were solicited, both in the selection of the appropriate model parameters and in the evaluation of the model's output. These opinions formed the basis of the model's reasonableness as an analysis tool.

EXPERIMENTAL DESIGN

Once the simulation model was developed, verified, and validated, experimentation was applied to determine the effect of changing scheduling heuristics and of altering the importance weights of the different supply classes used in determing the weighted scheduling priorities. The experiment was designed to show the effects on the level of user need satisfaction attained (in terms of an airlift score) for each combination of two scheduling heuristics (each at two levels) within four different sets of supply class importance multipliers. The final design also considered the variations caused by the random effects of applying different random number streams to each replication of the model. This produced a 2x2x4 nested, mixed effects factorial design.

User Satisfaction Score

An overall airlift score was computed and used as the measure of effectiveness of the resupply effort for each simulation run. The score is based on a weighted average fraction of the desired fifteen-day supply levels maintained over the period of conflict for each supply category at each division headquarters. A supply class score is computed by dividing the ACTUAL on-hand levels for each supply class by the DESIRED fifteen-day supply level, multiplying the resulting fraction by the assessed importance weight of the supply class, and adding this weighted fraction to a running total. This total is then divided by the number of days in the simulation run. Within each supply class, the lowest score from each of the three divisions[4] is used rather than the average score across the divisions.

The sum of all supply class scores gives the overall airlift score. If each supply class is consistently maintained at or above the fifteen-day level throughout the conflict period, the airlift score would attain the value 58.0.

$$\text{Score} = \sum_{i} \left\{ \min_{j} \left[\text{actual}_{ij} / \text{desired}_i \right] \times W_i \right\}$$

Deconfliction Policy

The first scheduling policy involves the use of the deconfliction heuristic described earlier. Recall that the purpose of deconfliction was to provide more efficient scheduling of the delivery missions. An aircraft scheduled for departure with a conflicting mission is rescheduled to another mission rather than allowing the aircrew and aircraft to spend excessive and unproductive time in waiting queues at the primary division base. The model was exercised both with and without this deconfliction heruistic.

Expected Consumption Policy

An additional heuristic was added to artificially decrease the supply levels in each class by the expected consumption before deriving the scheduling priorities. The purpose of this heuristic is to increase the priorities of the classes with low on-hand supply levels in the current period, and to provide a-priori consideration of the effects of the expected levels of conflict. The result should be to maintain higher average levels of supply across all classes and to limit classes from reaching the zero supply level. The model was exercised both with and without the expected consumption heuristic.

Alternative Supply Class Importance Multipliers

This heuristic applies different sets of multipliers to the unweighted priorities initially determined for each supply class. The effect is that each initial unweighted priority is adjusted according to the multiplier sets, and the resulting weighted priority is entered into the scheduling process. Due to the nature of the scheduling process, supply classes with higher priorities should be maintained at higher levels. The question is whether significantly different scores result from the use of alternative importance multipliers. Four multiplier sets were used.

1) EQUAL WEIGHTS, where equal multipliers are used for all classes, resulting in no adjustment to the initially determined priorities.

2) ARMY DOCTRINE WEIGHTS, where equal multipliers of 1.0 are used for all classes except POL, ammunition and repair parts. These classes were multiplied at 2.0, 3.0, and 5.0 respectively.

3) ASSESSED WEIGHTS, where the multipliers are assigned values respective to the values derived from the worth assessment process, as depicted in Table 2.

4) PREEMPTIVE WEIGHTS, where the multipliers are assigned values proportional to the values derived from the worth assessment process. The preemptive weights force the system to schedule deliveries to satisfy higher valued supply classes. Hence, deliveries of the highest valued class (Repair Parts) will be scheduled to attain the desired fifteen day supply level prior to scheduling deliveries of any lower valued classes. Deliveries of the next highest valued supply class (POL) are then scheduled, followed by scheduled deliveries for ammunition, medical supplies, etc.

