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Simulation of Container Queues for Port Investment Decisions

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Abstract Due to congestion of port or due to low tide situation or otherwise, sometimes the ships cannot come to the port directly. In such a situation, the ships are anchored offshore and the containers are transported to the ships through small crafts. This paper simulates this condition to find out the queue of containers at the port and also analyses the effect of increase in the facilities at the port to reduce this queue. However, a cost benefit analysis needs to be done for increasing the facilities at the port i.e. increasing the number of cranes and number of berths. The objective here is to analyse the effectiveness of the suggested solution before investing in increase in facilities. Thus, instead of actually implementing the solution, the advantages and disadvantages of the suggested solution are studied by simulation technique.

Keywords simulation; queuing; ships; containers; port investment

1 Introduction

Operations at port are very complicated. The complete situation at the port is very difficult to formulate as a single problem and can be divided into various sub-problems. Each sub-problem in turn can be solved to achieve optimum results. The sub-problems thus solved, may not achieve optimum results for the complete problem. Technically we can say that the local optima thus obtained may not lead to global optima. The situation therefore, needs to be analysed towards achieving global optima.

In addition to this, condition at every port is different and demands various solutions. An attempt therefore is made here to analyse the situation and obtain a generalized solution, which can be applied at various ports. The research may also try to look into similar condition at airports, railways, etc.

The general condition at any sea port can be explained as follows:

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1. Containers are stacked in the yards. Stacking can be done as per convenience.
2. Quays at the ports can have one or more berths.
3. Berths can be of various lengths.
4. Ship-size is also variable.
5. Allocation of berths to ship depends on the length of the ship and berth.
6. Allocation of berth to the ship also depends on the location of containers, depth at the berth, tidal conditions, availability of gantry cranes, manpower allocation, processing time required by the ships.
7. The change in the itinerary may also affect the overall processing time of the vessel.
8. Some times the ships do not directly come to the berth. The ship is anchored in the sea and the containers are transported to the ships by small crafts.
9. The queues thus seen are for the containers as well as for the ships.
10. In addition to loading, the containers from ships are to be unloaded at the ports. This unloading of containers from ships is beyond the scope of this problem.

The main objective here is to reduce the queue of containers at the port with minimum investment. An obvious solution to the problem is to increase the facilities at the port to reduce the queues. Increase in facilities involves increase in number of cranes, increase in number of berths, adding new machinery at the port, increase in working hours at berths and proper allocation of resources. The investment for these facilities is very high. Hence it is necessary to verify whether increase in facilities leads to reduction in queues or not.

Investments in Ports throughout the world are mainly done on the basis of intuitions. The costs involved are so high that the situation needs rational calculations. Although the situations at various ports seem to be alike, the situation at each port is unique in its sense. Even minor variations in these situations demand a separate queue model at each and every port. It is not feasible to have a separate system for varying situations at each port. Various situations can be designed, formulated and simulated to obtain results under these situations.

E.D.Edmond and R.P.Maggs [1] analysed various queue models for imports and gave a guideline for investments and proved that increase in cranes and berth facilities does not reduce the queues in the same proportion. Hence a proper cost analysis is to be carried out to compare various options. Jose Holguin-Veras and Sergio Jara-Diaz [2] discussed the practical implications of optimal space allocation and pricing. Opportunity costs of cargoes, handling costs and price elasticity of dwelling time are the main considerations. G.E.Horne and T.Z.Irony [3] discussed ship to shore transfer of cargo from ships that are located offshore. In this case, transport is done using smaller crafts. These crafts cycle back and forth. The queues discussed in this case are that of cargoes at loading and unloading points. P.Schonfeld and O.Sharafeldien [4] looked at this problem from the point of view of optimising berth and crane combinations in container ports. They optimised the design and operation of container at port. The model thus developed minimizes total port cost.

Henesey et al. [5] have investigated the use of simulation as the basis for a decision support system in analysing the assignment of berths to arriving container ships at a container terminal. The main objective was to improve the performance of the container terminal by efficiently utilising the resources available. The system is defined as Berth Allocation Management System (BAMS) as a part of decision support system. The main objective here was to assist in creating berth schedules for arriving ships under various conditions.

