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ABSTRACT

A ship overhaul is modeled as a dynamic production network with various policies applied to schedule the services needed from several shops. By treating the work hours required from the various shops for the activities as random variables, simulations are made to generate progress times in the overhaul with related probability distributions.

SIMULATION OF A SHIP OVERHAUL PROJECT NETWORK

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R. W. Shephard and K.-T. Mak

INTRODUCTION

A construction project can be modeled as a directed network structure, with nodes representing production activities and arcs indicating precedence for transfer of activity outputs as intermediate products. For example, in the case of a ship overhaul project, a repaired piece of machinery is an output of a repair activity to the activity of installing machinery. An equivalent network representation can be used which models arcs as activities and nodes as connections for transfer of intermediate products, with dummy arcs to show certain precedence relationships not otherwise indicated.

The individual activities utilize a variety of resources (inputs), some exogenous to the outputs of the activities of the network and others as transfers of intermediate product outputs from other activities. These resources are limited in time rate by labor supply, physical facilities, and work space limitations.

The production network for a construction project is a dynamic system because the output history of an activity (production unit) depends upon that of the predecessor activities involved in production leading to the intermediate products used. The transfers of intermediate products may be by continuous flow, discrete transfer, or mixtures of both. Since discrete transfer is most typical for a construction project, this kind of transfer will be used in the analysis to follow.

There are several reasons for simulating project networks. Since we are concerned with resource constrained networks, a production function (correspondence), defining maximal output in some way, requires an optimal assignment of system exogenous resources to individual activities as well as shared intermediate product transfers, and this assignment problem has not been solved dynamically for the discrete transfer case of a project network. Various policies of assigning resources may be compared by simulating the network under these policies. Such analyses may be carried out with the supposition that the service hours of various kinds of resources required for each producing activity are known. More realistically, these service hours are actually random variables for most construction projects. The time to carry out the project is an important random variable, the probability distribution of which cannot be calculated from those for the activities of the network, because of the complex convolutions involved in any large scale network. By repeated simulation of randomly selected values for the activities, with given policy of resource assignment, an approximate probability distribution for time to carry out a project can be estimated.

Related topics of interest are concerned with analyses of resource assignment policies and how the time to carry out a project depends upon levels of network exogenous resources.

Concerning hours of various services required, one would expect that, in the case where activity requirements are random variables, these summary random variables would be normally distributed, with mean and variance calculated from the same for the activities with the accuracy with which the latter are known.

For the reasons outlined above, simulations of a ship overhaul construction project were made. The results of this study are reported herewith.

1. THE OVERHAUL PRODUCTION NETWORK

1.1 Network Activities

The network describing a ship overhaul contains 399 production activities. They are classified as:

(i) Those requiring resources (Type 1)

(ii) Those not requiring resources and of fixed duration (Type 2)

(iii) Dummy activities for precedence relationships of an activity-on-arc representation of the network (Type 3).

For the network analyzed, an activity-on-arc network was used, requiring activities of Type 3. The number of activities of each type were:

Type 1	314
Type 2	33
Type 3	52

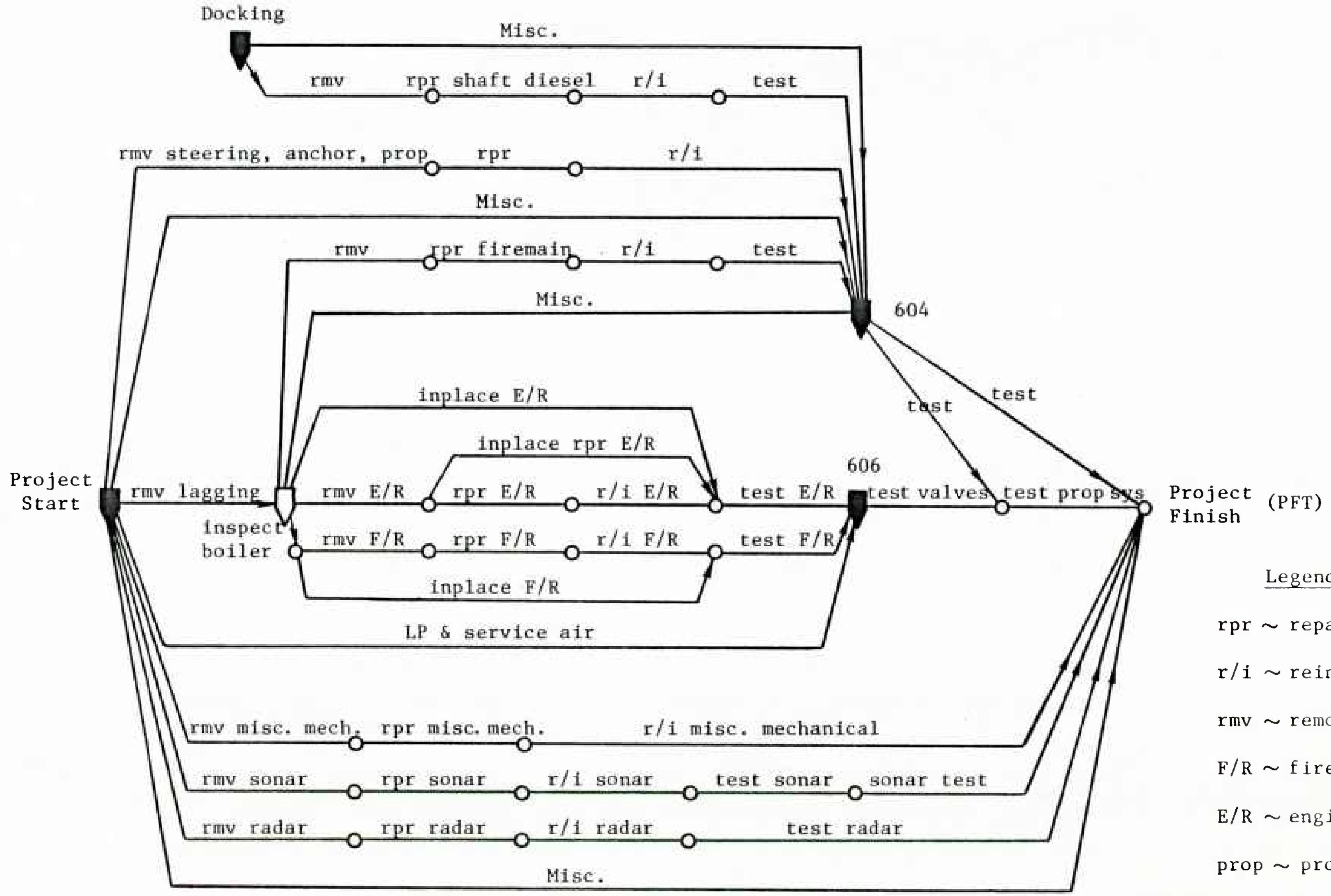
Activities of Type 2 were required to phase in various components of the production network. The average number of successors to an activity was 4.76, indicating substantial connectedness of activities in the overhaul network. An aggregated form of the network is displayed in Chart 1.

