SIMULATION OF RAPID SHIP UNLOADING BY HELICOPTER

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Introduction and Summary

A ship with helicopters aboard arrives in the vicinity of a shoreline. The commander intends to operate the helicopters so as to unload the ship as rapidly as possible. The ship's cargo is to be delivered to a specific point ashore by the helicopters. The arrival rate of the cargo at that point will measure the effectiveness of the unloading operation. The commander must decide at what distance to station the ship from the unloading point ashore, how many of his helicopters to use for the unloading, and the grouping of the participating helicopters. He knows, or has reliable estimates of, the time spent by helicopters while loading or refueling on the ship, unloading at the point ashore, and flying between the ship and point ashore. This paper describes a simulation model which can assist the commander with his decisions.

Discussion

This problem is faced by the amphibious forces of the U.S. Navy and exercises are conducted by the Navy to train forces and to test different policies for helicopter unloadings. The development of a model of the unloading process would permit testing alternate unloading policies without the expense of sending a ship to sea. It would permit examination of the implications of changes in the design of the ship, the design of helicopters, or the capacity of the unloading point.

Another problem is also faced by the Navy. If victims of a disaster such as a flood or earthquake require evacuation, the Navy would probably assign a ship with helicopters to the task. For medical reasons or because of the threat of loss of life, the helicopter evacuation may have to be conducted as rapidly as possible. The applicability of a model of ship unloading could readily be transferred to the evacuation problem.

The model could also be useful for examination of harbor operation policies where sufficient berthing space for waiting ships is unavailable. Under such conditions, the use of helicopters for unloading ships while in the roadstead might be an attractive alternative to having the ships wait for berthing space. The model can aid development of costing information to permit choice among these alternative harbor management policies.

Description of the System

The ship arrives in the unloading area and takes station as shown in Figure 1.

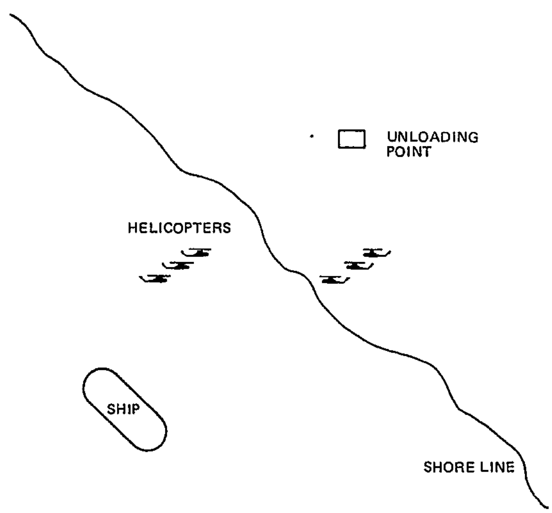

Figure 1. Sketch of System

Helicopters are stored on the ship with rotors folded to conserve space. When needed to ferry cargo, helicopters are brought up to the flight deck and prepared for flight. Because helicopter storage capacity beneath the flight deck exceeds the flight deck capacity when rotors are unfolded, several deckloads of helicopters are often available for unloading the ship. Helicopters operating from the ship are grouped into waves. In general, a deckload of helicopters makes up more than one wave and more than one deckload is used for an unloading. The waves flow through a system consisting of two primary nodes, the ship and the unloading point (called the landing zone). The activity of the first wave, which is typical, consists of an initial launch without cargo, movement to a marshaling area near the ship, return to the flight deck when all waves are airborne, loading of cargo, launch for the transit to the landing zone ashore, landing in the zone, unloading of cargo, launch for return to the ship, and re-landing on the ship for loading of more cargo and/or refueling. The cycle is then repeated by the first and other waves until the ship's cargo is unloaded.

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The build-up of the system to steady state operation is accomplished by launching all waves empty except the last deckload of waves to be launched. After the last deckload of waves is jointly launched with cargo for the landing zone, the empty airborne helicopters return to the ship, queue, land, load and then proceed for subsequent delivery to the landing zone. (For an initial maximum effort, all helicopters might be held offshore until all helicopters are loaded. The contents of all helicopters might then be landed as quickly as possible at a landing zone whose position will surprise an opponent ashore.) Steady state cyclic operations are underway when each wave has made its first delivery to the landing zone. The measures of effectiveness for the steady state operation of the system are the rate of build-up of cargo ashore and the total unproductive flying time (time spent in queues). The first measure is to be maximized while the second is minimized.