Sample Size and Reliability

Pilot runs were accomplished for conflict periods of

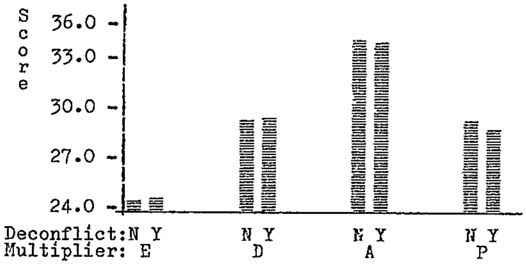

Figure 3. Effect of Deconfliction Heuristic

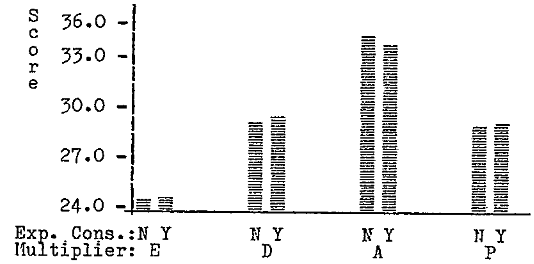

Figure 4. Effect of Consumption Heuristic

Importance Multiplier Policy	Deconfliction	Expected Consumption	Mean Airlift Score	Variance of the Mean
Assessed Weights	Not Used	Not Used	35.514	0.563
	Not Used	Applied	35.096	0.470
	Applied	Not Used	34.981	0.529
	Applied	Applied	34.724	0.550
Army Doctrine Weights	Not Used	Not Used	29.804	0.221
	Not Used	Applied	29.980	0.221
	Applied	Not Used	30.210	0.243
	Applied	Applied	30.237	0.278
Pre-emptive Weights	Not Used	Not Used	29.786	0.998
	Not Used	Applied	29.426	0.026
	Applied	Not Used	30.071	0.228
	Applied	Applied	29.459	0.231
Equal Weights	Not Used	Not Used	24.569	0.306
	Not Used	Applied	24.864	0.277
	Applied	Not Used	24.880	0.272
	Applied	Applied	25.123	0.315

Table 4. Mean Airlift Score and Variance for Alternative Importance Multiplier Policies

	Importance Multiplier Policy			
System Measures	Equal Weights	Army Doctrine Weights	Assessed Weights	Pre-emptive Weights
Airlift Score	24.569	29.804	35.514	29.786
Supply Levels				
Subsistence	0.427	0.238	0.426	0.201
Individ. Eq.	0.432	0.260	0.152	0.123
POL	0.414	0.433	0.734	0.779
Const. Mat.	0.382	0.204	0.243	0.112
Ammunition	0.442	0.670	0.672	0.323
Personal Dmd.	0.428	0.239	0.096	0.079
Medical Supp.	0.462	0.269	0.576	0.293
Repair Parts.	0.432	0.957	0.772	0.965
Overall Avg.	0.427	0.409	0.459	0.359
Casualities	784	889	1115	5016
Delays at Dest. Facilities				
Cargo	0.001	0.016	0.001	0.002
POL	0.073	0.086	0.139	0.165
Casualities	0.002	0.000	0.000	0.000
Delays at POD Facilities				
Cargo	0.054	0.073	0.012	0.008
POL	0.177	0.233	0.769	2.466
Casualities	0.021	0.012	0.034	0.000

Table 5. Mean Values of System Measures

both thirty and sixty days, with three replications per run. There was no significant reduction in the variance between the scores for these two periods. Thus, experimental runs were performed for a simulated conflict period of thirty days.

Even with the thirty day run length, resource constraints limited the number of replications which could be achieved with the simulation model. We chose ten replications as being a realistic sample size. When combined with the sixteen policy combinations, this produced a requirement for 160 runs of the computer model.

Ten replications of the baseline model (equal importance multipliers without applying either scheduling heuristic) were performed, each simulating thirty days of conflict. This produced an estimated variance of the mean airlift score of 0.30625. Limiting the chance of Type I errors to five percent and Type II errors to twenty percent (alpha=.95 and beta=.80), the amount that the airlift scores must differ to statistically distinguish between policy combinations was derived.[5] The resulting value is approximately 0.5 -- i.e., the mean airlift scores must differ by 0.5 or more to be considered statistically different. This was considered to be an acceptable value.

ANALYSIS OF RESULTS

Table 4 presents values for the mean airlift score and associated variance of the mean for each of the policy combinations. (These results are also graphically depicted in Figures 3 and 4.) An initial observation suggests that the importance multiplier policies have a profound effect on the airlift score. The remainder of this paper will concentrate on discussing the effects on the airlift score of changing policies and applying scheduling heuristics. Multiple ranking procedures are applied to determine if a single "best" policy exists. Multivariate analysis of variance is applied to assess the statistical significance of the effects of changing scheduling policies and heuristics on the system measures.

Multiple Ranking Procedure

One purpose of the study is to compare and distinguish between the policy combinations. Multiple ranking procedures were applied to distinguish those policy combinations which resulted in a significantly higher airlift score at 95 percent confidence.

