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The effects of LCAC load policy on the duration of amphibious assault

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The Effects of LCAC Load Policy on the Duration of Amphibious Assault

by

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ABSTRACT

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I. INTRODUCTION

During World War II, the U.S. Navy and Marine Corps developed the capability to conduct amphibious assault, that is, the opposed movement of military forces from ships to the enemy shore. This capability required careful load planning and close control of landing craft to maximize the rate of force buildup ashore.

In the mid sixties, helicopters became widely available for use in amphibious assaults. This new tool greatly increased the options available to the Commander, Amphibious Task Force (CATF) and Commander, Landing Force (CLF). Small assaults could now be launched from over the horizon, increasing the factor of surprise. Additionally, helicopters were unaffected by hydrography and beach terrain, opening a much larger portion of the world's beaches to assault. Unfortunately, even the largest helicopters are incapable of carrying the heavy equipment necessary to conduct a full-scale assault (the largest helo-transportable piece of equipment is the 13 ton Light Armored Vehicle (LAV)), so heliborne operations are limited to fairly small raids.

Amphibious assault capability increased in the late eighties when the landing craft, air cushioned (LCAC) was introduced to the fleet. Like the helicopter, this craft could start from over the horizon, move to the beach at high speed, and cross the high water mark for landing, nearly unaffected by hydrography or terrain. Like the conventional landing craft, the LCAC could carry the heavy loads required for full scale amphibious assault. This increase in capability has produced a need to re-examine the doctrine of landing craft employment.

Because conventional landing craft moved quite slowly, they were likely to spend most of their time in transit to and from the beach. Therefore, the amphibious ships loading them were frequently idle. In other words, movement of material to the beach was constrained by the landing craft. For this reason, it became the policy always to load the craft fully.

When the conventional craft are replaced by LCAC's, however, the situation may be reversed. The LCAC's spend much less time in transit (at typical distances from the beach), so queues of LCAC's may form either at the beach or at the ships.

A. GOALS OF THIS RESEARCH.

The goal of this research is to investigate the effects of different load policies on the total time to complete the offload of amphibious shipping. It will be assumed that the time required to load an LCAC is a function of the cargo weight to be loaded. An analytical model, sufficiently accurate and user-friendly for fleet use as a decision aid, will be developed. This decision aid will assist amphibious planners by providing information about the effects of loading policy on the time to complete the offload.

B. OTHER WORK IN THIS AREA.

A number of CNA research memoranda contain data on LCAC operations. Specifically, studies of operation Team Spirit 89 [Ref 1] and Kernel Blitz 87-2 [Ref 2] list load weights carried by each LCAC in these exercises and the time required to take on these loads. A scatter plot of this data lends support to the idea that the time required to load large amounts of cargo on a single LCAC is significantly larger than that required for small loads (Figure 1). This effect is not addressed in either publication, although it is central to the analysis here.

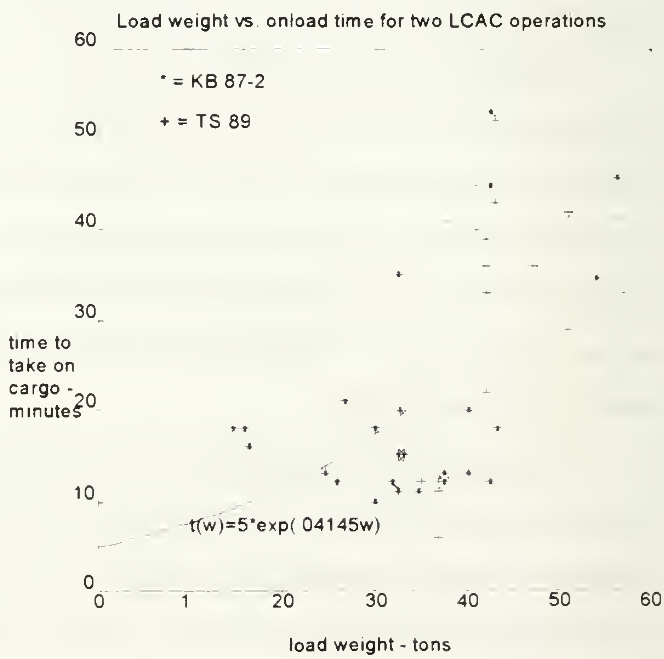

Figure 1

Horne, in a CNA publication [Ref 3], developed deterministic, stochastic, and simulation models for offload operations. In the conclusion, he states:

> In most cases, $E[T_0]$ (expected value of total offload time) was insensitive to the type of distribution used to model the cycle time components. Further research may shed more light on the extent of these distribution forms' effect on $E[T_0]$.

Horne built on these results in his later work with Irony (discussed below).

Horne and Irony [Ref 4] developed an analytical (stochastic) model of LCAC operations that treated the LCAC loading and unloading processes as exponential random variables, developing expressions for the expected value of time spent by LCAC's queueing for beach and well spots. While this analytic model does not account for transit time, the authors showed that for many situations of practical interest, the transit time did not affect the results.

In the same article, Horne and Irony used the simulation language SIMSCRIPT to develop a simulation of LCAC operations, assuming that the loading and unloading times were random variables drawn from the shifted gamma distribution[1]. The authors found good agreement between the analytical and simulation models.

C. LCAC MISSION CYCLE.

The LCAC mission cycle can be divided into four phases:

- loading
- transit to the beach
- offloading
- transit back to the ships

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[1] The simulation used the shifted gamma distribution because it was a better fit to the LCAC offload data, but the analytic model used the exponential distribution because the problem becomes analytically intractable when the shifted gamma distribution is used. As discussed above, the author stated that the results were insensitive to the choice of distribution.

1. Loading.

During this phase, staged cargo is moved from the well to the LCAC, spotted on the LCAC deck, and fastened to the deck with tie-downs known as gripes (Fig 2). The time required to load the LCAC and gripe down the vehicles on the deck depends on the size of the load. Once the load is completely griped down, the LCAC raises bow and stern ramps, admits air to the skirt system ("comes on cushion") and backs out of the well.