1.2 Resources

The services of twelve different shops are used to carry out a ship overhaul (several small shops were neglected):

Index	Shop No.	Service
1	11	Structural Repair
2	17	Structural Installation
3	26	Weld and Burn
4	31	Mechanical Shop-Shore
5	38	Mechanical Shop-Ship
6	41	Boiler
7	51	Electrical
8	56	Pipe Fitting
9	67	Electronic
10	64	Shipwright
11	71	Painting
12	72	Rigging

CHART 1



Legend:

rpr ~ repair

r/i ~ reinstall

rmv ~ remove

F/R ~ fire room

E/R ~ engine room

prop ~ propulsion

1.3 Activity Duration and Shop Manhour Requirements

An activity may contain a number of more elementary work packages (subpackages) or be itself a single work package. For each work package of the overhaul, a time duration for the work to be done is estimated. Also, the man (service) hours required from each shop is estimated. A work package is sometimes referred to as a Key-Operation or Key-Op.

Let

$$d_i \ , \ i = 1,2, \ldots, 399$$

denote estimated work durations required by the activities. In the case of the 52 Dummy Type 3 activities d_i is zero, and for the 33 Fixed Lag Type 2 activities d_i is a given time lag. Otherwise, the durations d_i are summaries for the work packages of an activity. In making these summaries, only durations of serially related packages are added, and the duration of the largest subpackage is used for parallel subpackages.

Let

$$H_{ij} \ , \ i = 1,2, \ldots, 399 \ , \ j = 1,2, \ldots, 12$$

denote the shop service hours required for the activities. These quantities are summaries over component work packages of activities. Clearly, the H_{ij} for Type 2 and Type 3 activities are zero.

The size of a ship overhaul construction project may be appreciated by adding the service hours over all activities for each shop, as illustrated in the following table.

j	Shop No.	$\sum_{i=1}^{399} H_{ij}$
1	11	10,700
2	17	11,100
3	26	18,300
4	31	34,500
5	38	40,900
6	41	18,500
7	51	24,300
8	56	47,300
9	67	22,400
10	64	5,100
11	71	24,000
12	72	4,300

Shops 31, 38 and 56 supply the largest estimated service (man) hours.

1.4 Linear Activity Analysis Model

The activities are taken to be worked with variable intensity, with input and output coefficients driven by intensity to determine the shop hours used and ultimate duration of work for the activity. See references [1], [2], [3].

Denote the work intensity per unit time for the i^{th} activity by

$$z_i \ , \ i = 1,2, \ldots, 399 \ .$$

Let a_{ij} denote the j^{th} shop hours per unit intensity required by the i^{th} activity. Then for an estimated duration d_i of the work by the i^{th} activity, the intensity variable must satisfy

$$d_i z_i a_{ij} = H_{ij} \qquad (j = 1,2, \ldots, 12) \ ,$$

implying

$$z_i a_{ij} = \frac{H_{ij}}{d_i} \qquad (j = 1,2, \ldots, 12) \ .$$

In order to set a scale for the intensity variable z_i, it will be taken to have unit value when the estimated duration d_i uses the shop hours H_{ij}. Thus one may define

$$a_{ij} = \frac{H_{ij}}{d_i} \qquad (j = 1,2, \ldots, 12) \ ; \ (i = 1,2, \ldots, 399)$$

as input coefficients for the i^{th} activity. Then a positive intensity $z_i^{(-)}$ less than one implies a duration D_i greater than d_i, since

$$D_i \cdot z^{(-)} \cdot \frac{H_{ij}}{d_i} = H_{ij}$$

implies

$$D_i = \frac{d_i}{z_i^{(-)}} > d_i ,$$

while an intensity $z_i^{(+)}$ greater than unity implies

$$D_i = \frac{d_i}{z_i^{(+)}} < d_i .$$

Within bounds which have to be specified, intensity of performing work is exchangeable for time to perform the work of an activity.

In a similar way, let c_i denote the fraction of activity output completed per unit intensity for the i^{th} activity. If the activity yields more than a single output, a fixed composition of such outputs is assumed and completion of activity output implies availability in these proportions.

In the case of activities of dummy Type 3, the input coefficients a_{ij} $(j = 1,2, \ldots, 12)$ are zero and the duration $d_i = 0$. For activities of fixed lag Type 2, a_{ij} $(j = 1,2, \ldots, 12)$ are also zero with fixed duration d_i . In this case, the output coefficient takes the value

$$c_i = \frac{1}{d_i} , \; i \in \text{Type 2}$$

with intensity z_i always taking unit value. Otherwise for Type 1 activities, the output coefficient c_i is

$$c_i = \frac{1}{d_i}\ , \quad i \in \text{Type } 1$$

with intensity z_i varying within bounds. For example, if $z_i = 2$,

$$D_i c_i \, 2 = 1$$

implies a duration D_i equal to $d_i/2$, etc.

An impression of the density and magnitude of positive input coefficients for Type 1 activities is obtainable from the following Table 1.

1.5 Bounds on Activity Intensities

In a practical case with data on work space and structure being worked on, minimal and maximal shop hours per unit time can be estimated directly for each activity, giving rise to constraints of the form

$$h_{ij}^{(-)} \leqq z_i a_{ij} \leqq h_{ij}^{(+)} \qquad \begin{array}{l} j = 1,2,\ \ldots,\ 12 \\ i \in \text{Type } 1, \end{array}$$

which imply

$$\frac{d_i h_{ij}^{(-)}}{H_{ij}} \leqq z_i \leqq \frac{d_i h_{ij}^{(+)}}{H_{ij}} \qquad j = 1,2,\ \ldots,\ 12\ ;\ i \in \text{Type } 1.$$

The lower and upper bounds on intensity z_i would be

$$ZL_i = \underset{j}{\text{Max}} \left(\frac{d_i h_{ij}^{(-)}}{H_{ij}} \right) \qquad i \in \text{Type } 1$$

$$ZU_i = \underset{j}{\text{Min}} \left(\frac{d_i h_{ij}^{(+)}}{H_{ij}} \right) \qquad i \in \text{Type } 1.$$

TABLE 1

DISTRIBUTION OF INPUT COEFFICIENTS

(hrs/day/unit intensity)

Index	Shop	No. $a_{ij} > 0$	No. $a_{ij} > 5$	No. $a_{ij} > 10$
1	11	148	19	8
2	17	115	15	8
3	26	186	28	14
4	31	133	41	25
5	38	212	112	67
6	41	26	16	14
7	51	224	56	26
8	56	196	76	46
9	67	94	32	15
10	64	76	8	2
11	71	156	21	16
12	72	52	5	3

However, for this study the data $h_{ij}^{(-)}$, $h_{ij}^{(+)}$ were not available, and bounds on the activity intensities had to be determined from suppositions.