Efficient planning of berth allocation for container terminals in Asia was studied and discussed by Imai et al. [6]. The objective here was to utilize the terminal efficiently for container ports. The paper focuses on berth allocation that minimizes dissatisfaction of the ships in terms of berthing order and minimizing the sum of the time the ships spend waiting for berths. An algorithm is presented in the paper, which identifies non-inferior solutions to the berth allocation problem.

The berth allocation problems generally discussed are static in nature, in the sense that the allocations are not changed with respect to time. But in actual practice, the change in the itinerary, tidal conditions, non-availability of resources, etc. affect the allocation of ships to various berths. Imai et al. [7] developed a heuristic procedure based on Lagrangian relaxation. They conducted a large amount of computational experiments to show that the proposed algorithm could be easily adapted in the real life conditions.

Berth allocation planning for the ships in the public berth system was done using genetic algorithm by Nishimura et al. [8]. A heuristic procedure was developed based on genetic algorithm. The algorithm was tested using various real life problems and it was found that the algorithm was adaptable to real life situations.

Major differences between standard vehicle routing scheduling problems and ship routing problem as discussed by Ronen [9] are:

1. Each ship has unique operating characteristics such as capacity, speed, cost structure, etc. Due to market fluctuations, even two identical ships may have different cost structure.
2. The scheduling environment depends to a great extent on the mode of operation of the ship.
3. Ships do not return necessarily return to their origin.
4. Higher uncertainty is involved in scheduling ships due to longer voyages.
5. Ships are operated round the clock while vehicles are usually not operated during the night (except few vehicles such as truck). Thus ships do not have planned idle periods, which absorb delays in operations.
6. Destination of ships may be changed at sea.

The review emphasises the fact that the objective of ship routing and scheduling is not always clear, especially in cases where not all cargoes available are known in advance. Linear operations try to maximize the profit per time unit in the long run but may divert from this objective in the short run in order to gain market share.

A conceptual model for high speed vessels was developed by Lagoudis et al. [10]. The paper reviews the role of high speed vessels in the context of the total supply chain. A mode choice is presented in the paper within the context of supply chain transport strategies. The model relates mode choice to volume supply, product cost, shipping distance, frequency of service, transit time and product type. The emphasis in this paper is on selection of mode of transport.

2 Description of the Problem

Containers to be transported by ships at various locations face a very common problem of high waiting times at the port. Export containers arrive at the port before the arrival of the ship. These containers are stacked at the back of the berths and wait for 3 to 4 days. These containers are then transported to berth and then to the ship. This movement of containers is done through cranes and straddle carriers. The maximum capacity of crane is to handle 30 containers per hour. This handling capacity cannot be achieved at all times because of breakdown of cranes and/or straddle carriers. However, a fairly realistic rate of 18 containers per hour can be considered as good actual rate [1]. The containers are then transported to the ship, which is docked at the berth.

There is a possibility of congestion of port and unavailability of berths due to which ships cannot directly come to the port. Sometimes this may happen due to low tide situation or insufficient port facility or early arrival at port. In such cases, the ship is anchored offshore and the containers are transferred to the ship through small crafts.

The containers transported from the stack to the berth are loaded on these crafts, which in turn transport the containers to the ships, instead of loading the containers to the ships directly. As the number containers loaded per crafts is 45, the time taken by the crane to transport the containers to the berth is 2.5 hours (Handling time of crane: 18 containers per hour). The average time of loading the containers to the crafts is considered as 233 min. These small crafts transport the containers further to the ship. The transport time of the crafts depends on the distance of the ship from the berth and the speed of the craft. The mean transport time is considered to be 32.4 min. The containers are finally unloaded from the crafts and loaded to the ship. The average time of unloading of containers from the craft and loading to the ship is considered to be 42.4 min. All this data was obtained from reference [2].

The entire process of loading the containers to the ship through small crafts, is considered to be divided in five processes as follows:

1. Transport to berth by crane: Time for transporting the containers to berth (2.5 hrs).
2. Craft loading: Time to load the containers onto the craft (233/60=3.88 hrs.).
3. Craft transport: Time of transport of the crafts nearer to ship (32.4/60=0.54 hrs.).
4. Ship loading: Time to load the containers into the ship (42.4/60= 0.71 hrs.).