Because the LCAC requires its center of gravity to remain within strict limits to achieve level flight, proper spotting of vehicles on deck is critical to mission success. With larger load sizes, increased care is required to ensure that all of the designated cargo fits on the deck and that the load is properly balanced. Additionally, LCAC loads must be fastened to the deck ("griped") to prevent them from shifting in transit. Large loads take more time to gripe because there is less room for the gripers to move about on deck.

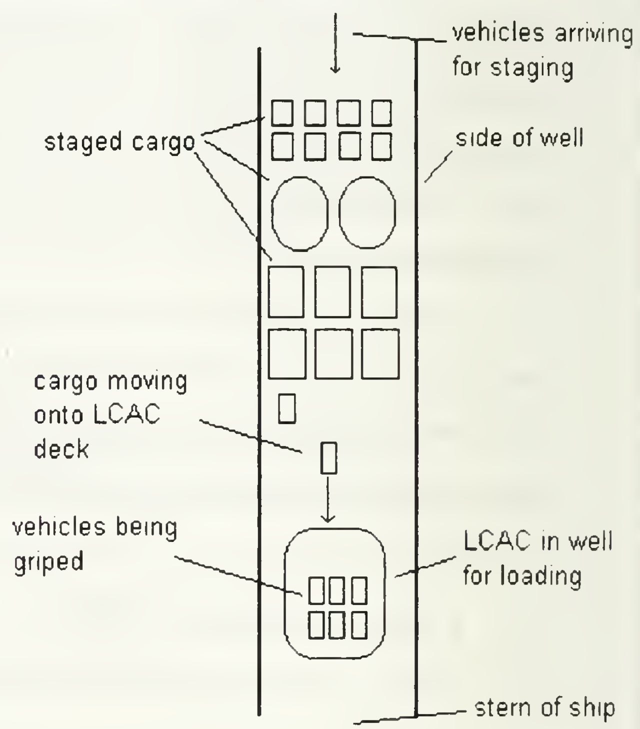

Figure 2

In the absence of hard data regarding LCAC load times, it is necessary to make assumptions to obtain a function describing the relationship between the load weight and the time to load a single LCAC. The author's experience is that the load time increases slowly with load weight at lower weights, but at higher weights, the load time increases more rapidly, as the effects discussed above become more important. An exponential function of the form

$$t_{1a} = \alpha e^{\beta w}$$

can be used to represent this effect, where t_{1a} is the mean time to load the craft, α and β are constants describing the relationship between load weight and time, and w is the load weight. Even if no load was to be placed on deck, a certain minimum time would be required to prepare to take on cargo. Therefore

$$t_{1a}(0) = 5.$$

Also, at the maximum cargo weight of 60 tons[2], it was assumed that the mean load time would be no more than an hour:

$$t_{1a}(60) = 60$$

From these two boundary conditions it follows that α is 5 and β is .04145, resulting in the following equation

$$t_{1a}(w) = 5\exp(.04145w).$$

Figure 1 shows the fit of this equation to data from LCAC exercises.

Additionally, the time to load the craft is not completely determined by the load size - random factors are also important. It is postulated that t_{1a} represents the mean of the LCAC loading time, which is a normal random variable. Also, the standard deviation of the load time is believed to increase with w, therefore, the standard deviation was modeled as follows:

$$\sigma(w) = w / 12.$$

The ship's well is also unavailable for loading during the landing and launch of the LCAC. Landing and launch require about five minutes each. Therefore, the total amount of time the well is unavailable (t_1) is

$$t_1 = t_{1a} + t_{1b} = 5\exp(.04145w) + 10,$$

where t_{1b} is the time to land and launch.

It is important to note that t_1 is convex as a function of w. The greatest rate of offload can be found by maximizing t_1/w, which occurs when w is 24 tons, not when w is 60 tons. It is therefore possible that the best load policy is not to fully load each LCAC

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[2] LCAC's are capable of taking 75 ton loads under certain circumstances. This complicating factor is not addressed in this research.

2. Transit.

After the craft has left the well, it proceeds to the beach for landing. Typically, LCAC's transit at speeds of about 40 knots. The distance from the amphibious ships varies due to threat conditions and hydrography, but usually falls between two and fifty miles. The time between launch from the ship and arrival in the vicinity of the beach is defined as t_2.

3. Offload.

Once the LCAC arrives at the beach, it is directed to an open landing spot by the shore party. If no open spot is available, it waits in a queue outside the surf zone. Once it has been assigned to a spot, the LCAC comes to 25 knots, crosses the high water mark to the landing spot, stops, and comes off-cushion. It then lowers bow and stern ramps and begins offloading. This evolution of positioning to start offloading takes about five minutes from the time a spot is assigned.

The craft crew and embarked troops begin ungriping vehicles as soon as the LCAC comes off cushion. As soon as the vehicles are ungriped, they are driven off the craft. Completion of the offload varies depending on the nature of the load, but usually takes about ten minutes[3]. Following the offload, the craft raises its ramps and departs, reversing the procedure used to land, and begins the transit back to the ships.

The time to land, offload, and launch from the beach is defined as t_3, which can be written as

$$t_3 = t_{3a} + t_{3b},$$

where t_{3a} is the mean time to offload the vehicles and t_{3b} is the time to land and launch (10 minutes).

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[3] Offloading is considerably faster and less dependent on the load weight than onloading, because gripes are much easier to unfasten than to fasten, and problems involved in arranging the vehicles on the deck are eliminated.

4. Transit back to ships.

Once the craft have returned to the vicinity of the ships, they form a queue to await the first open well. The time between launch from the beach and arrival in the area of the ships is defined as t_4.