Suppose a minimal application of skilled workers from each shop (a "crew") was set at 5 manhours/day and a week consisted of 5 days. Two factors seem to affect the smallest intensity for an activity: (1) the shop hours per unit intensity, and (2) the activity duration. By definition, a lead shop coefficient $\bar{a}_{ij^*}$ is defined by

$$\bar{a}_{ij^*} := \max_j \{a_{ij} : j = 1,2, \ldots, 12\} .$$

If $\bar{a}_{ij^*}$ is small, say $\bar{a}_{ij^*} \leqq 5$, it follows for one crew that

$$\bar{a}_{ij^*} z_i d_i = H_{ij} \quad \text{or} \quad z_i = \frac{H_{ij}/d_i}{\bar{a}_{ij^*}} = \frac{5}{\bar{a}_{ij^*}}$$

and

$$z_i = \frac{5}{\bar{a}_{ij^*}} \geqq 1 .$$

If $5 < \bar{a}_{ij^*} \leqq 25$, it follows that

$$0.2 \leqq \frac{5}{\bar{a}_{ij^*}} = z_i < 1 .$$

The intensity level 0.2 will be taken as an absolute lower bound for all values of $\bar{a}_{ij^*}$ exceeding 25. Thus we have as requirements for a lower bound to the intensity z_i of an activity that

$$ZL'_i = \begin{cases} 1 & \text{if } \bar{a}_{ij^*} \leqq 5 \\ \dfrac{5}{\bar{a}_i} & \text{if } 5 < \bar{a}_{ij^*} \leqq 25 \\ 0.2 & \text{if } \bar{a}_{ij^*} > 25 . \end{cases}$$

Next, concerning activity duration, it is assumed that 50% of the duration d_i of an activity is available for time substitution by varying intensity. Analogous to the lower bounds taken for activity intensities, in terms of activity duration the following bounds were used:

$$ZL''_i = \begin{cases} 1 & \text{if } .5d_i \leqq 5 \text{ (days)} \\ \dfrac{5}{.5d_i} & \text{if } 5 < .5d_i \leqq 25 \\ 0.2 & \text{if } .5d_i > 25 . \end{cases}$$

Then the actual lower bounds to activity intensities were taken as

$$ZL_i := \text{Max } (ZL'_i, ZL''_i) \text{ , Type 1 Activities.}$$

A uniform upper bound of 1.2 was taken for the activity intensities, i.e., a daily allocation of shop hours twenty percent greater than needed to complete work in the estimated time would not be exceeded. These upper bounds apply only to Type 1 activities.

In the case of fixed lag Type 2 and dummy Type 3 activities, there is no need to apply activity intensity bounds, since intensity is always one for Type 2 and no intensities are involved for Type 3 activities.

1.6 Limitations on Resources

Each resource used in a construction project has a time history of daily availability of service hours defined by the man and machines involved. In this case of ship overhaul, there were 12 shops providing service hours (see end of §1.3). Since this study is concerned with a single ship overhaul, and also for simplicity of calculation, the time histories were taken at constant level. In order to set a scale for limitation of daily resource capacity, the peak load of a resource used unrestrictedly was taken as 100% with capacity limitations expressed by a percentage less than 100.

The method of calculation was based on a greedy policy without limitation, as follows:

(i) A unit intensity for each activity, that is $z_i = 1$, $i \varepsilon$ Type 1 and Type 2, with $z_i = 0$ for Type 3, under no restriction on availability of shop daily hours, represents a free peaking of resources to carry out the overhaul according to estimate.

(ii) From (i), a shop service profile for each shop is obtained. The peak daily service rate for each shop profile was taken as shop capacity.

(iii) Operation of the network by simulation is then taken at various percentages of the shop capacities, expressed as a constant maximal daily rate history of shop service hours available.

The reason for taking various percentages of shop capacity is that a ship overhaul or other project may be one of several sharing common resources. Under these circumstances, it is important to know the delays in ship completion times caused by depression of peak loading.

Using the data of the ship overhaul project studied, shop peak load rates and average daily load for the profiles used to set shop capacities are displayed in Table 2.

Except in one shop (67), the peak daily service hours of the profiles were predominantly greater than twice the average daily service. Hence the shop profiles used to determine shop capacities were quite generous for the activity needs.

TABLE 2

SHOP PEAK LOAD SERVICE RATES

(man hrs/day)

(j)	Shop	Peak Daily Service	Average Daily Service	Ratio of Average to Peak
1	11	185	58	.31
2	17	134	60	.45
3	26	277	99	.36
4	31	528	186	.35
5	38	538	221	.41
6	41	357	100	.28
7	51	268	131	.49
8	56	480	250	.52
9	67	188	121	.64
10	64	109	28	.26
11	71	439	130	.30
12	72	75	23	.31

2. SCHEDULING POLICIES

2.1 Early Late Start (ELS)

The activities of the project network are ordered by late start times.[†] Priority for shop service hours decreases as late start times increase.

If all the predecessors of a first priority activity are completed and sufficient daily shop service hours are available from all shops, the activity is put into operation at unit intensity and will remain so until completed; otherwise the activity is operated at the largest intensity consistent with daily shop service hours available. If an increase in daily shop service hours occurs by reason of an activity completion, the resources made available by completed activities are used to augment activity intensities using less than unit value in order of earliest late start date, and then used to start new activities with completed predecessors in early late start order.

2.2 Modified Early Late Start (MODELS POLICY)

This heuristic scheduling scheme incorporates an early late start priority as a basis for allocating resources into a policy where the allocation is modified to provide some resources for all ready activities. The rules of this heuristic are as follows:

(i) Daily shop man hours committed to an activity will not be decreased until the activity is completed.

[†] A late start time for an activity is a time point where initiation of the activity beyond this point will prolong the time for the project, when all activities operate at unit intensity without resource restriction.