Time rates considered for these processes are as follows:

$$2.5 \quad 3.88 \quad 0.54 \quad 0.71$$

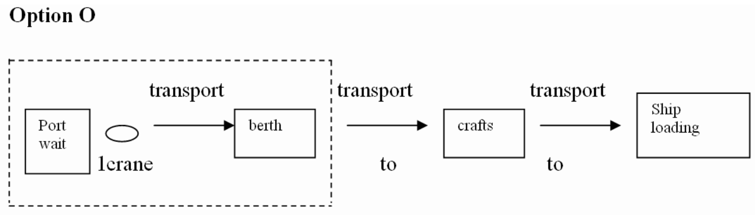

Figure 1: Option “O”: 1 Berth and 1 crane

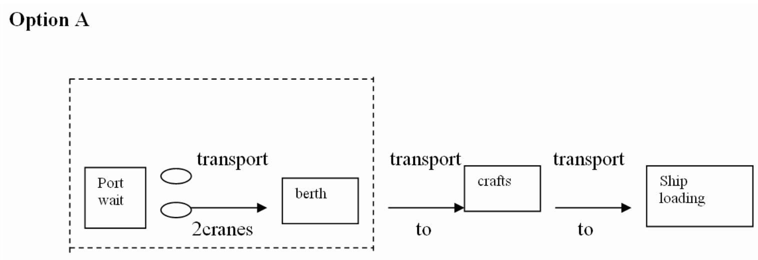

Figure 2: Option “A”: 1 Berth and 2 cranes

This can be represented schematically as shown in fig. 1.

Large queues of containers are formed at the port, when the ship is anchored offshore and the containers are transferred to the ship through small crafts. An attempt is made in this study, to reduce the queue of containers thus formed, using simulation technique.

The sequence of processes in option ‘O’ is simulated to find out the queue at the port. Three more options, which are considered as solution to the problem, are also studied. The number of cranes is increased in these options and in the last option one more berth is introduced. In Option O, only one crane is considered with one berth, as shown in fig. 1. For Option A, two cranes are considered with one berth only, as shown in fig. 2. Option B considers three cranes and one berth only as shown in fig. 3, whereas Option C considers three cranes and two berths as shown in fig. 4.

3 Simulation

The three options stated above involve lot of investment. The first option suggests increase of one crane at the berth. This increase involves cost of buying one crane, maintaining it and operating it. In addition to this, parallel working of cranes cause interference at the loading point. This clearly indicates that by increasing one crane, the loading and unloading capacities can not be doubled. The second option is to increase two cranes and the third option involves increasing two cranes and increasing one more berth. Instead of actually implementing these options, the advantages and disadvantages of the options are studied by simulation.

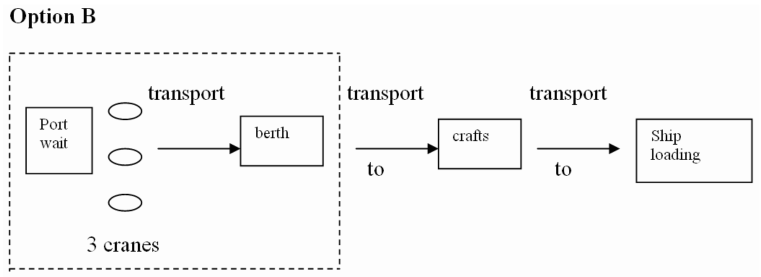

Figure 3: Option “B”: 1 Berth and 3 cranes

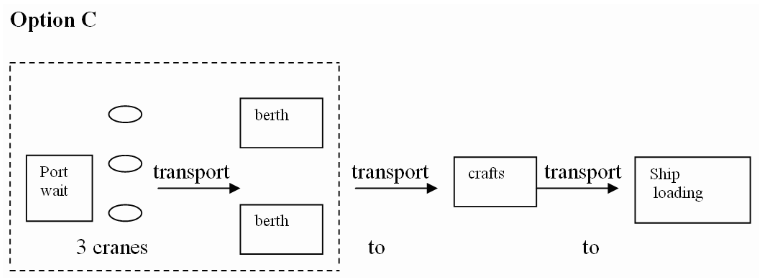

Figure 4: Option “C”: 2 Berths and 3 cranes

Simulation is a powerful tool to evaluate performance of proposed system and choosing appropriate design before actually implementing it. It helps in visualising the solution before implementation. The advantages of simulation can be as follows:

1. The complete problem can be divided into small problems.
2. Each sub-problem can be treated as a separate problem and yet a global optima can be achieved.
3. Facilities can be added or removed at any time.
4. Arrival as well as service distributions as well as their parameters can be changed at any moment and results can be obtained within minutes.
5. Separate distribution can be assigned to individual facility.
6. Simulation models can be realistic. Since they are not equation based, linearity, differentiability, time dependencies etc. are not the issues. The number of complex systems subject to realistic simulation-based experimentation is much greater than the number subject to realistic mathematical modelling.
7. The system whose behaviour is to be investigated need not actually exist. It has to exist in the mind of the designer.
8. Time can be compressed in simulation models. The equivalent of days, weeks, and months of real time operation often can be simulated only in seconds, minutes or hours on computer. Thus a large number of simulated alternatives can

be investigated, and results can be made available soon enough to influence the choice of design for a system.