The two-stage multiple ranking procedure proposed by Bechofer, Dunnet and Sobel was applied. This approach suggests that if the highest policy combination mean is at least 1.8 units greater than the next highest, then that policy combination is statistically "better". Upon reviewing the averaged airlift scores for each policy combination, it is apparent that a "best" policy combination cannot be distinguished. The multiple ranking procedure does suggest that the effects of changing the importance multipliers is statistically significant. However, no statistical conclusions may be drawn concerning the effect of the two scheduling heuristics.

Multivariate Analysis of Variance

Multivariate analysis of variance techniques were applied to test for the significance of the effects of the alternative importance multiplier policies, and of the scheduling heuristics within the alternative importance multiplier policies. The effects of the scheduling heuristics are dependent on the values of the importance multipliers, and cannot be considered as independent across the policies. Thus, analysis of these effects must apply nested techniques.

To get an understanding of the effects of the scheduling policies on the airlift system, the scope of the analysis must be expanded beyond merely looking at the airlift score. A causal loop diagram of this system is presented in Figure 5. The maximum values for the onload/offload and mission departure rates were fixed within the model. Restricting the onload and offload rates allowed queues to developed for facilities at both the PODs and the destinations. Maintenance delays, maintenance caused cancellations, and exceeding crew duty time are all incorporated into the mission departure rates. Restricting these rates cause delays in the departure of the scheduled missions.

The supply consumption rate was discussed earlier, and only affects the levels of POL and ammunition. The importance multiplier policy applied affects the rate at which deliveries are scheduled for each supply class. The two scheduling heuristics also affect the mission scheduling rate.

The mean values of the airlift score, the percentage of the desired supply levels attained, the number of casualities, and the length of delays encountered at the PODs and destinations are presented in Table 5 for each of the importance multiplier policies where neither scheduling heuristic was applied. The importance multiplier policies resulted in statistically significant changes across all system measures. The effects of applying the scheduling heuristics are summarized in Table 6. These effects will now be discussed.

Effect of Importance Multiplier Policies. Changing the importance multiplier policy alters the weights applied to determine the priority for scheduling airlift missions. When higher priority is given to a specific supply class, then deliveries of that class are scheduled rather than deliveries of a lower priority class. Hence, deliveries of the lower priority supply classes are sacrificed. Delivery of POL requires a specially configured aircraft, and requires special services at the destination bases. As more POL sorties are scheduled, queues should develop for these services, producing lower airlift scores. The other type of airlift mission requiring special configurations and special services is casuality evacuation. When preemptive, assessed or Army doctrine weight sets are used, these missions are sacrificed in lieu of the higher priority supply class deliveries.

Under equal weighting, approximately equal average levels are maintained across the supply classes. The data in Table 5 suggest that the airlift resources can only maintain a 6.5 day level of supplies, on average, when equal weighting is given to all supply classes.

When Army doctrine multiplier sets are applied, the specially configured POL missions, as well as missions supplying repair parts and ammunition, are given higher priorities. The data in Table 5 confirm that these classes each attain higher average levels, while the remaining classes have approximately equal average levels. The delays for cargo and POL facilities increase as more missions are dedicated to these supply classes. Also note the increase in casualities. Since the mission priority remains at the 'equal' level, less missions are available for evacuation resulting in an increased number of casualities at the destinations. These data also confirm that this is a restricted resource problem. If the levels in some supply classes increase, the levels in other supply classes must decrease.

The assessed weights give different priorities to each supply class (casuality evacuations remain valued at one). The average supply levels attained are proportional to the importance multipliers. Since the airlift score also assigns values proportional to the assessed weights, it was anticipated that this policy would produce a higher airlift score. Notice that although repair parts and POL have approximately the same priority, the average POL level is lower. This results from the increased delays of waiting for POL facilities at both the destinations and the PODs. On the other hand, the delays for cargo facilities decrease, suggesting that the allocation of cargo missions based on the assessed weights seems to regulate the flow of deliveries. This regulating effect is also suggested by the increased overall average supply level. Since less missions are available for casuality evacuation, the number of casualities at the destinations increase.

The preemptive weights should prioritize deliveries to maximize desired supply levels in an ordinal sequence, with deliveries of the highest valued classes scheduled first. Note that the average level for repair parts, the highest valued class, is 96.5 percent of the desired level. The next highest valued class is POL, which attains an average level of 77.9 percent. The increased emphasis on POL missions appears to overload the POL facilities, especially at the PODs. In fact, the increased delays result in the cancellation of missions due to exceeding crew duty time. The average levels maintained in the remaining classes are all significantly lower than those attained under the assessed weighting policy. Since casuality evacuation missions have one of the lowest importance values, the number of missions available for evacuations is reduced, resulting in increased numbers remaining at the destinations.