(ii) Only at the beginning of each work week (5 days) are activities added to the set of possible starters (if their predecessors were completed during the previous week) in order to avoid continuously revised project schedules within a week.

(iii) Shop daily service hours made available by activity completions within a week may be used to augment operating activities to unit intensity (if needed) according to early late start date priority.

(iv) Let D_t denote the set of ready activities not yet started. Let LS_i denote the late start time of activity A_i .

$$LS_* = \text{Min } \{LS_i \mid A_i \varepsilon D_t\} .$$

Partition D_t into subsets $B_1, B_2, \ldots$ by 20 day intervals, i.e.,

$$B_1 : = \{A_j \varepsilon D_t : (LS_j - LS_*) \leqq 20\}$$

$$B_2 : = \{A_j \varepsilon D_t \backslash B_1 : (LS_j - LS_*) \leqq 40\}$$

etc.

With t denoting the start of a week, start operation of the activities of B_1 at their lower intensity bounds (ZL_i , for $A_i \varepsilon B_1$) successively according to an early late start priority. If all activities of B_1 are so started, and daily shop service hours needed are still available, upgrade to unit intensity as much as possible the activities of B_1 by early late start priority.

Continue in the same way for the subsets $B_2, B_3, \ldots$. If there are daily shop service hours available after passing through all subsets, upgrade successively the activities to their upper intensity bounds by early late start priority.

(v) The early late start priorities are updated every 20 days by recomputation for the partial project network not completed.

One may argue the reasons for the foregoing scheduling heuristic as follows: since activities with earlier late start date should be started as early as possible and take precedence, they might also be operated more intensively than later start date activities. However, from another viewpoint, it appears that a policy of starting and operating simultaneously as many activities as possible would work toward project completion. The heuristic used is a compromise between these two viewpoints.

As a result of some experimental simulations of the ELS and MODELS policies for hypothetical variations on the service hours H_{ij} ($i = 1,2, \ldots, 399$, $j = 1,2, \ldots, 12$) required, it was observed that the project finishing time for MODELS policy was larger than that for the ELS policy, and this excess did not seem to be realistic. Further investigation showed that it occurred because of the simplification of a single intensity variable for each activity, exemplified by the following data from activity 6:

		Available Shop Time
input coeff.	$a_{6,2} = .97$	0
input coeff.	$a_{6,8} = 52.57$	200 hrs.

Here, for lack of less than one man-hour per day from the shop with index 2 (structural installation), hundreds of man-hours per day of shop with index 8 (pipe fitting) are left idle. The impact of this kind of anomaly on the ELS policy was less because of the freedom of more rapid upgrading of intensity to unit value. A modification of the linear activity network model was required for improvement of the MODELS POLICY.

3. MODIFICATION OF OVERHAUL PRODUCTION NETWORK

3.1 Lead Shops and Flexible Shops for Activity Inputs

For a Type 1 activity, the j^{th} shop is a lead shop for shop service hour inputs and designated by j^* if

$$a_{ij^*} = \text{Max}\ \{a_{ij} \mid j = 1,2, \ldots, 12\} .$$

A shop k is a flexible shop for shop service hour inputs to an activity if

$$a_{ij} > 0 \quad \text{and} \quad a_{ik} \leqq 0.1\ a_{ij^*} .$$

The implication of flexibility for a shop with respect to an activity is that the requirements for service hours are relatively small and may be satisfied by local rearrangements of work.

Since a single intensity variable is used for each activity, it is possible that a minor work task of a flexible shop may stall the bulk of the work to be done for an activity when shop hours for that task are not available. Hence in operating the MODELS policy, work progress of an activity is constrained only by non-flexible shops for that activity.

The distribution of lead shops and flexible shops, in the case simulated, is indicated by the following table.

The last column of this table represents the greedy peak daily rate of service hours with the shop serving as a non-flexible shop under no limit on availability of hours.

TABLE 3

DISTRIBUTION OF LEAD AND FLEXIBLE SHOPS

j Index	Shop No.	No. of activities with j as lead shop	No. of activities with j as flexible shop	Average lead shop coefficient	Average flexible shop coefficient	Peak daily rate for nonflexible shop
1	11	11	72	9.99	1.09	169.8
2	17	9	75	19.66	.78	118.2
3	26	12	94	10.05	.78	252.3
4	31	30	61	16.31	.82	515.0
5	38	99	43	15.32	.65	530.6
6	41	14	6	55.74	1.16	353.7
7	51	33	64	11.51	1.17	245.6
8	56	50	49	20.41	1.37	466.5
9	67	35	41	11.56	.62	179.7
10	64	6	53	15.68	.58	96.4
11	71	15	97	27.36	.84	388.7
12	72	0	34	0	1.52	63.0

3.2 Modification in Use of MODELS POLICY

Only shop hours required by an activity for non-flexible input are entered as a demand against shop daily capacity for service hours. It is assumed that flexible demands for shop hours can be filled in by local rearrangement of work.

Shop capacity is taken as a stated fraction of the peak daily rate of non-flexible service hours for unconstrained shop hours as stated in the last column of the table in §3.1. This determination of peak load might be smaller than that for the ELS policy because of exclusion of flexible shops.

4. SIMULATIONS

4.1 Comparison of Scheduling Policies

For the overhaul production network, three time points seemed to be of main interest:

(1) PROJECT FINISHING TIME (PFT)

(2) READY FOR ENGINE ROOM TESTS (606)

At this location in the overhaul network, more than 90% of the work to be done (in man hour terms) has been completed, with mainly testing work remains to be performed.

(3) UNDOCKING (604)

The time when a ship may be undocked is an important consideration for use of limited docking facilities in a shipyard.

See Chart 1 for location of these three milestones.

Simulations were carried out for 5 different realizations of work to be done by the activities of Type 1 as represented by the following uniform scalings of the vector $(H_{i1}, H_{i2}, \ldots, H_{i,12})$.

(a) $w_i = 0.8$ uniformly only 80% of shop hours needed

(b) $w_i = 0.9$ uniformly only 90% of shop hours needed

(c) $w_i = 1.0$ uniformly 100% of shop hours needed

(d) $w_i = 1.1$ uniformly 110% of shop hours needed

(e) $w_i = 1.2$ uniformly 120% of shop hours needed.

Simulations were carried out for each of these five cases under 60% of peak capacity as daily availability of shop service hours, using ELS and MODELS scheduling policies. The results are shown in Table 4.