9. All variables can be held constant, except those whose influence is being studied. As a result, the possible effect of uncontrolled variable on system behaviour need not be taken into account, as is done when experiments are performed on a real system.

Some of the disadvantages of simulation can be:

1. Past data must be available to predict the situation.
2. It can analyse various conditions but can not give “the best” solution.
3. A person should be educated in a variety of areas before becoming a simulation practitioner.
4. Simulation studies also involve cost, such as cost of hardware, software, training, etc.

Steps in simulation studies:

1. To formulate the problem and plan the study.
2. To collect data and define a model.
3. To validate the model.
4. To construct computer model and verify it.
5. To take pilot runs.
6. To validate the model again.
7. To Design Experiments.
8. To take production runs.
9. To analyse the output data.
10. To document and implement the results.

3.1 GPSS/H modelling language

A system under study is a collection of interrelated elements that work together to achieve a stated objective. A GPSS/H model takes the form of a series of statements. A GPSS/H model can be expressed as a Block Diagram, or as the statement equivalent of a Block Diagram.

Units of traffic move along the one-way paths in a block diagram. The name transaction is given to a unit traffic in GPSS/H. The movement of transactions from block to block as a simulation proceeds is a vital part of GPSS/H.

A model is built by selecting appropriate blocks from the available types. Selected blocks are then sequenced in a Block diagram to form patterns, corresponding to patterns in the system being modelled. The Blocks are used to represent such things as system resource, information gathering and decision making capabilities. The physical and logical aspects of the system being modelled and the type of information that the model is to provide, determine which Blocks are used in constructing the model. When a model is executed by computer, it is the movement of units of traffic from Block to Block that is analogues to (simulates) the movement of traffic through the system being modelled. As the simulation proceeds, transactions in

Table 1: Summary of relevant simulated results

	Option O	Option A	Option B	Option C
Maximum queue at port	28	11	3	3
Maximum queue at berth	6	23	31	12 (for each berth)
Crane utilization	97%	96%	82%	78%
Average waiting time per craft	8.81 hrs.	15.33hrs.	15.40 hrs.	7.02 hrs.

GPSS/H move along path from Block to Block in a model. Each block represents an action to be performed whenever the Block is executed.

The GENERATE block creates a transaction while TERMINATE block destroys the transaction. When traffic moves in a system it reaches a point at which it pauses and spends time before returning its movement. These points frequently correspond to locations in a system at which traffic receives service. This condition is depicted by ADVANCE block. The service times required can have various distributions and varied parameters. QUEUE and DEPART blocks collect the statistical data about the system. These blocks are mainly used to find WIP at various stages of the system. SEIZE and RELEASE blocks are used to engage and disengage a facility or service. ENTER and LEAVE replace SEIZE and RELEASE when there are multiple facilities or service stations available.

The system is simulated using GPSS/H package and the results obtained are summarised in table 1. The program and output files are attached at the end of the report.

4 Results and Conclusions

The system is simulated for all the four situations and the results obtained are as follows:

1. Queue at the port decreases by increasing the number of cranes but an increase in the queue is observed at the berth.
2. Although the simulation results show that the maximum queue contents at the port are reduced, this simulation does not consider the breakdown of the cranes, which is a common feature. In addition to this, parallel movement of the cranes is not possible in all cases.
3. Crane utilization decreases with increase in number of cranes.
4. Average waiting time of the craft increases drastically. The crafts have to wait before coming to berth since they are getting loaded faster due to increase in number of cranes.
5. The increase in queue at berth demands a cost benefit analysis to be done before adding cranes and berth.

6. Average waiting time of the craft in option 'c' shows a decrease but this time is at two berths. Thus total time is 7 *2 = 14 hrs. approx.