Effect of Deconfliction Heuristic. Applying the heuristic to deconflict arrivals, departures and aircraft configuration changes did not produce any consistent influences on the airlift scores across the importance multiplier policies. These results may be derived for the data presented in Table 6, and are also depicted graphically in Figure 3. It was expected that deconflicting the schedule would smooth the flow of supply deliveries, thus increasing the airlift score. The heuristic appears to work at the destination facilities, since delays are decreased (except for the cargo facility under equal weighting). The heuristic also works as anticipated at POD facilities under equal and Army doctrine weighting policies. Under the assessed and preemptive weighting policies, delays increase at the POL facilities. Under these two policies, POL facilities are a restriction to the increased flow of supplies resulting from higher scheduling priorities. Also, reducing the restrictions at the destination facilities allow the aircraft to cycle back to the POD at a faster rate. This compounds the queuing problem, resulting in increased delays and fewer missions. In most cases, the average levels of the supply classes increase when POL delays decrease, and decrease when POL delays increase.

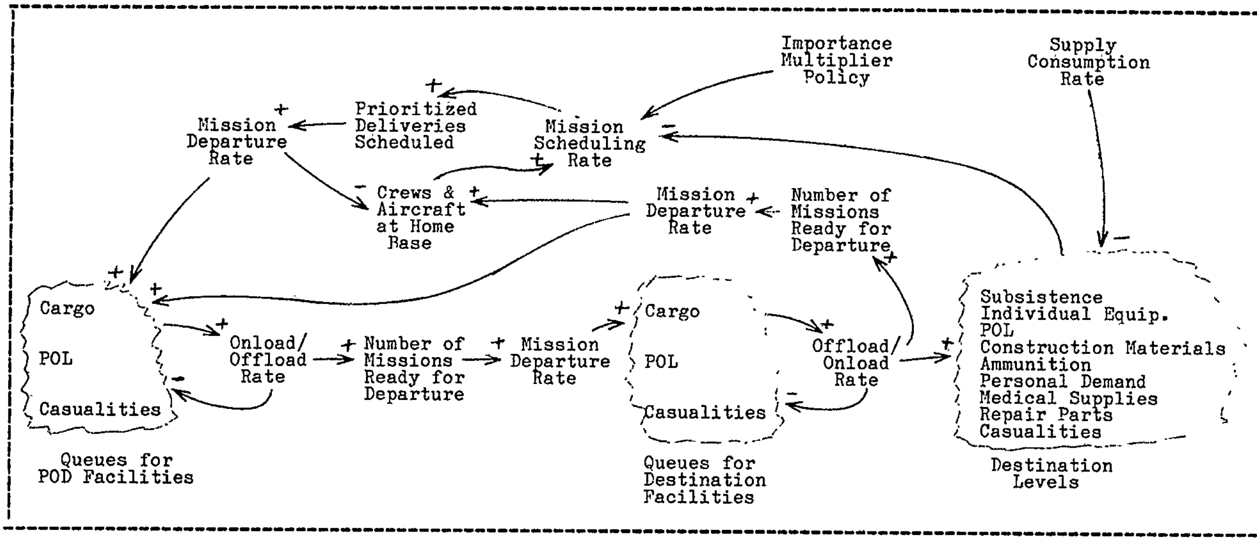

Figure 5. Causal Loop Diagram

Treatment Affecting System Measure	Importance Multiplier Policy Applied							
	Equal Weighting		Army Doctrine Weighting		Assessed Weighting		Preemptive Weighting	
	Decon-fliction	Expected Consump.	Decon-fliction	Expected Consump.	Decon-fliction	Expected Consump.	Decon-fliction	Expected Consump.
System Measures								
Airlift Score	Increase	Increase	(Inc)	Increase	Decrease*	Decrease	(Dec)	(Inc)
Average Supply Level								
Subsistence	Increase	(Inc)	Increase	Increase	(Dec)	(Inc)	(Dec)	(Dec)
Individual Equip.	Increase	(Inc)	Increase	Increase	Decrease*	Increase	(Dec)	Increase
POL	Increase	(Dec)	Increase	Decrease	(Dec)	Decrease	(Dec)	(Inc)
Construction Mat.	(Dec)	(Inc)	(Dec)	Increase	Decrease*	Increase	(Dec)	Increase*
Ammunition	Increase	(Dec)	Increase	Decrease	(Dec)	Decrease	(Dec)	(Dec)
Personal Demand	Increase	(Inc)	Increase	Increase	(Dec)	Increase	Decrease*	Increase
Medical Supplies	(Inc)	Increase	(Inc)	Increase	Decrease	Increase	(Dec)	(Dec)
Repair Parts	Increase*	(Inc)	(Inc)	(Inc)	(Dec)	Decrease	(Inc)	Increase
Casualities	(Dec)	Increase	Decrease	Increase	(Inc)	(Inc)	(Inc)	(Inc)
Total Stockouts					(Inc)	Decrease	(Inc)	Decrease
Destination Delays								
Cargo Facilities	(Inc)	(Dec)	Decrease	(Inc)	Decrease*	Increase	Decrease	(Inc)
POL Facilities	Decrease*	(Inc)	(Dec)	Increase	Decrease	Increase	Decrease	Increase
Casuality Facility	Decrease	(Dec)						
POD Delays								
Cargo Facilities	Decrease	(Dec)	Decrease	(Dec)	(Dec)	(Inc)	(Dec)	Increase
POL Facilities	Decrease	Increase	Decrease	(Inc)	Increase	Decrease	(Inc)	Decrease
Casuality Facility	(Dec)	(Dec)	(Dec)	(Dec)	(Dec)	(Dec)		