5. Other quantities of interest.

There are a number of times that are of interest to the amphibious planner. The cycle time (t_c) is the time required for an LCAC to complete an entire cycle (exclusive of queueing time)

$$t_c = t_1 + t_2 + t_3 + t_4 .$$

It is also important to be precise when discussing the time to complete the mission. There are three possible times of interest: the time at which all cargo has left the ship (T_1), the time at which all cargo has arrived at the beach (T_2), and the time at which all LCAC's have returned from their last trip to the beach (T_3). Then

$$T_2 = T_1 + t_2 + t_3$$

and

$$T_3 = T_2 + t_4 .$$

Since T_2 and T_3 differ only by a constant, it makes no difference which is chosen for analysis. T_3 will be used in this thesis

II. DETERMINISTIC MODELS

Some insight into the problem can be gained by suppressing randomness in the loading, transit, and offload phases of the LCAC mission cycle. The result is a deterministic approximation for the time to complete the offload. There are a number of possible queuing policies.

A. THE SINGLE QUEUE MODEL.

In this model, one queue of LCAC's serves multiple ships on a first come, first served basis. The same load policy is used by all ships. There are three constraints upon the rate of offload. If the offload is limited by the number of LCAC's available, then

$$l = \frac{L}{t_c} w,$$

where l is the best possible offload rate (tons/min) when constrained by the number of LCAC's, and L is the number of LCAC's in the model. If the number of ships is the constraining factor, then

$$s = \frac{S}{t_1} w,$$

where s is the best possible offload rate when constrained by the number of ships, and S is the number of ships. If the offload is constrained by the number of beach spots, then

$$b = \frac{B}{t_3} w,$$

where b is the best possible offload rate when constrained by beach spots, and B is the number of beach spots.

Therefore, in the steady state

$$r = \min(l, s, b),$$

where r is the best possible rate of offload under any circumstances. Also

$$T_3 = \frac{W}{r} + t_2 + t_3 + t_4,$$

where W is the total amount of cargo to be offloaded from all ships. Changes in loading policy affect t_1 and therefore t_c, but not t_3.

The above equations were used to create a QBASIC program which automatically calculates the offload rates for a reasonable range of load policies and highlights the optimum policy. This program is discussed in greater detail in Chapter IV.

If the ships to be offloaded contain different amounts of cargo, the solution must be obtained in parts. The first step is to calculate the time required to empty the first ship. For example, given three ships, loaded with 500, 300, and 100 tons of cargo, one must solve for T at the optimum rate for three ships, where W = 300 — or 100 tons from each ship. Then the rate of offload is recalculated based on two ships, which contain 400 and 200 tons of cargo. Next, T is recalculated using the new rate of offload until the new lightest ship is empty. These steps are repeated until all the ships are empty. The total time to conduct the offload is found by adding the times for the various steps.

B. MULTIPLE QUEUE MODEL.

The policy described above, in which a single LCAC queue serves all ships, may be thought of as "myopic offload" — each increment of offload effort is expended at the ship that will maximize the instantaneous rate of offload. Although this policy works well if all ships have the same amount of cargo onboard, it can be shown to be less than optimum if the ships carry differing amounts. In particular, if the offload is poor in LCAC's, a significant decrease in the total time to complete the offload may be observed if separate queues are maintained for each ship. This occurs because the time to complete the offload is bounded below by the time required to complete the offload of the larger ship — if the LCAC's are shared among the ships to be offloaded, the largest ship may be "starved" for LCAC's.

For example, consider two ships loaded with 500 and 100 tons of cargo being served by six LCAC's. Three beach spots are available at a distance such that the one way transit time is 60 minutes. Using the QBASIC model to solve for the rate of offloading until the lightest ship is empty, yields 1.71 tons/minute. At this point, 100 tons of cargo have been removed from each ship, requiring 2 * 100 tons / (1.71 tons/min) = 117.0 minutes. Then, recalculating using one ship, six LCAC's and three spots, the offload rate is found to be 1.12 tons/minute. The offload proceeds at this rate until the remaining 400 tons of cargo has been removed, requiring 400 tons / (1.12 tons/min) = 357.1 minutes. Therefore, the total time to complete the offload is 117.0 minutes (step 1) +357.1 minutes (step 2) +140.0 minutes (time to make the last LCAC trip) = 614.1 minutes. If however, two queues are established, with five LCAC's being assigned to the larger ship and one to the smaller, the smaller ship is offloaded at a rate of .286 tons/minute, which means that the time to offload it is 100 tons / (.286 tons/min) = 349.7 minutes. At the same time, the larger ship is being offloaded at a rate of 1.10 tons/minute, which means that the time to complete its offload is 500 tons / (1.10 tons/min) = 454.5 minutes +140 minutes (transit time for last load) = 594.5 minutes. For this case, then, twenty minutes may be saved by assigning five of the six LCAC's to the larger ship instead of sharing them equally.

It may seem strange to the experienced reader that splitting the queue can actually result in an increase in efficiency in the process. The advantage of splitting the queue is that it allows separate load policies to be established for each ship. This allows the commander to sacrifice efficiency of offload of the lightly loaded ship(s) for increased efficiency of the heavily loaded ship. Because the time to complete the offload is bounded below by the heavily loaded ship, the multiple queue policy can reduce the total offload time.

However, the randomness in the model has the opposite effect, because LCAC's may have to wait to be served by the heavily loaded ship while the lightly loaded ship(s) is available to load cargo. Because the above example was chosen to accentuate the difference between the two policies, it is unlikely that any gain would result from this policy in practice (see page 14 for details).

C. OTHER POLICIES.

It is possible to imagine any number of alternative policies for LCAC employment For example, the load weight could be adjusted according to the number of LCAC's in queue for the well This would have the effect of smoothing out unevenness in the flow of LCAC's, loading them quickly with smaller loads when many were waiting, and loading them more slowly with larger loads when the queue was empty. This policy, like other alternative policies, was too complicated to address here In any case, these policies probably would be difficult to implement operationally, because of the heavy demand they would place on C^3 assets. The only policies to be investigated in this thesis are the single and multiple queue policies discussed above.

III. SIMULATION MODELS

A. SIMULATION USING GPSS.

1. History of GPSS.

This model of amphibious operations was constructed using the General Purpose Simulation System (GPSS). This simulation language was created by IBM for the mainframe in 1961. By 1978, IBM had stopped maintaining GPSS, but its development was continued by Wolverine Software. That year, the company released GPSS/H, which eventually was made available for many computer systems, including those running MS-DOS. GPSS/H was used in this thesis to model LCAC operations.

