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A HYBRID ANALYTICAL / SIMULATION MODELING APPROACH FOR PLANNING MASS TACTICAL AIRBORNE OPERATIONS

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ABSTRACT

A hybrid analytical/simulation model is developed to plan for mass tactical airborne operations. This automated tool enables the user to properly load aircraft according to the mission and user specifications, so that the minimum amount of time is required to seize all assigned objectives. The first portion is a mathematical model that once solved provides the optimal manifest under "perfect conditions". This analytical model is represented by a transportation network, and optimized using a transportation algorithm. The results of this solution are input to an integrated simulation model that introduces the inherent variability. The simulation returns the expected, best, and worst arrival times, and the build up of power over time. This hybrid approach allows a very large problem to be solved efficiently with a great deal of time savings.

1 INTRODUCTION

Mass tactical airborne operations are one of the most complex and dangerous of all offensive military operations. In just under one minute, over one thousand paratroopers can be delivered from the air into a single drop zone. Each jumper is assigned an objective that he must move towards immediately after hitting the ground. Because the jumpers exit in the order they are seated, the personnel seating assignment on the aircraft (i.e., the manifest) has a direct impact on *where* each individual jumper lands and as a result how long it takes him to reach his objective. The goal of the commander is to load his aircraft in such a way that the minimum amount of time is required to seize all assigned objectives. Therefore, a good air plan is crucial in the execution of the ground tactical plan.

The current recommended air plan practices for all U.S. Army airborne units is described in the 82nd Airborne Division's Airborne Standard Operating Procedures (ASOP). The process outlined in ASOP can lead to effective air plans, if it is properly followed; however, it is a very time-consuming process. Moreover, in practice, a great deal of negotiation, bartering, and politics influence the air plan and, as a result, the commander's intent is not always fulfilled.

In this paper, we present an automated tool to objectively generate an effective manifest that would meet the commander's goals and would reduce the subjectivity that is generally involved in the process. This automated tool is developed based on a hybrid analytical/simulation modeling approach. Hybrid modeling is an approach in which independent analytical and simulation models of the total system are built and solved, and their solution procedures are used together for problem solving (Sargent 1994, and Shanthikumar and Sargent 1983). This approach was selected because the airborne manifest problem is an assignment problem that can be solved using a transportation algorithm. However, a number of simplifying assumptions must be made in order to solve this mathematical model. Therefore, the analytical model only provides a solution to "*the world is perfect*" scenario. A simulation model, on the other hand, allows for the introduction of the variability that exists in such operations. The sources of variability include aircraft speed, direction and altitude, along with jumper exit intervals, wind drift, descent rate, paratrooper impact recovery, and orientation and ground speed to the objectives. The optimal solution to the mathematical model would provide a good starting solution to the simulation model and together, the two models allow the commander to estimate the probabilities of reaching the targets within specified time limits. The output of the hybrid model will include the minimum, maximum, and the expected time for building the combat power to 50%, 75%, 90%, and 100% at each objective.

The organization of this paper is as follows: In Section 2, the methodology is presented. Section 3 includes a case scenario and the results. In section 4, a summary and conclusions are presented.

2 METHODOLOGY

The proposed approach includes two components: a mathematical model and a simulation model. The objective of the mathematical model is to provide a loading strategy that would minimize the total travel time from the point of impact on the ground to the assigned objectives. In other words, the solution to this model (i.e., the optimal manifest) would allow the required number of paratroopers to seize their corresponding objectives with minimum traveling time. This model will be set up and solved with the assumption that everything occurs exactly as planned. To better reflect reality, the output of the mathematical model (i.e., the optimal loading strategy) will be input into a discrete event simulation that models the inherent variability in airborne operations. Figure 1 demonstrates how the two portions of the hybrid model interact with one another.

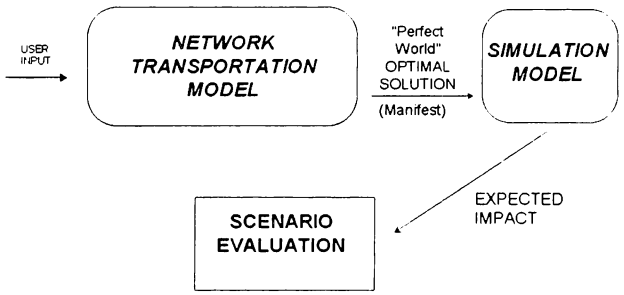

Figure 1: Proposed Hybrid Modeling Approach

2.1 Mathematical Model

The problem of mass tactical airborne operations is modeled as an assignment problem that can be formulated as a network transportation problem as follows:

$$\text{Minimize} \quad \sum_{i=1}^{M} \sum_{j=1}^{N} c_{ij} x_{ij} \qquad (1)$$

$$\text{subject to:} \quad \sum_{j=1}^{N} x_{ij} \le S \qquad \text{for } i = 1, 2, 3 \ldots, M$$

$$\sum_{i=1}^{M} x_{ij} = D_j \qquad \text{for } j = 1, 2, 3 \ldots, N$$

$$x_{ij} \ge 0 \text{ for all } i \text{ and } j$$

where

c_{ij}: time-distance coefficients for connecting jumper landing position i with objectives j

x_{ij}: number of personnel to be transported from impact point i to objective j

S: total number of aircraft

D_j: number of personnel assigned to seize objective j

M: number of personnel in each aircraft

N: number of objectives

To formulate the mathematical model, the user must provide initial values for several input parameters including the number of aircraft in a serial, the length of the drop zone, the type of aircraft (which defines the number of seats on each aircraft), direction of flight, the expected impact location of the first jumper, number of passes the aircraft will make, and the number of objectives. Once the number of objectives is specified, the user must provide information on the location of each objective as well as the number of paratroopers that must move towards that objective upon landing. In addition, each objective must be defined as:

1. Mission Essential - Those missions that absolutely must be accomplished for the overall success of the operation,
2. Mission Support - Those missions that directly support the mission essential, or
3. Secondary Mission Support - Those missions that are not critical to the essential or primary support missions.

These missions are, of course, not of the same importance level. In order to account for that, the user can input a factor indicating his priority level for each objective. For example, if the user feels that an objective that is Mission Essential is twice as important as an objective that is Mission Support, he can assign factors of 8 and 4 to those, respectively. These factors are then used in the objective function of the mathematical model to calculate a weighted cost functional value.

The user must also specify the environmental conditions under which the mission is to be carried out. These environmental factors return a maximum sustainable speed, in meters per second, and are obtained from the Dismounted Infantry Movement Rate Study (Hayes 1994) that models core temperature and human performance under stress.

Once the values of the above input variables are provided, the location where each jumper impacts on the ground is calculated by the software. The Military Grid Reference System (MGRS) is used to determine these locations. In the MGRS, the X-coordinate is a false Easting value expressed in meters, increasing from left to right. The Y-coordinate is the Northing component, and increases from bottom to top. Angles are measured from grid north and increase clockwise. All measurements are in meters.

The first jumper exiting from the primary door impacts on the Personnel Point of Impact (PPI) and gains the PPI's X and Y coordinates. Each subsequent jumper's X and Y position must then be calculated incorporating the heading, or Direction of Flight. The following is the formula for determining X and Y coordinates for jumpers one through n on the primary door:

$$X_n = X_{n-1} + [sin(DoF) * 68.58 \text{ meters}]$$
$$Y_n = Y_{n-1} + [cos(DoF) * 68.58 \text{ meters}]$$

where

X_n : the Easting coordinate for jumper n,
Y_n: the Northing coordinate for jumper n, and
DoF: the direction of flight in degrees from true north.

Note that 68.58 meters is equal to 75 yards which is the distance traveled in one second at 125 knots.

The first jumper from the non-primary door ideally exits one half second after the primary door. His location is then found using the formulas below, with jumpers 2 through n using the formula above and substituting X_1 and Y_1's location for X_{n-1} and Y_{n-1}.

$$X_1 = X_{PPI} + [sin(DoF) * 34.29 \text{ meters}]$$
$$Y_1 = Y_{PPI} + [cos(DoF) * 34.29 \text{ meters}]$$

Note that 34.29 meters is the distance traveled in 1/2 second at 125 knots per hour.

Once the impact location for each jumper is determined, the distance from the impact point to each objective is calculated. This is done simply by using the Pythagorean Theorem as follows:

$$Distance = [(X_{OBJ} - X_n)^2 + (Y_{OBJ} - Y_n)^2]^{1/2}$$

where X_{OBJ} and Y_{OBJ} are the X and Y location of each objective and X_n and Y_n are the impact locations for each jumper. These distances are then converted to time factors using the maximum sustainable speeds from the heat stress model found in the Dismounted Infantry Movement Rate Study (Hayes 1994).

Once all the input variables are provided and the distance between each point of impact and each objective is calculated, the model is solved using a transportation algorithm (Taha 1992). This algorithm is coded in Microsoft Visual Basic for Windows (Microsoft 1992). The main reason for using this software is that once compiled, the application is free-standing and royalty free. The solution to this transportation problem provides the optimal seating assignment for each aircraft under "perfect conditions". Real life airborne operations, however, includes many sources of variability that must be accounted for.

2.2 Simulation Model

To introduce the inherent variability that exists in airborne operations, the optimal solution obtained from the analytical model is fed into a simulation model to provide a good starting solution. Various sources of variability are included in the simulation model in order to represent what happens in real life.

One source of variability comes from the fact that the aircraft may not be flying the exact heading as indicated in the pre-flight briefing. Experience has shown that the plane can deviate approximately 5 degrees in either direction and aircraft speed can range from 110 knots to 130 knots, with a mean of 125.

Another source of variability involves the jumper interval spacing for each door and the jump interval between the primary and non-primary door. Recall that the mathematical model was formulated based on the assumption that jumpers exit uniformly at one second intervals and that the assistant jumpmaster's door exits jumpers exactly one-half second after the primary door begins. This, however, does not happen exactly as planned in real life. The actual data were thus obtained from the last round of C-141 testing done in October 1994 by the TEXCOM Airborne and Special Operations Test Directorate. The BestFit statistical package (Palisade 1994) was used in fitting distributions to the time between jumps.