TABLE 4

SCALED COMPARISON OF SCHEDULING POLICIES

60% Capacity		w_i = .8	w_i = .9	w_i = 1.0	w_i = 1.1	w_i = 1.2
PFT	MODELS	238 days	273 days	280 days	321 days	337 days
	ELS	219	247	273	279	312
606	MODELS	171	171	187	205	233
	ELS	161	186	186	201	221
604	MODELS	162	173	190	201	223
	ELS	147	174	175	198	205

In most cases, the ELS scheduling policy appears to be better than the MODELS policy. However, a more conclusive comparison can be obtained by random samples of work content rather than uniformly scaled versions of original estimates. For this purpose, twenty randomly chosen realizations of the scaling factors w_i for Type 1 activities were used for simulated scheduling under shop capacities of 50, 55, 60, 65, 70, 75, 80 percent of peak load. The results of these simulations are summarized by cumulative distributions

$$F_{PFT}(t) = \frac{1}{20}\{\text{No. of simulation runs with PFT} \leqq t\}$$

$$F_{606}(t) = \frac{1}{20}\{\text{No. of simulation runs with occurrence time of 606} \leqq t\}$$

$$F_{604}(t) = \frac{1}{20}\{\text{No. of simulation runs with occurrence time of 604} \leqq t\} .$$

Examples of the cumulative distributions F_{PFT} , F_{606} , F_{604} for ELS and MODELS scheduling policies are shown in charts 2, 3, 4, 5, 6, 7. In each chart two distributions are plotted, namely for shop capacities of .6 and .8. Note that the reduction in shop capacity strongly impacts the distribution of event occurrence.

These curves give an indication of the relative frequency of reaching the milestones PFT , 606 , 604 by various elapsed time of work on the overhaul project. With more data on shop requirements and durations of work, one can obtain a good estimate of these probability distributions from 100 simulations, which are easily obtained. Also, differences between the two policies can be observed.

Another way of summarizing the foregoing simulations would be to plot for each milestone the average number of days taken to attain the