2. Architecture of GPSS.

GPSS was designed to model queueing processes in industrial systems. GPSS "facilities" or "storages"[4] represent servers of one kind or another, while "transactions" represent the customers of the facilities/storages. For example, in a simulation of a bank, tellers would be represented as facilities, and customers as transactions.

The time required to serve the customers is represented by "advance" statements. These statements allow transactions to be delayed by an amount of time that is either fixed or random, and allows the modeler to select from uniform, normal, exponential, or user-defined distributions to represent randomness.

"Transfer" statements control the movement of transactions in the model, allowing them to choose among several facilities according to rules set by the modeler.

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[4] Facilities can serve one transaction at a time; storages can serve several.

3. Modeling LCAC operations using GPSS.

A. Single queue model.

This model of LCAC operations was constructed using transactions to represent LCAC's and facilities to represent ship wells[5] and beach landing spots. A single queue of LCAC's serves all ships. As each craft enters the ship to be offloaded, it decrements the cargo remaining by an amount equal to the LCAC load size. When all ships are empty, LCAC's are removed from the model as they return from their last trip to the beach. When all the LCAC's are removed from the model, the simulation is terminated. The model was executed for the case of three ships, eight LCAC's, and varying numbers of beach landing spots. A block listing of the GPSS model used for the simulation is found in Appendix A.

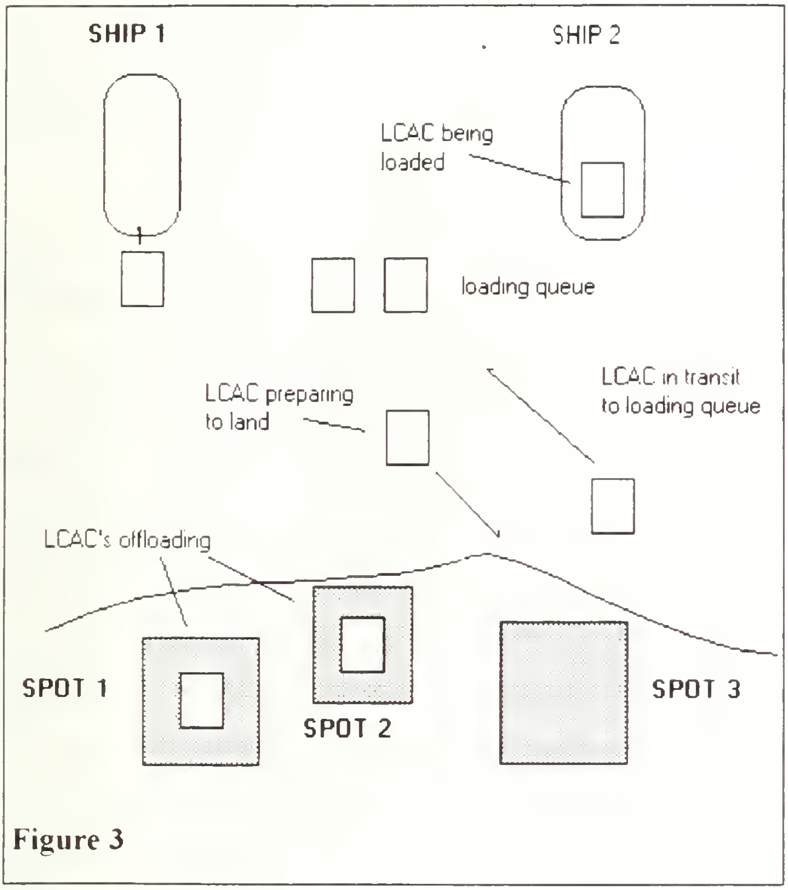

Figure 3

[5] Although it is possible for ships to take on more than one LCAC at a time for loading, it has been shown that loading one at a time is always the optimum policy (ref 5). Therefore, facilities rather than storages were chosen to represent wells.

B. Multiple queue model.

This model was executed for two ships, six LCAC's, and three beach spots. The distance to the beach was thirty minutes. The operations in this model are similar to those in the single queue model, except that the LCAC's are split into two groups. Five LCAC's serve the more heavily laden ship (500 tons cargo) exclusively, and the remaining LCAC serves the lightly loaded ships (100 tons cargo) exclusively. A block listing of this model is found in Appendix B.

4. Model validation.

Both the single queue and the multiple queue simulation models were validated by replacing the randomly varying advance times with constants, and comparing the output with the results of a model consisting of physical representations of LCAC's and ships, and the same rules for transit and service times. The results for the physical models and the computer models were identical. Additionally, the single queue GPSS model was run with the standard deviations of the random quantities reduced to zero. The results of the deterministic model and the single queue model were identical for total ship weights that were integer multiples of the LCAC load weight. For the other weights, the single queue simulation model results were a few minutes higher than the deterministic results. The difference is the result of the "last load effect". The deterministic model slightly underestimates the time required to take on the last load in cases where the load on a ship is not evenly divisible by the LCAC load size. For example, if a ship carries 400 tons of cargo and the LCAC load size is 30 tons, the last load will be only 10 tons. The deterministic model assumes that every load of cargo is being loaded onto the LCAC at a rate of 30 tons/(5 exp(.04145*30) minutes) = 1.73 tons/minute. For ten tons of cargo, this produces an loading time (t_{1a}) of 5.78 minutes. In fact, however, the loading rate is 10 tons/(5 exp(.04145*10) minutes) = 1.32 tons/minute, which implies a loading time of 7.56 minutes, a difference of 1.78 minutes.