The system being simulated operates under many constraints, including:

a) The number of helicopters participating in the unloading is limited by the capacity of the ship to store helicopters while transiting to the unloading area.

b) The capacities of both the ship's flight deck and the landing zone are limited, generally to values less than the number of helicopters participating in the unloading.

c) During an unloading, helicopters will find it necessary to refuel during some stops on the ship for cargo pick-up. The time required for refueling and cargo pick-up on the flight deck generally exceeds the time required for cargo pick-up alone.

d) There is a minimum distance that the ship can be stationed from the landing zone ashore. The minimum distance is fixed by the distance from the landing zone to the shore line.

Background

Some analytic work has been performed in the past on the problem of unloading ships by helicopter. An earlier paper[1] summarized known efforts, and also treated analytically the question of trading off fuel carried for more cargo payload. In particular, the earlier paper showed that the maximum cargo delivery rate occurs when helicopters are refueled less frequently than every stop at the ship for cargo pick up, but more frequently than the number of stops permitted by a full fuel load. (The optimum scheme requires that the cargo payload be incremented at each pick up such that the sum of fuel weight and cargo weight remains a constant.) The earlier analysis is based on an expected value model wherein the action times at system nodes are deterministic and equal to the expected values of measured distributions. Such an analysis, although valuable in indicating an appropriate trade-off policy, fails to treat the real-world problem of how to minimize queues that build during an actual unloading.

Data collection, although tedious, presented no real difficulty.[2] An observer was stationed with a full view of the flight deck during an unloading lasting several hours. Landing and launch times were recorded along with the reason for the flight deck stops. Distributions of these on-deck times were then prepared. Similarly, a second observer was given earphones to listen to helicopter pilot radio transmissions. Times of arrival in the vicinity of the landing zone were recorded based on these radio transmissions. From these data, distributions of flight time between ship and landing zone were prepared. The only data which was unavailable was the distribution of unloading times in the landing zone; stationing an observer there was relatively difficult. The simulation used the distribution of flight deck loading times for the landing zone unloading time distribution. (Observation of the back-loading of cargo after conclusion of the unloading exercise indicated this substitution was a good approximation.)

Features of the Simulation

A simulation model of the unloading operation has been written in the GPSS language and coded for use on either the UNIVAC 1108 or the IBM/360. Features of the model include:

a) Times spent by waves

1) on the ship's flight deck,

2) flying to the landing zone,

3) in the landing zone, and

4) flying back

are all treated stochastically.

b) Within waves, individual helicopters are permitted variations in behavior such as different action times at system nodes.

c) Extreme deviations in individual helicopter behavior are permitted. For example, a helicopter may be returned to the ship for repairs immediately on observation of maintenance difficulties or damage. When a simulated emergency occurs, the helicopter separates from the others in its wave and proceeds directly to the ship's flight deck. It waits at the ship until its parent wave returns to the flight deck, and rejoins the wave there.

d) The possibility of complete loss of a helicopter is included, with the loss being replaced when the parent wave next stops at the ship.

e) Fuel on board helicopters is decremented as flight time accrues, and refueling is scheduled as necessary during cargo pick-up stops at the ship.

f) Considerable generality is incorporated in the model. The following can be varied from run to run:

1) The capacity of the flight deck and of the landing zone.
2) The number of helicopters in a full-strength wave.
3) The number of minutes of flight corresponding to a full fuel load.
4) The probability that helicopters encounter malfunction or damage in flight.
5) The probability that a helicopter's resulting difficulty is so severe that loss of the helicopter results.
6) The separation distance between ship and landing zone.

Validation of the Model

The simulation model has been verified by comparison to actual data collected during an unloading. The physical characteristics of the actual unloading were introduced as model inputs. Time distributions for loading and refueling on the deck had been carefully measured during the actual unloading; so had flight times between the ship and landing zone. These measured distributions were entered into the program. Three hours of unloading were then simulated, which was the actual unloading time during which data had been collected. The queue distributions resulting from the simulation run were then compared to the queue distributions (for flight deck and landing zone) measured during the actual unloading and the agreement was good.