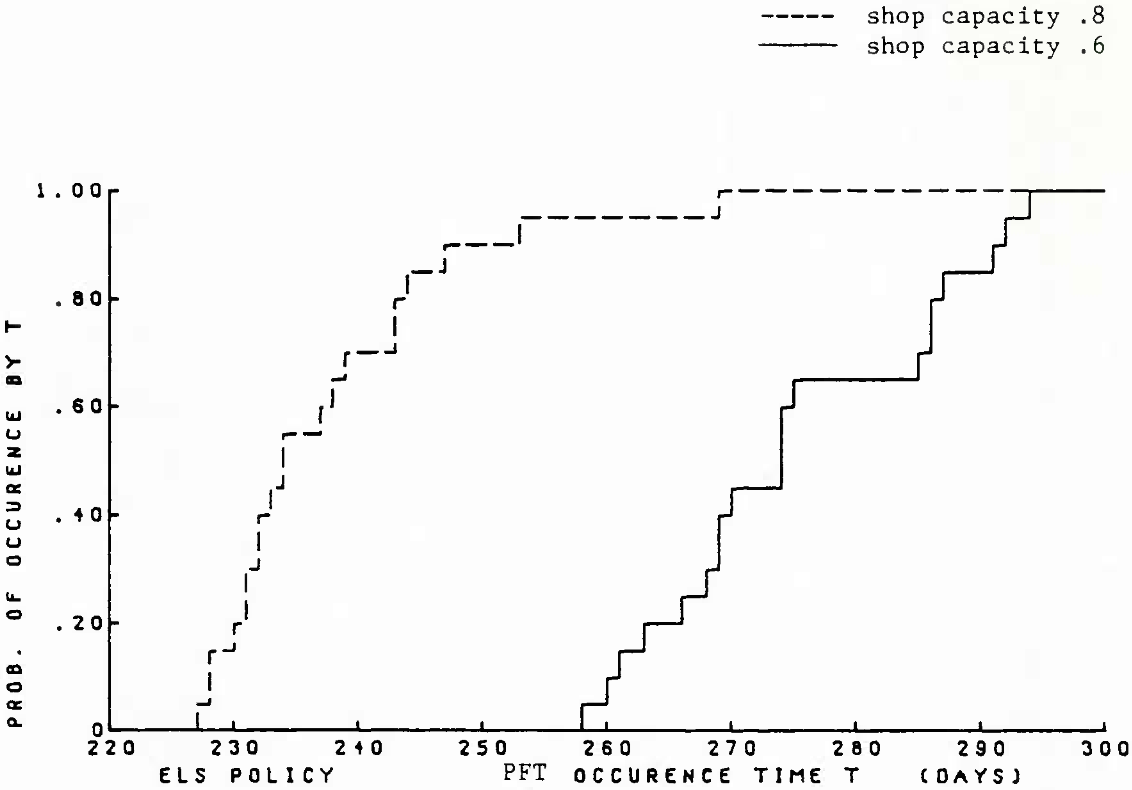


CHART 2: Cumulative Distribution - PFT - ELS Policy

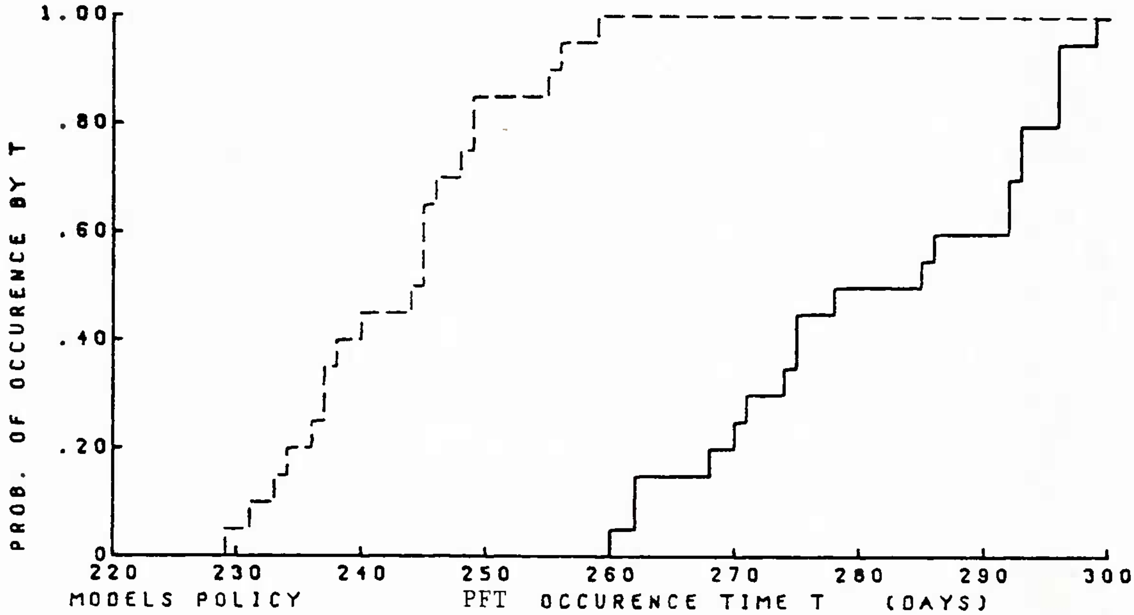


CHART 3: Cumulative Distribution - PFT - MODELS Policy

----- shop capacity .8
——— shop capacity .6

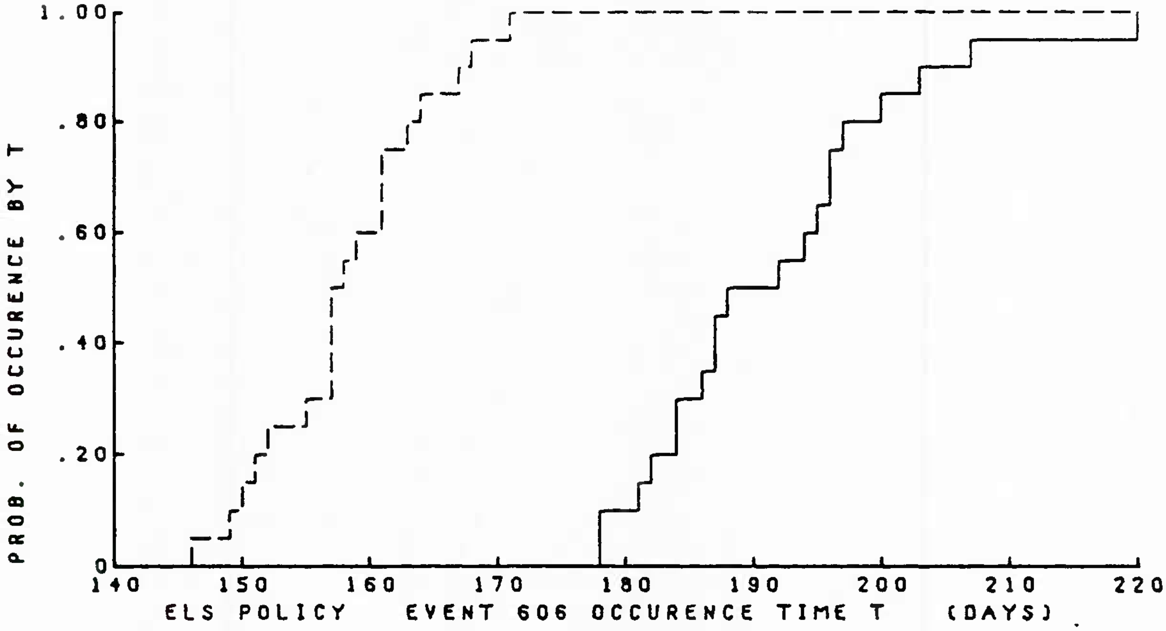


CHART 4: Cumulative Distribution - Event 606 - ELS Policy

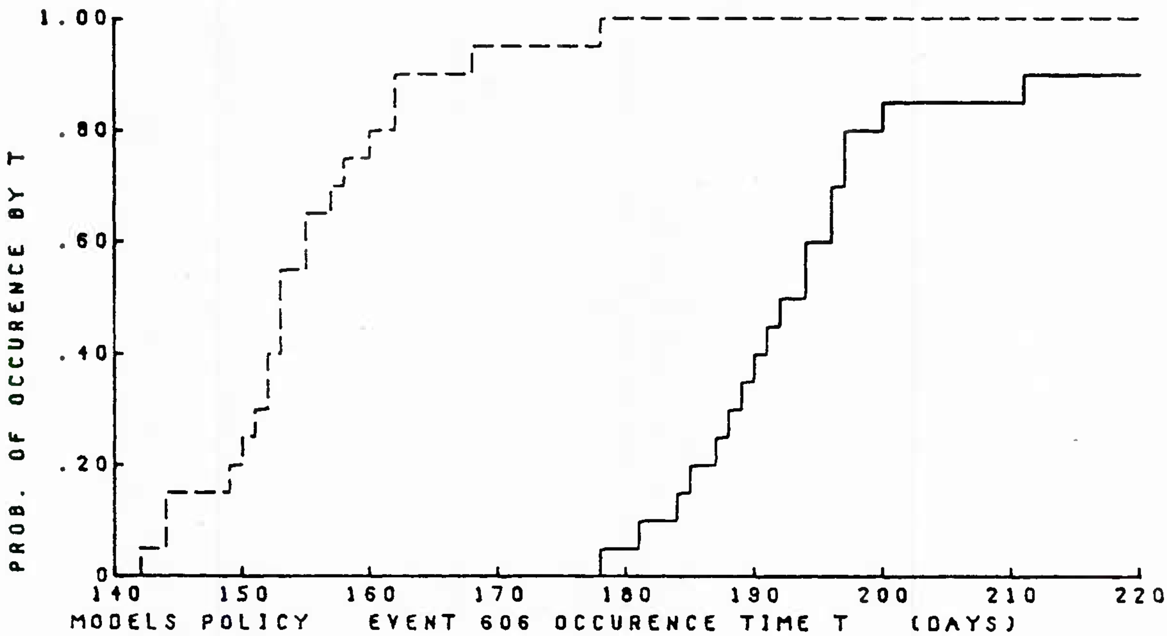


CHART 5: Cumulative Distribution - Event 606 - MODELS Policy