IV. RESULTS

A. COMPARISON OF SIMULATION AND DETERMINISTIC MODELS.

Figures 4 and 5 are the deterministic and single queue simulation results, respectively, for the deterministic and single queue simulation models for three ships, eight LCAC's and three beach spots. Each ship is loaded with 400 tons of cargo. As can be seen from the figures, the simulation results are somewhat higher than the deterministic results

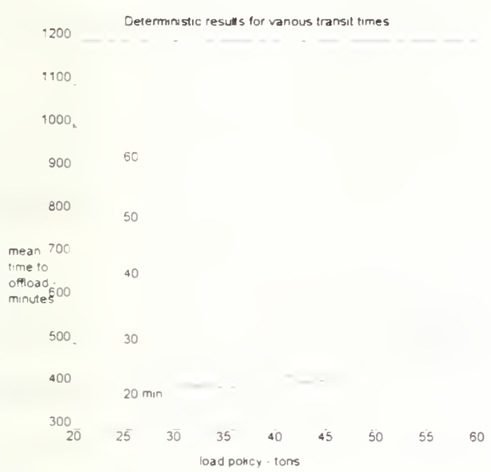

Figure 4

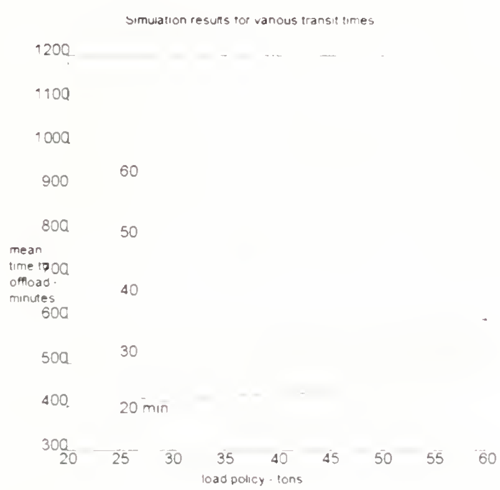

Figure 5

This occurs because the deterministic model is unable to capture accurately the effects of occasional queueing, that is, the formation of queues that are present intermittently during the operation. This phenomenon would be expected to occur near the crossover points between LCAC limited and well or beach limited cases, because the randomness of LCAC service times would produce fluctuations in the LCAC flow rate. At the extreme points, where the operation is clearly limited by only one of the entities, the two models should provide the same results. This, in fact, is what is observed. From this it can be concluded that the deterministic model can be used without reservation near the extreme points. Near the crossover points, the deterministic model will slightly underestimate the total time to offload.

B. LIMITING CASES OF THE SINGLE QUEUE MODEL.

There are three facilities involved in the transport of cargo to the beach: the wells, the LCAC's, and the beach spots. Each of these facilities has the potential to act as a bottleneck in the flow of cargo to the beach.

1. LCAC (or transit) limited case.

The LCAC-limited case occurs when the number of LCAC's available is small compared to the distance to the beach. In this case, the LCAC's spend most of their time in transit. Figure 4 shows LCAC-limited behavior for all transit distances at lower load weights. In general, if a situation is LCAC-limited, loads should be increased toward 60 tons, the LCAC load limit. Alternatively, the amphibious ships could be moved closer to the beach.

2. Well-limited case.

A situation is well-limited if the number of wells is small compared to the rate of LCAC arrival for loading. This usually occurs if the transit distance is small. Figure 4 shows well-limited behavior for transit distances less than sixty minutes and higher load policies. In general, if the situation is well-limited, the loads should be made smaller. However,as the load weight is reduced to less than 24 tons, the total offload time will begin to increase, because cargo is loaded onto the LCAC at the fastest rate using this load policy (see page 5 for details). In well limited situations, the offload rate is independent of the distance from the beach.

3. Beach-limited case.

In real amphibious operations, the beach-limited case is less common than the others for two reasons. First, many real beaches have, in effect, an unlimited number of beach spots[6]. Second, unloading the LCAC's is considerably faster than loading them, so the LCAC's spend less time there. A situation is beach-limited if the rate of LCAC arrival for unloading is large compared to the number of beach spots. This occurs if the transit distances are small and the situation is rich in LCAC's.

Figures 6 and 7 show results from the deterministic model for 2 beach spots and

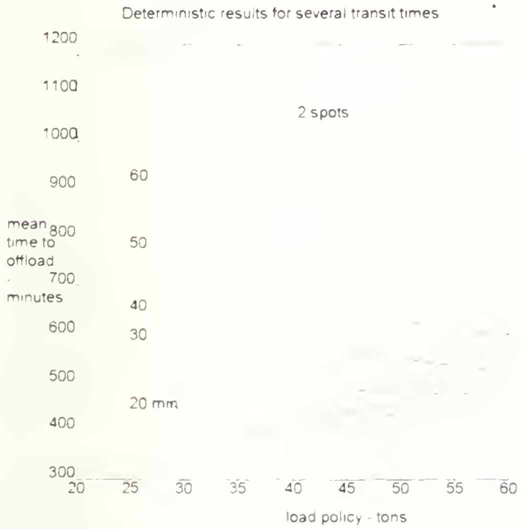

Figure 6

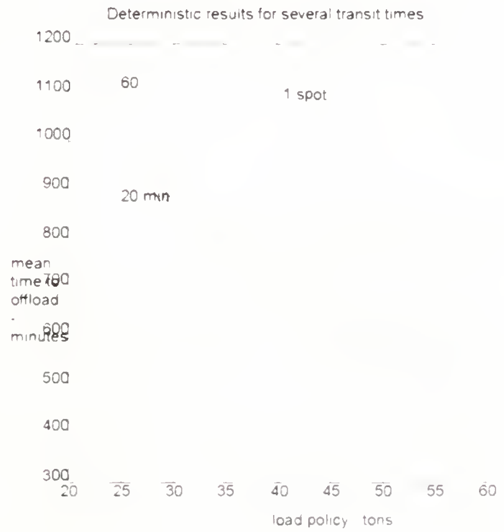

Figure 7

one beach spot, respectively. Figure 6 shows beach-limited behavior for transit time 20 minutes and load policies less than 25 tons. Figure 7 shows beach-limited behavior everywhere except for the 60 minute transit at weights greater than 45 tons, and for the other transit times at load weights greater than 55 tons. If it is impossible to provide more beach spots, the offload rate can be increased by increasing the LCAC load size.