Thus it can be concluded that increase in the port facility does not increase the output. This increase leads to container queues at berth. Since this queue is not desirable, the solutions given by options A, B and C do not work out to be feasible solutions.

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*         SIMULATION FOR CONDITION '0' ONE BERTH AND 1 CRANE
*         ALL DURATIONS ARE IN HOURS

        SIMULATE

        GENERATE 1


        QUEUE CRN
        SEIZE CRNT
        ADVANCE 2.5,.5
        RELEASE CRNT
        DEPART CRN

        QUEUE CRFT
        SEIZE CRFTL
        ADVANCE 3.88,.3
        RELEASE CRFTL
        DEPART CRFT


        QUEUE CRTR
        SEIZE CRAFTT
        ADVANCE 0.54
        RELEASE CRAFTT
        DEPART CRTR

        QUEUE LOAD
        SEIZE SHIPL
        ADVANCE 0.706,.07
        RELEASE SHIPL
        DEPART LOAD
        TERMINATE 1

        START 10

        END
```

Results of swo.lis

FACILITY	--AVG-UTIL-DURING-- TOTAL TIME	AVAIL TIME	UNAVL TIME	ENTRIES	AVERAGE TIME/XACT	CURRENT STATUS	PERCENT AVAIL	SEIZING XACT	PREEMPTING XACT
CRNT	0.977			17	2.499	AVAIL		17	
CRFTL	0.925			11	3.656	AVAIL		11	
CRAFTT	0.124			10	0.540	AVAIL			
SHIPL	0.173			10	0.752	AVAIL			

QUEUE	MAXIMUM CONTENTS	AVERAGE CONTENTS	TOTAL ENTRIES	ZERO ENTRIES	AVERAGE TIME/UNIT	$AVERAGE TIME/UNIT	CURRENT CONTENTS
CRN	28	13.616	43	0	13.770	13.770	27
CRFT	6	3.243	16	0	8.814	8.814	6
CRTR	1	0.124	10	0	0.540	0.540	0
LOAD	1	0.173	10	0	0.752	0.752	0

```
*        SIMULATION FOR CONDITION 'A' ONE BERTH AND 2 CRANE
*        ALL DURATIONS ARE IN HOURS

        SIMULATE

  CRNT  STORAGE 2

        GENERATE 1


        QUEUE CRN
        ENTER CRNT
        ADVANCE 2.5,.5
        LEAVE CRNT
        DEPART CRN

        QUEUE CRFT
        SEIZE CRFTL
        ADVANCE 3.88,.3
        RELEASE CRFTL
        DEPART CRFT


        QUEUE CRTR
        SEIZE CRAFTT
        ADVANCE 0.54
        RELEASE CRAFTT
        DEPART CRTR

        QUEUE LOAD
        SEIZE SHIPL
        ADVANCE 0.706,.07
        RELEASE SHIPL
        DEPART LOAD
        TERMINATE 1

        START 10

        END
```

Results of swa.lis

FACILITY	--AVG-UTIL-DURING-- TOTAL TIME	AVAIL TIME	UNAVL TIME	ENTRIES	AVERAGE TIME/XACT	CURRENT STATUS	PERCENT AVAIL	SEIZING XACT	PREEMPTING XACT
CRFTL	0.925			11	3.682	AVAIL		11	
CRAFTT	0.123			10	0.540	AVAIL			
SHIPL	0.179			10	0.783	AVAIL			

STORAGE	--AVG-UTIL-DURING-- TOTAL TIME	ENTRIES	AVERAGE TIME/UNIT	CURRENT STATUS	PERCENT AVAIL	CAPACITY	AVERAGE CONTENTS	CURRENT CONTENTS
CRNT	0.966	35	2.416	AVAIL	100.0	2	1.931	2

QUEUE	MAXIMUM CONTENTS	AVERAGE CONTENTS	TOTAL ENTRIES	ZERO ENTRIES	AVERAGE TIME/UNIT	$AVERAGE TIME/UNIT	CURRENT CONTENTS
CRN	11	5.690	43	0	5.792	5.792	10
CRFT	23	11.409	33	0	15.133	15.133	23
CRTR	1	0.123	10	0	0.540	0.540	0
LOAD	1	0.179	10	0	0.783	0.783	0