A third source of variability is determined by the actual drop altitude. The drop altitude plays an important role in the amount of inherent drift of the parachute. For every 100 feet above the ground under an inflated canopy, each parachute can drift 4.2 yards in any direction. This drift can be accentuated if the lead aircraft in a serial is flying above or below the requisite 800 ft Above Ground Level (AGL). Trail aircraft in a serial also tend to fly an average of 50 feet above the aircraft in front to avoid hitting paratroopers in the sky.

Once a jumper impacts the ground, he must immediately get his weapon into operation, roll up his parachute and air items, and begin moving towards his objective. The approximate time for each trooper to accomplish this maneuver is 7.5 minutes, with a standard deviation of 2.0 minutes. Approximately 5% of the jumpers get lost on the way to their objective and are delayed anywhere from 10 to 60 minutes.

The above sources of variability are included in a simulation model written in MODSIM II for Windows, which is an object-oriented, discrete-event simulation language (CACI 1991). This language was selected for several reasons including:

1. Once compiled, the runtime executable file runs in Windows 3.1 and is royalty free.
2. Can readily import the optimal manifest and

initialization parameters generated by the optimization package in Visual Basic.

3. It is object-oriented, and can track the several hundred entities and their actions with less memory requirements than other packages.

Upon development, the simulation model was validated by sub-component to ensure the distributions were functioning properly, and then as a whole by demonstrating the model to experienced leaders.

As with any simulation model that includes probabilistic events, the model must be replicated. The number of replications in this tool is determined by the requirement that the half width of the 90% confidence interval for the measure of effectiveness (time to build up to 90% combat power at each objective) is less than 10% of the mean. Replications of the model are then made and the build-up of combat power over time at each of the objective areas is collected. Critical percentages achieved (at 50%, 75%, 90%, and 100%) are tagged. Minimum, maximum, and mean distances to each objective as well as the time required to reach each objective are recorded for the commander's review.

3 APPLICATION AND RESULTS

The proposed approach was tested using several scenarios. The example presented in this paper is a relatively common battalion-sized training mass tactical operation taking place on Sicily Drop Zone, Fort Bragg, North Carolina. In this scenario, five C-141 aircraft dropping 120 paratroopers each on a single pass were modeled. Each paratrooper was assigned to one of six objectives. The required number of paratroopers assigned to seize the objectives were specified for each objective. The environmental factors are assumed to be the same for all objective and are: 75°F temperature, 50% humidity, at night, on a level hard packed surface.

Once the parameters were entered, the transportation network was formed and solved. A portion of the mathematical model output is shown in Table 1.

Table 1: Manifest Summary Table

Aircraft Number	Unit TmSupport	Unit TmA/2-325	Unit TmB/2-325
1	1..8	9..18	19..28 39..40
2	1..8	9..18	19..28
3	1..8	9..18	19..28
4	1..8	9..18	19..28
5	1..6	7..20	21..26

This solution indicates that, for example, jumpers seated in seats 1 through 8 of aircraft 1 should head to the objective assigned to Team Support. The user can view the results and stop here or choose to simulate the generated manifest. To start the simulation, the user simply has to choose the "Run Simulation" option.

Once the simulation option was selected, the generated manifest along with other initialization parameters were automatically transferred into the model and the execution of the model began. The example scenario was replicated seven times. Upon completion, the user was presented with a summary table that displayed the required time to build-up the required combat power at each unit's objective. The mean, standard deviation, and the maximum and minimum times required to build up combat power to 50%, 75%, 90%, and 100% were displayed. Table 2 shows the Summary Table for Objective Tower. This result indicates that, for example, 90% of the required combat power will be at Objective Tower in 24.1 minutes, on average.

Table 2: Simulation Summary for the Objective Tower

OBJ TOWER Tm A/2-325

CbtPwr	MEAN	MIN	MAX	STD DEV
50 %:	16.79	15.26	18.77	1.07
75 %:	19.83	18.21	22.44	1.41
90 %:	24.10	21.23	28.08	2.36
100 %:	37.74	29.50	52.93	7.93

In order to assess the performance of the proposed approach, the results obtained from the automated tool were compared with the results obtained from the current method. A manifest was generated manually for the problem at hand by an experienced S-3 Air Officer. This manifest was then simulated using our automated tool and the jumper arrival times to each objective was collected. These jumper arrival times were directly compared with those obtained from the automated approach using a pairwise t-test. The results of the t-test indicate that with 90% confidence, the automated approach resulted in a superior solution over the manual method. In fact, the solution obtained from our approach was as good or better than the current method for all scenarios tested. More importantly, this was achieved with a great deal of savings in time.

4 CONCLUSIONS

An automated planning tool is developed to aid in the planning of mass tactical airborne operations. This tool aids the commanders in the development of the manifest in such a way that the time to build up the required strength at each objective is minimized.

In all scenarios tested, the solution obtained from the automated tool was as good or better than the current method. In addition, the process forces the airborne commander to examine, in detail, the priorities for his assault units and objectives. But most importantly, the solution is achieved with a great deal of time savings.

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