Increase and Decrease are statistically significant at the 0.95 confidence level.
Items marked with an asterisk (*) are statistically significant at the 0.90 confidence level.
Items enclosed in parentheses are not statistically significant, and are presented only to indicate the trend of the system measures.

Table 6. Effect of Scheduling Heuristics on System Measures Within Each Importance Multiplier Policy.

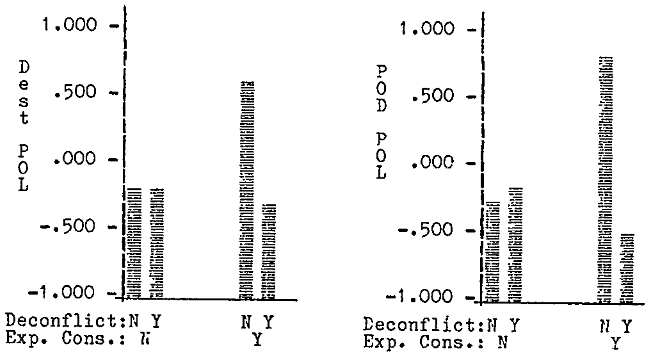

Figure 6. Standardized Interaction Effects at POL Facilities.

Effect of Expected Consumption Heuristic. The purpose of the expected consumption heuristic is to base the schedule for supply deliveries on forecasted supply levels rather than historical levels. In situations where consumption is dependent on the current state of conflict, and the current state can be accurately forecast, this heuristic should improve the airlift score. As shown in Figure 4, these results are inconsistent across the importance multiplier policies.

Within the scenario of this study, only two supply class consumption rates vary with the state of conflict. Namely, POL and ammunition. The data in Table 5 show decreased average levels for both of these classes (except for POL under the preemptive weighting policy). Note the increase in delays for both POL and cargo facilities at the destinations when policies give increased importance to POL and ammunition classes (all except equal weighting). As before, the increased delays result in lower average supply levels.

With the exception of the preemptive weighting policy, applying the expected consumption heuristic increases the average levels of all other supply classes. The exception is repair parts under the assessed weighting scheme. Since this is the highest valued supply class, it will be maintained at a higher average level. The heuristic will increase the priorities of the lower valued classes, diverting missions from repair parts to these other classes.

Stockouts only occurred in this system under the assessed and preemptive weighting policies. Note that the expected consumption heuristic does reduce the number of stockouts. In fact, this may provide a better true user satisfaction even though the airlift score decreases. The airlift score does not include penalties for stockouts.

INTERACTION EFFECTS

Two significant interactions occurred under the equal weighting policy. Both concerned the delays at POL facilities. Figure 6 graphically depicts these interaction effects at the destination and POD POL facilities. As can been seen, implementing the expected consumption heuristic without implementing the deconfliction heuristic produces a significant increase in the delays for POL facilities. Implementing both heuristics produces a net decrease in the delays at the POL facilities.

CONCLUSIONS

The results suggest that proper combinations of scheduling heuristics and weights can be used in scheduling cargo aircraft to better satisfy the needs and desires of the users, according to how they value each type of cargo. The study demonstrates that the use of weighted scoring functions within a simulation model is a viable technique to compare the effect of alternative scheduling policies in a multiple goal environment. We recommend future studies that incorporate a penalty for stockouts in the scoring function. Also, a higher order scoring function should be developed which increases the priorities at a higher rate at the supply levels decrease. These recommendation are based on our finding that the scheduling heuristics tended to work as anticipated, although this does not always result in an improved airlift score.

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