```
*        SIMULATION FOR CONDITION 'B' ONE BERTH AND 3 CRANES
*        ALL DURATIONS ARE IN HOURS


        SIMULATE

  CRNT  STORAGE 3

        GENERATE 1


        QUEUE CRN
        ENTER CRNT
        ADVANCE 2.5,.5
        LEAVE CRNT
        DEPART CRN

        QUEUE CRFT
        SEIZE CRFTL
        ADVANCE 3.88,.3
        RELEASE CRFTL
        DEPART CRFT


        QUEUE CRTR
        SEIZE CRAFTT
        ADVANCE 0.54
        RELEASE CRAFTT
        DEPART CRTR

        QUEUE LOAD
        SEIZE SHIPL
        ADVANCE 0.706,.07
        RELEASE SHIPL
        DEPART LOAD
        TERMINATE 1

        START 10

        END
```

Results of swb.lis

FACILITY	--AVG-UTIL-DURING-- TOTAL TIME	AVAIL TIME	UNAVL TIME	ENTRIES	AVERAGE TIME/XACT	CURRENT STATUS	PERCENT AVAIL	SEIZING XACT	PREEMPTING XACT
CRFTL	0.925			11	3.660	AVAIL		11	
CRAFTT	0.124			10	0.540	AVAIL			
SHIPL	0.171			10	0.745	AVAIL			

STORAGE	--AVG-UTIL-DURING-- TOTAL TIME	ENTRIES	AVERAGE TIME/UNIT	CURRENT STATUS	PERCENT AVAIL	CAPACITY	AVERAGE CONTENTS	CURRENT CONTENTS	MAXIMUM CONTENTS
CRNT	0.821	43	2.492	AVAIL	100.0	3	2.462	2	3

QUEUE	MAXIMUM CONTENTS	AVERAGE CONTENTS	TOTAL ENTRIES	ZERO ENTRIES	AVERAGE TIME/UNIT	$AVERAGE TIME/UNIT	CURRENT CONTENTS
CRN	3	2.462	43	0	2.492	2.492	2
CRFT	31	14.506	41	0	15.401	15.401	31
CRTR	1	0.124	10	0	0.540	0.540	0
LOAD	1	0.171	10	0	0.745	0.745	0

```
*        SIMULATION FOR CONDITION 'B' ONE BERTH AND 3 CRANES
*        ALL DURATIONS ARE IN HOURS


       SIMULATE

  CRNT  STORAGE 3

       GENERATE 1


       QUEUE CRN
       ENTER CRNT
       ADVANCE 2.5,.5
       LEAVE CRNT
       DEPART CRN

       QUEUE CRFT
       SEIZE CRFTL
       ADVANCE 3.88,.3
       RELEASE CRFTL
       DEPART CRFT


       QUEUE CRTR
       SEIZE CRAFTT
       ADVANCE 0.54
       RELEASE CRAFTT
       DEPART CRTR

       QUEUE LOAD
       SEIZE SHIPL
       ADVANCE 0.706,.07
       RELEASE SHIPL
       DEPART LOAD
       TERMINATE 1

       START 10

       END
```

Results of swc.lis

FACILITY	--AVG-UTIL-DURING-- TOTAL TIME	AVAIL TIME	UNAVL TIME	ENTRIES	AVERAGE TIME/XACT	CURRENT STATUS	PERCENT AVAIL	SEIZING XACT	PREEMPTING XACT
CRAFTT	0.212			10	0.540	AVAIL			
SHIPL	0.299			10	0.762	AVAIL			

STORAGE	--AVG-UTIL-DURING-- TOTAL TIME	ENTRIES	AVERAGE TIME/UNIT	CURRENT STATUS	PERCENT AVAIL	CAPACITY	AVERAGE CONTENTS	CURRENT CONTENTS	MAXIMUM CONTENTS
CRNT	0.782	25	2.395	AVAIL	100.0	3	2.347	3	3
CRFTL	0.848	12	3.603	AVAIL	100.0	2	1.695	2	2

QUEUE	MAXIMUM CONTENTS	AVERAGE CONTENTS	TOTAL ENTRIES	ZERO ENTRIES	AVERAGE TIME/UNIT	$AVERAGE TIME/UNIT	CURRENT CONTENTS
CRN	3	2.347	25	0	2.395	2.395	3
CRFT	12	6.060	22	0	7.025	7.025	12
CRTR	1	0.212	10	0	0.540	0.540	0
LOAD	1	0.299	10	0	0.762	0.762	0