C. MULTIPLE QUEUE MODEL.

To test the predictions of the multiple queue model, the GPSS simulation was modified to allow LCAC's to be assigned to a specified ship. The parameters were the

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[6] It is easy to imagine, however, circumstances in which this is untrue. For example, in wartime, beaches are likely to be mined, and each beach spot cleared would represent a substantial investment in mine clearance effort.

same as those given for the example case in Chapter II. Although the deterministic multiple queue model predicted a savings of twenty minutes by switching to two queues, this gain was not realized in the simulation. The simulation produced a mean time of 606.6 minutes, a savings of only about 8.5 minutes. Since this example was picked to favor the split queue model, it is likely that less favorable scenarios would fare even worse. Therefore, it is concluded that the multiple queue policy is unlikely to be operationally useful.

D. QBASIC MODEL.

As discussed above, the equations developed in Chapter II have been incorporated into a program written in Microsoft QBASIC. This program provides users with the capability to judge the adequacy of resources such as beach spots, LCAC's and wells; and to choose the proper tactics for the situation. A listing of this program is included in Appendix C. Additional copies may be obtained from Dr. Alan Washburn, at the address shown in the distribution list.

V. CONCLUSIONS

A. EFFECTS OF LOAD POLICY ON TIME TO COMPLETE OFFLOAD.

It has been shown that the total time to complete the offload can be minimized if the proper load policy is selected (assuming that the exponential function relating LCAC load weight to loading time is correct). This minimum point does not usually occur at the maximum possible load policy, as might be expected from casual observation, but rather occurs most often in the middle of the range of load policies.

This implies that planning for LCAC operations should include an examination of the optimum load policy for the operation. Accordingly, a decision aid has been presented which provides planners with the information necessary to make better decisions regarding LCAC load policy. This decision aid was developed from a mathematical analysis of the process of amphibious assault and was compared to a simulation of the same process. The similarity of the results provides increased confidence in the validity of the model.

B. AREAS FOR FURTHER STUDY.

1. Nature of the loading process.

In this research, it was assumed that the time required to load an LCAC is an exponential function of the load weight. This assumption was based on the author's experience as officer-in-charge of an LCAC detachment during operation Desert Storm. Although there is some data that suggests that the time to load an LCAC increases with load weight, there is not enough to show that the relationship is exponential. Further work to explore the nature of the loading process is desirable. If insufficient correlation between the load weight and loading time is found, it may be worthwhile to include the square footage of the load as a predictor of the loading time.

2. Discrete nature of cargo.

Both the analytical and simulation models treat cargo as a continuous quantity that could be loaded onto LCAC's in any desired quantity. In reality, of course, cargo arrives for loading in discrete amounts ranging from less than five tons (a towed electrical generator, for example) to sixty tons (an M60 tank). The use of continuous cargo in the models may have caused the advantages of optimum LCAC loading to be overstated, because it may be quite difficult to actually load the "ideal" amount of cargo. In future research, a more general model that includes the effect of discrete cargo should be developed. Since the order of cargo arrival is likely to have a strong influence on the efficiency of LCAC loading, the study of discrete cargo also implies that the order of cargo loading in amphibious shipping should be modeled, because it is very difficult to rearrange cargo once loaded into the ship.

APPENDIX A

The following is a listing of the GPSS model that was used to obtain the results shown in figure 5

```
************** SINGLE QUEUE MODEL *************************
************** 50 replications ********************************
*
************** CONTROL STATEMENT SECTION **********************
*
    INTEGER     &SHIP1LD,&SHIP2LD,&SHIP3LD,&LCACLD,&I,&J,&K,&TRANSIT
    REAL          &ADVMN,&ADVVAR
    LET           &SHIP1LD=400
    LET           &SHIP2LD=400
    LET           &SHIP3LD=400
    LET           &LCACLD=20
    LET           &TRANSIT=20
*
************** BLOCK SECTION **********************************
*
    GENERATE      0,0,0,8                      ; create LCAC's
    TRANSFER      ALL,GATOR1,GATOR3,13
*
************** FIRST SHIP *************************************
*
 GATOR1   SEIZE          SHIP1
    TEST G        &SHIP1LD,0,EMPTY1
* check to see if there is cargo left
    ADVANCE       5                            ; time to land in well
    BLET          &ADVMN=5*EXP(&LCACLD*.04145)
    BLET          &ADVVAR=&LCACLD/12
    ADVANCE       RVNORM(1,&ADVMN,&ADVVAR)     ; time to load
    BLET          &SHIP1LD=&SHIP1LD-&LCACLD    ; decrement ship load
    ADVANCE       5                            ; takeoff from well
    RELEASE       SHIP1
    TRANSFER      ,INGRESS                     ; send to beach
 EMPTY1   RELEASE        SHIP1
    FUNAVAIL      SHIP1
    TRANSFER      ,DONE
*
************** SECOND SHIP ************************************
*
 GATOR2   SEIZE          SHIP2
    TEST G        &SHIP2LD,0,EMPTY2
* check to see if there is cargo left
    ADVANCE       5                            ; time to land in well
    BLET          &ADVMN=5*EXP(&LCACLD*.04145)
    BLET          &ADVVAR=&LCACLD/12
    ADVANCE       RVNORM(2,&ADVMN,&ADVVAR)     ; time to load
```

```
    BLET          &SHIP2LD=&SHIP2LD-&LCACLD    ;decrement ship load
    ADVANCE       5                            ; takeoff from well
    RELEASE       SHIP2
    TRANSFER      ,INGRESS
 EMPTY2   RELEASE       SHIP2
    FUNAVAIL      SHIP2
    TRANSFER      ,DONE
*
************** THIRD SHIP **************************************
*
 GATOR3   SEIZE         SHIP3
    TEST G        &SHIP3LD,0,EMPTY3
* check to see if there is cargo left
    ADVANCE       5                           ; time to land in well
    BLET          &ADVMN=5*EXP(&LCACLD*.04145)
    BLET          &ADVVAR=&LCACLD/12
    ADVANCE       RVNORM(3,&ADVMN,&ADVVAR)    ; time to load
    BLET          &SHIP3LD=&SHIP3LD-&LCACLD   ; decrement ship load
    ADVANCE       5                           ; takeoff from well
    RELEASE       SHIP3
    TRANSFER      ,INGRESS                    ; send to beach
 EMPTY3   RELEASE       SHIP3
    TERMINATE     1
    TRANSFER      ,DONE
*
*************** TRANSIT TO BEACH ********************************
*
 INGRESS  ADVANCE       RVNORM(4,&TRANSIT,2) ; time to get to beach
    TRANSFER      ALL,BEACH1,BEACH3,6
*
*************** BEACH SPOT 1 ************************************
*
 BEACH1   SEIZE         SPOT1
    ADVANCE       5                           ; landing
    ADVANCE       RVNORM(5,10,1.5)            ; offload
    ADVANCE       5                           ; takeoff
    RELEASE       SPOT1
    TRANSFER      ,EGRESS                     ; return to ships
*
*************** BEACH SPOT 2 ************************************
*
 BEACH2   SEIZE         SPOT2
    ADVANCE       5                           ; landing
    ADVANCE       RVNORM(6,10,1.5)            ; offload
    ADVANCE       5                           ; takeoff
    RELEASE       SPOT2
    TRANSFER      ,EGRESS                     ; return to ships
*
*************** BEACH SPOT 3 ************************************
*
 BEACH3   SEIZE         SPOT3
    ADVANCE       5                           ; landing
    ADVANCE       RVNORM(7,10,1.5)            ; offload
    ADVANCE       5                           ; takeoff
    RELEASE       SPOT3
    TRANSFER      ,EGRESS                     ; return to ships
```

```
*
*************** RETURN TO SHIPS *********************************
*
 EGRESS   ADVANCE    PVNORM(8,&TRANSIT,2)     ; time to return to
ships
 DCNE     TRANSFER       ALL,GATOR1,GATOR3,13
*
*************** MORE CONTROL STATEMENTS *************************
*
    DO             &J=1,5                          ; time loop
    DO             &K=1,9                          ; load loop
    DO             &I=1,50                         ; replication loop
    START          6
    LET            &SHIP1LD=400
    LET            &SHIP2LD=400
    LET            &SHIP3LD=400
    CLEAR
    ENDDO
    LET            &LCACLD=&LCACLD+5
    ENDDO
    LET            &LCACLD=20
    LET            &TRANSIT=&TRANSIT+10
    ENDDO
    END
```