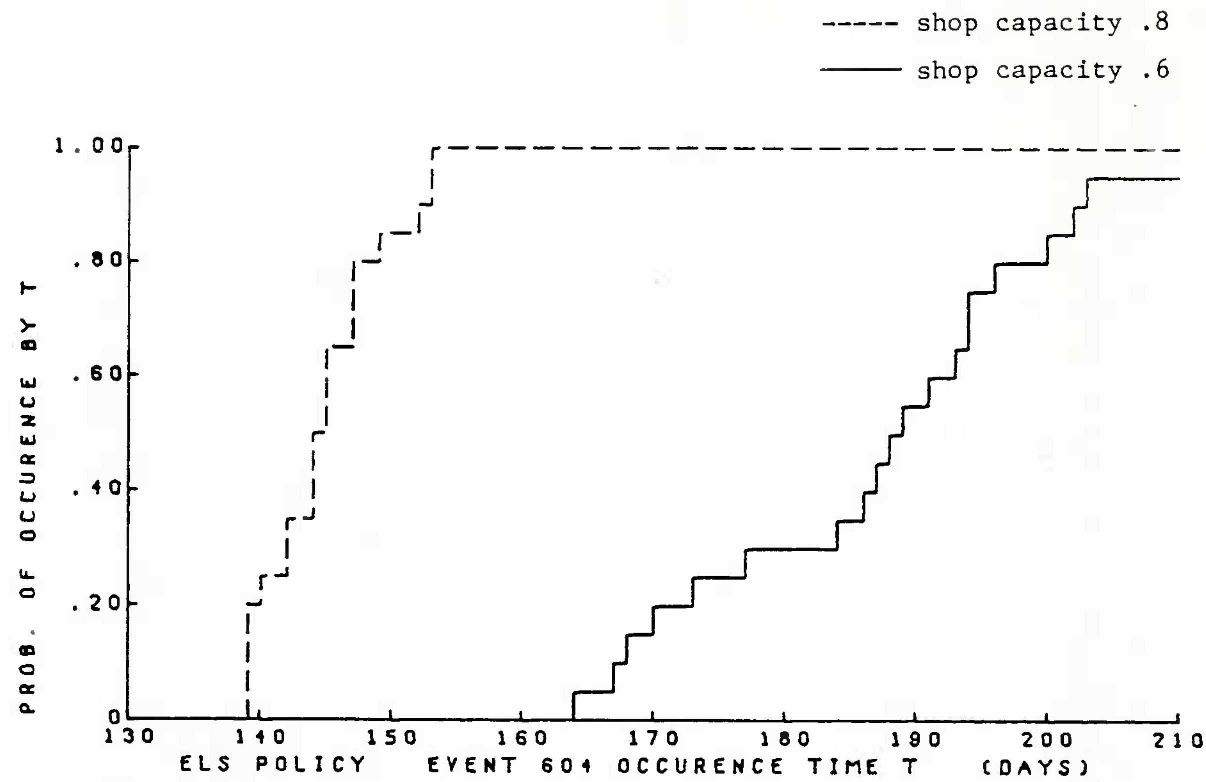


CHART 6: Cumulative Distribution - Event 604 - ELS Policy

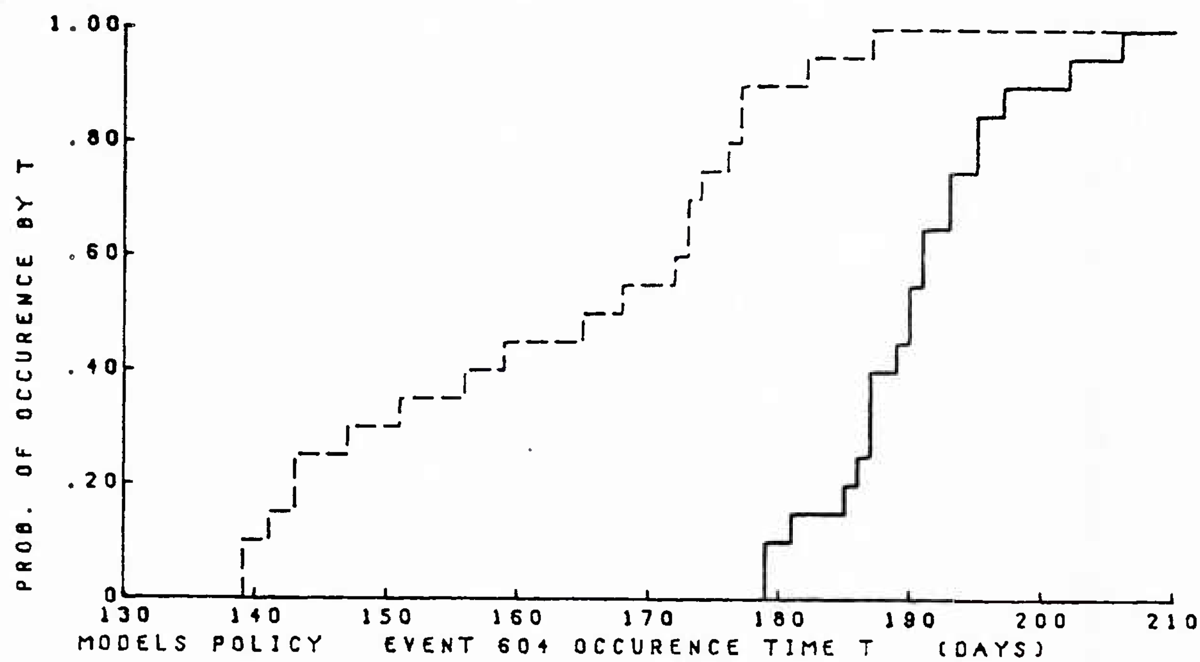


CHART 7: Cumulative Distribution - Event 604 - MODELS Policy

milestone for each of the seven capacities as percentages of peak load, with the two policies plotted on the same graph. See charts 8, 9, and 10. Here the effect of shop capacity change is clearly observable.