Tables I and II show characteristics of the actual and simulation distributions of times spent by waves in the queues for the flight deck and for the landing zone:

TABLE I

COMPARISON OF DISTRIBUTIONS
QUEUE FOR FLIGHT DECK
ACTUAL vs. SIMULATION RESULTS

	Actual	Simulation Results
No. Waves Queuing	38	38
Percent Waves with Zero Queuing Time	65	55
Mean Queuing Time (minutes)	2.9	2.1
Standard Deviation (minutes)	5.1	4.2

TABLE II

COMPARISON OF DISTRIBUTIONS
QUEUE FOR LANDING ZONE
ACTUAL vs. SIMULATION RESULTS

	Actual	Simulation Results
No. Waves Queuing	38	37
Percent Waves with Zero Queuing Time	72	89
Mean Queuing Time (minutes)	0.4	0.1
Standard Deviation (minutes)	0.9	0.3

The close agreement of these distributions lends considerable validity to the simulation model. The model has thus been used to consider alternate modes of operation of helicopters with a view toward finding the mode which maximizes cargo delivery rate while minimizing queuing time.

Use of the Model

Once validated, the model generated results for consideration by Navy decision makers. The model was used to examine the implications of changes, generally in one variable at a time, in the conditions under which unloadings take place. For example, the results shown in Tables I and II are for a landing zone capacity of eight (8) helicopters. Other runs were made to examine the effect on cargo arrival rate and queue size of variation in landing zone capacity. The results of such capacity variation, with all other variables held fixed, are shown in Table III. (The length of steady-state unloading is three hours in Table III and all other tables.)

TABLE III

SIMULATION RESULTS
EFFECT OF VARIATION IN LANDING ZONE CAPACITY

Max. No. of Helicopters Permitted in Zone	No. Helicopters Arriving	Mean Queue Time for Zone
2	127	8.7
4	149	1.3
8	144	0.1
12	144	0

The capacity of the landing zone is not generally under the control of a ship's commander, so the results in Table III are of most use in choosing among alternate sites ashore for cargo placement. (In a combat unloading, the tactical situation ashore will be the prime determinant of the cargo landing site.) The Table III results show little variation in helicopter loads delivered as a function of zone capacity, but substantial inverse dependence of waiting time on capacity. Based on Table III, a commander might select a site ashore which has larger capacity but a less favorable position so as to minimize wasted flying time.

The effect of crowding was also examined. Tables I and II were constructed from runs in which 6 waves of 4 helicopters each were cycled through the system. Table IV shows the effect of changes in the number of waves of 4 helicopters each, with all other variables held constant.

TABLE IV

SIMULATION RESULTS
EFFECT OF VARIATION IN NUMBER OF WAVES

Number of Participating Waves	Number Helicopters Arriving		Mean Queue Time	
	Zone	Ship	Zone	Ship
4	114	132	0	0.07
6	144	176	0.10	2.1
8	179	240	.13	3.1
10	218	269	.56	5.0

The delivery rate can be seen from Table IV to increase with the number of participating waves. Within the range of values simulated, the delivery rate goes up with crowding. However, the delivery rate increase is obtained at the expense of a more rapid increase in the amount of time spent by helicopters in queues. The ship's commander must balance off long-term considerations (extra hours of flight will require that scheduled maintenance come sooner) against the short-term consideration of as rapid a cargo delivery as possible.

An option available to the commander besides crowding more waves of helicopters into the unloading process is to alter the flying distance to the landing zone by moving the ship closer to shore. Simulation runs were made wherein the flying time distribution was manipulated to reflect changes in the ship's distance from the landing zone. For instance, all randomly selected values from the flight time distribution were multiplied by 1/2 during one run to examine the effect of cutting the ship-to-zone distance in half. Table V contains the results of simulation runs where flying times were so manipulated. In the Table V runs, 6 waves of 4 helicopters each unload the ship for 3 hours into a landing zone of capacity 8 helicopters.