APPENDIX B

The following is a listing of the GPSS model that was used to obtain the results for the multiple queue situation.

```
*************** MULTIPLE QUEUE MODEL **************************
*************** 50 replications ***********************************
*
*************** CONTROL STATEMENT SECTION **********************
*
    INTEGER        &SHIP1LD,&SHIP2LD,&LCACLD,&I,&J,&TRANSIT
    REAL           &ADVMN,&ADVVAR
    LET            &SHIP1LD=500
    LET            &SHIP2LD=100
    LET            &LCACLD=20
    LET            &TRANSIT=60
*
*************** BLOCK SECTION *************************************
*
    GENERATE       0,0,0,1                        ; create LCAC's
*
*************** FIRST QUEUE ****************************************
*
 GATOR1   SEIZE          SHIP1
    TEST G         &SHIP1LD,0,EMPTY1
* check to see if there is cargo left
    ADVANCE        5                              ; time to land in well
    BLET           &ADVMN=5*EXP(&LCACLD*.04145)
    BLET           &ADVVAR=&LCACLD/12
    ADVANCE        RVNORM(1,&ADVMN,&ADVVAR)       ; time to load
    BLET           &SHIP1LD=&SHIP1LD-&LCACLD      ; decrement ship load
    ADVANCE        5                              ; takeoff from well
    RELEASE        SHIP1
    TRANSFER       ,INGRESS                       ; send to beach
 EMPTY1   RELEASE        SHIP1
    TERMINATE      1
**************** TRANSIT TO BEACH *********************************
*
 INGRESS  ADVANCE        RVNORM(4,&TRANSIT,2)     ; time to get to beach
    TRANSFER       ALL,BEACH11,BEACH13,6
*
**************** BEACH SPOT 1 *************************************
*
 BEACH11   SEIZE          SPOT1
    ADVANCE        5                              ; landing
    ADVANCE        RVNORM(5,10,1.5)               ; offload
    ADVANCE        5                              ; takeoff
    RELEASE        SPOT1
    TRANSFER       ,EGRESS                        ; return to ships
```

```
*
*************** BEACH SPOT 2 ************************************
*
BEACH12   SEIZE         SPOT2
    ADVANCE       5                              ; landing
    ADVANCE       RVNORM(6,10,1.5)               ; offload
    ADVANCE       5                              ; takeoff
    RELEASE       SPOT2
    TRANSFER      ,EGRESS                        ; return to ships
*
*************** BEACH SPOT 3 ************************************
*
BEACH13   SEIZE         SPOT3
    ADVANCE       5                              ; landing
    ADVANCE       RVNORM(7,10,1.5)               ; offload
    ADVANCE       5                              ; takeoff
    RELEASE       SPOT3
    TRANSFER      ,EGRESS                        ; return to ships
EGRESS   ADVANCE        RVNORM(8,&TRANSIT,2)     ; time to return to
ships
DONE      TRANSFER      ,GATOR1
*
************** SECOND SHIP *************************************
*
    GENERATE      0,0,0,5                        ; create LCAC's
GATOR2   SEIZE         SHIP2
    TEST G        &SHIP2LD,0,EMPTY2
* check to see if there is cargo left
    ADVANCE       5                              ; time to land in well
    BLET          &ADVMN=5*EXP(&LCACLD*.04145)
    BLET          &ADVVAR=&LCACLD/12
    ADVANCE       RVNORM(2,&ADVMN,&ADVVAR)       ; time to load
    BLET          &SHIP2LD=&SHIP2LD-&LCACLD      ; decrement ship load
    ADVANCE       5                              ; takeoff from well
    RELEASE       SHIP2
    TRANSFER      ,INGRESS
EMPTY2   RELEASE        SHIP2
    FUNAVAIL      SHIP2
    TRANSFER      ,DONE
*
*************** TRANSIT TO BEACH ********************************
*
INGRESS  ADVANCE        RVNORM(4,&TRANSIT,2)     ; time to get to beach
    TRANSFER      ALL,BEACH21,BEACH23,6
*
*************** BEACH SPOT 1 ***********************************
*
BEACH21   SEIZE         SPOT1
    ADVANCE       5                              ; landing
    ADVANCE       RVNORM(5,10,1.5)               ; offload
    ADVANCE       5                              ; takeoff
    RELEASE       SPOT1
    TRANSFER      ,EGRESS                        ; return to ships
*
*************** BEACH SPOT 2 ************************************
*
```

```
 BEACH22   SEIZE         SPOT2
    ADVANCE       5                           ; landing
    ADVANCE       RVNORM(6,10,1.5)            ; offload
    ADVANCE       5                           ; takeoff
    RELEASE       SPOT2
    TRANSFER      ,EGRESS                     ; return to ships
*
*************** BEACH SPOT 3 **********************************
*
 BEACH23   SEIZE         SPOT3
    ADVANCE       5                           ; landing
    ADVANCE       RVNORM(7,10,1.5)            ; offload
    ADVANCE       5                           ; takeoff
    RELEASE       SPOT3
    TRANSFER      ,EGRESS                     ; return to ships
*
*************** RETURN TO SHIPS *******************************
*
 EGRESS    ADVANCE       RVNORM(8,&TRANSIT,2)   ; time to return to
ships
 DONE      TRANSFER      ,GATOR2
*
*************** MORE CONTROL STATEMENTS ***********************
*
    DO            &K=1,9                      ; load loop
    DO            &I=1,50                     ; replication loop
    START         6
    LET           &SHIP1LD=400
    LET           &SHIP2LD=400
    LET           &SHIP3LD=400
    CLEAR
    ENDDO
    LET           &LCACLD=&LCACLD+5
    ENDDO
    LET           &LCACLD=20
    END
```

APPENDIX C.

The following is the text of the QBASIC program to calculate the best load weight given values for time spent on the beach and in transit, and the number of LCAC's, ships, and beach spots

```
PRINT "This program calculates the LCAC load weight that maximizes the"
  PRINT "rate of offload, given the parameters you specify. It will also"
  PRINT "show the offload rate for several load policies and identify"
  PRINT "the limiting facility."
  PRINT
  PRINT "You will be asked to provide the expected amount of time spent"
  PRINT "on the beach, the two way transit time, and the number of "
  PRINT "beach spots, LCAC's, and ships available."
  PRINT
10 INPUT "Please enter the amount of time spent on the beach in minutes";
tb
20 INPUT "Please enter the two-way transit time in minutes"; tt
   PRINT "Please enter the number of beach spots, LCAC's, and ships,"
30 INPUT "placing a comma between the values"; b, l, s
   REM ***********************************************************
   REM The above section gets initial values of the parameters
   REM ***********************************************************
40 bestrate = 0: bestw = 0
50 PRINT "load size"; " beach "; "transit "; "loading "; "limit  "
60 FOR w = 20 TO 60 STEP 5
70 ts = (5 * EXP(.04145 * w)) + 10
   REM ***********************************************************
   REM Calculates the time the well is unavailable
   REM ***********************************************************
80 wb = w * b / tb: wt = w * l / (tb + tt + ts): ws = w * s / ts
   REM ***********************************************************
   REM Calculates maximum service rates for each facility
   REM ***********************************************************
90 rate = wb
100 IF wt < rate THEN rate = wt
110 IF ws < rate THEN rate = ws
120 IF rate > bestrate THEN
130     bestrate = rate
140     bestw = w
    REM ***********************************************************
    REM Determines which is the limiting facility and establishes it
    REM as the limiting factor
    REM ***********************************************************
150 END IF
160 PRINT USING "###.###"; w; wb; wt; ws; rate
170 NEXT w
180 PRINT "The best offload rate is "; bestrate; " tons/min"
190 PRINT "The best load weight is "; bestw; " tons"
200 PRINT
210 INPUT "Would you like to recalculate for different parameters (Y/N)";
DECIDE$
220 IF NOT DECIDE$ = "Y" THEN END
230 PRINT "Which variable would you like to change?"
```

```
    240 PRINT "1=time on beach, 2=two way transit time, 3=number of beach
spots"
    250 INPUT "4=number of LCAC's, 5=number of ships", choice
    260 SELECT CASE choice
        CASE IS = 1
           INPUT "Please enter the expected time spent on the beach", tb
           INPUT "Would you like to change another variable (y/n)"; ANOTH$
           IF ANOTH$ = "Y" THEN GOTO 230 ELSE GOTO 40
           GOTO 40
        CASE IS = 2
           INPUT "Please enter the two-way transit time"; tt
           INPUT "Would you like to change another variable (y/n)"; ANOTH$
           IF ANOTH$ = "Y" THEN GOTO 230 ELSE GOTO 40
        CASE IS = 3
           INPUT "Please enter the number of beach spots"; b
           INPUT "Would you like to change another variable (y/n)"; ANOTH$
           IF ANOTH$ = "Y" THEN GOTO 230 ELSE GOTO 40

        CASE IS = 4
           INPUT "Please enter the number of LCAC's"; l
           INPUT "Would you like to change another variable (y/n)"; ANOTH$
           IF ANOTH$ = "Y" THEN GOTO 230 ELSE GOTO 40

        CASE IS = 5
           INPUT "Please enter the number of ships"; s
           INPUT "Would you like to change another variable (y/n)"; ANOTH$
           IF ANOTH$ = "Y" THEN GOTO 230 ELSE GOTO 40

        CASE ELSE
           INPUT "Do you want to quit (y/n)"; DONE$
           IF NOT DONE$ = "n" THEN END
     END SELECT
     REM *****************************************************************
     REM Above section allows user to change parameters
     REM *****************************************************************
```

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