TABLE V

SIMULATION RESULTS
EFFECT OF VARIATION OF FLYING DISTANCE

Multiplication Factor	No. of Helicopters Arriving		Mean Queue Time	
	Zone	Ship	Zone	Ship
0.5	245	272	0.11	0.89
1.0	144	176	0.10	2.07
2.0	94	120	0.17	1.28

The effect of crowding is not apparent in the queue times of Table V as it was in Table IV. Moving the ship closer to shore does, however, greatly increase the delivery rate to the landing zone. Table V suggests that, with 24 helicopters grouped into waves of 4 helicopters each, the ship be moved as close to the landing zone as possible to maximize delivery rate.

Another important decision facing the ship's commander is how to group the available helicopters into waves. The model was used to examine alternate groupings of 40 helicopters. With a flight deck capacity of 10 helicopters and maximum utilization of flight deck space consistent with a policy which calls for landing or launch simultaneously by all helicopters of a wave, Table VI shows the results of simulations where 40 helicopters are grouped differently. Landing zone capacity is 12.

TABLE VI

SIMULATION RESULTS
ALTERNATE GROUPINGS OF 40 HELICOPTERS

Helicopters/ Wave	No. Waves	Number Helicopters Arriving at Zone	Mean Time in Queue At Ship	Mean Time in Queue At Zone
5	8	216	6.08	0.31
4	10	213	5.98	0.06
3	13	222	3.68	0

Maximum delivery rate is achieved with a wave size of 3 helicopters, although the variation in the number of helicopters arriving is very small. Minimum queue length at the ship occurs for a wave size of 3 helicopters, also. The choice of 3 helicopters in each wave can be made over either 4 or 5 helicopters because both measures of effectiveness are optimized with 3 helicopters per wave. (The value of 2 helicopters per wave was not simulated because the model uses ASSEMBLE blocks. If 2 members of an assembly set are not always available, the program will not continue running.) It appears that the smaller number of helicopters per wave when 13 waves are operated permits taking better advantage of deck or landing zone space when it becomes available. This conclusion might well change if the policy of landing/ launching all helicopters of a wave simultaneously were abandoned.

Comments on the Model

The model is straightforward. The waves of helicopters are first generated and then allowed to move back and forth between ship and landing zone. (The model treats this movement by aggregating all helicopters of a wave into one transaction.) It is the variation on this movement that introduces complexity into the model. Some of the helicopters will encounter difficulty and require repairs. When they do, they are separated from their parent waves (a new transaction is created) and return to the ship. The model places such returning helicopters on a user chain to simulate repair time; the helicopter in repair is freed from the user chain when its parent wave returns to the ship.

The model corresponds closely to reality when the loss of a helicopter is simulated. In the actual situation, the difficulty encountered by an airborne helicopter may be so severe as to cause the loss of the helicopter. When that occurs, the other helicopters in the wave suffering the loss return to the ship after rescue efforts for the downed crew. While on the flight deck, a fresh helicopter is brought up from storage on a lower deck. The fresh helicopter is made ready to fly and launches with the wave which was deficient on landing. The model simulates this activity by use of branch points. The model tests waves arriving at the flight deck to see if the sum of arriving helicopters and helicopters in repair from that wave is equal to the nominal wave size. If not, access is granted to coding which generates a sufficient number of replacement helicopters.

The GPSS language was selected for this simulation because it is very well suited to describing the physical process simulated. Basically, the information sought about the physical process is the rate of flow of helicopters though a closed loop and the nature of the queues preceding nodes of limited capacity. GPSS was designed to describe this type of physical process, and no other language could have produced as much useful information with similar programming ease.

Development of the simulation model took approximately four man-months, with one of the analysts well versed in the subject of ship unloading by helicopter primarily through data collection whose results were used in the simulation. About 150 runs were made as the model was refined, consuming a total of about one hour of computer time with 50,000 words of UNIVAC 1108 core usage per run.

References

1. D. E. Willhite and B. F. Powers, "The Marine H-34 Helicopter in Combat Ship-to-Shore Operations," Study 719 (Center for Naval Analyses), 1969.

2. B. F. Powers, "Analysis of Helicopter Ship-to-Shore Operations in Amphibious Exercises," Proceedings of the Fifteenth Military Operations Research Symposium, 1965.