Chart 8

Effect of Shop Capacity Change - PFT

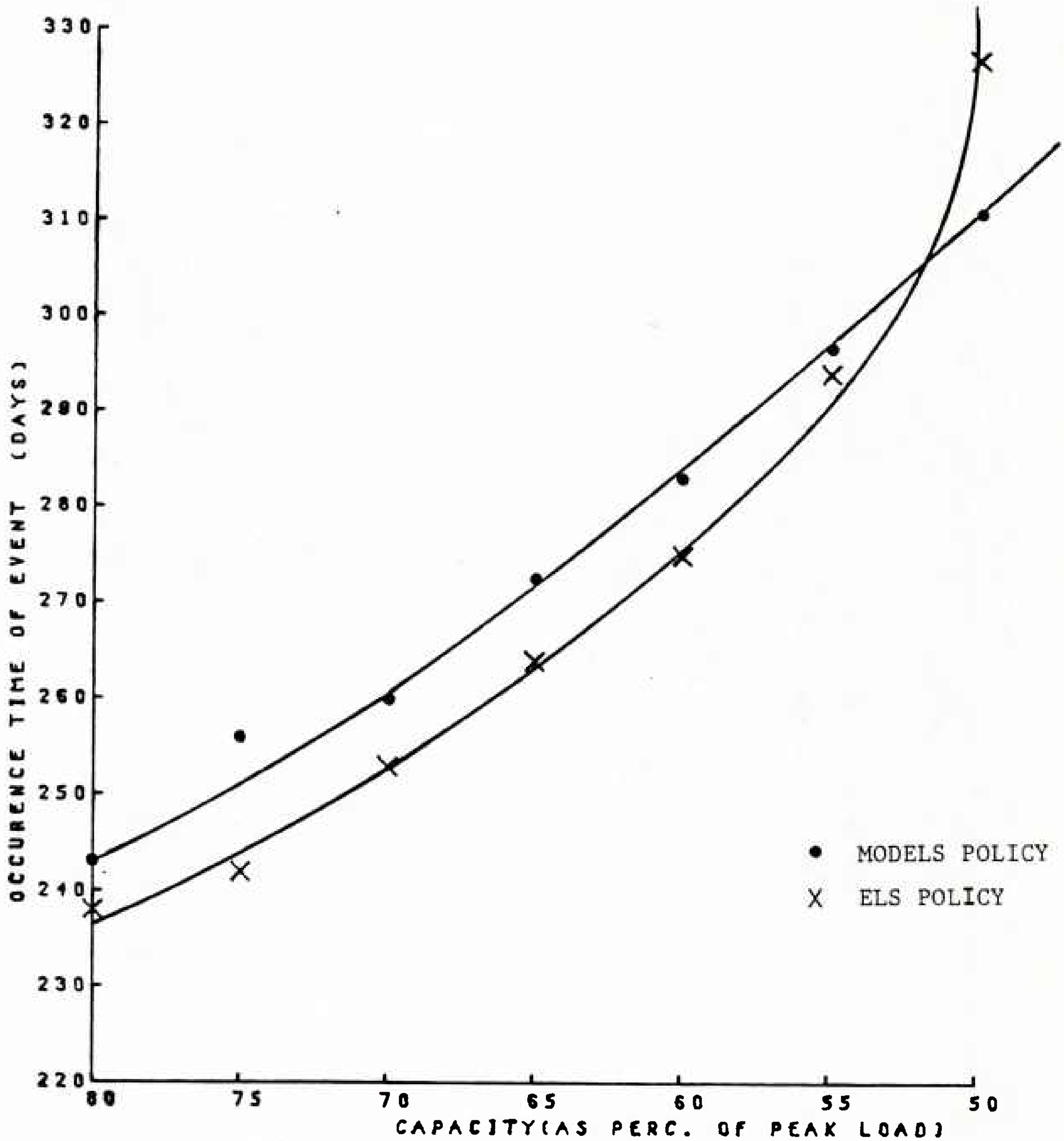


Chart 9

Effect of Shop Capacity Change - Event 606

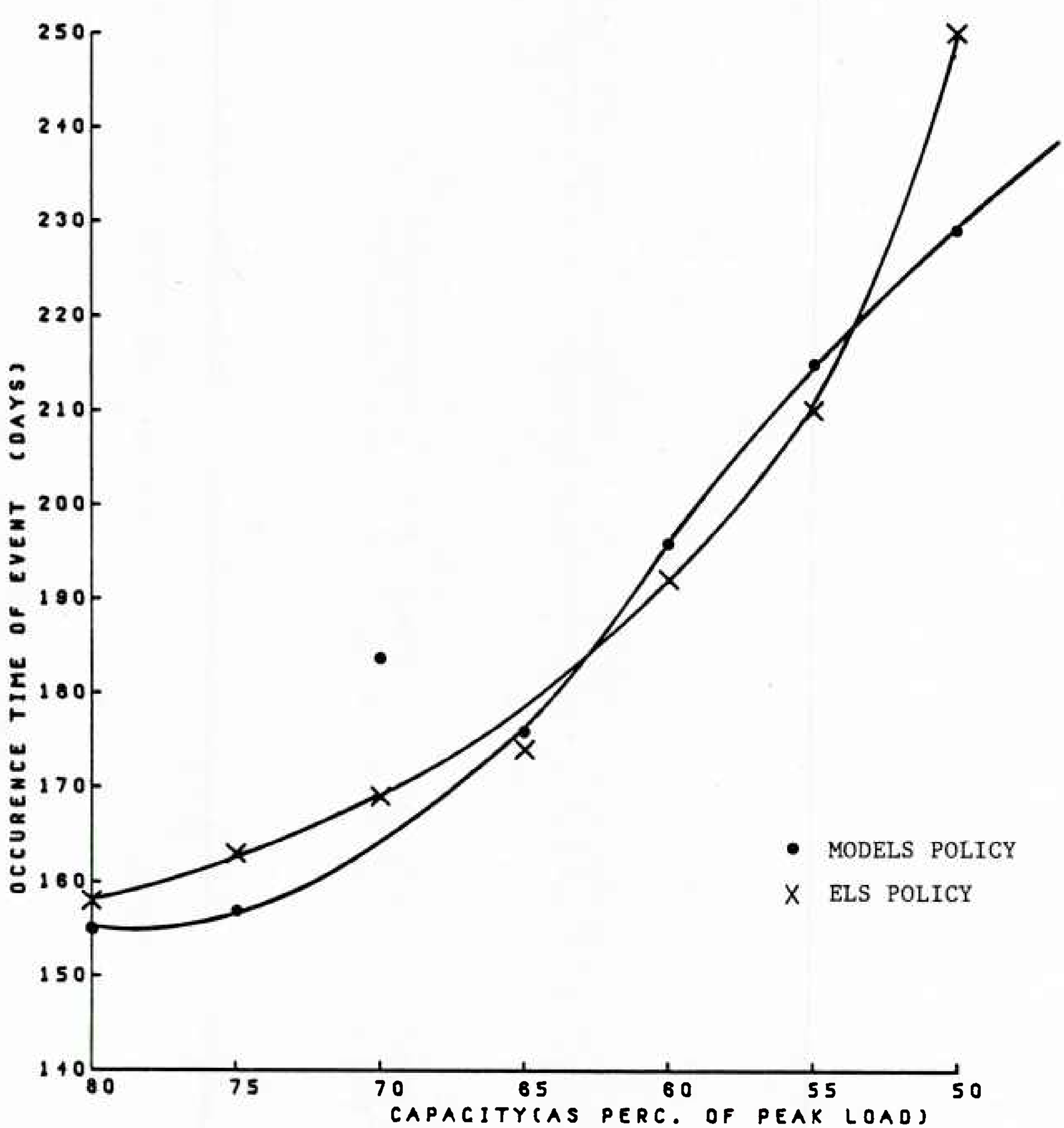
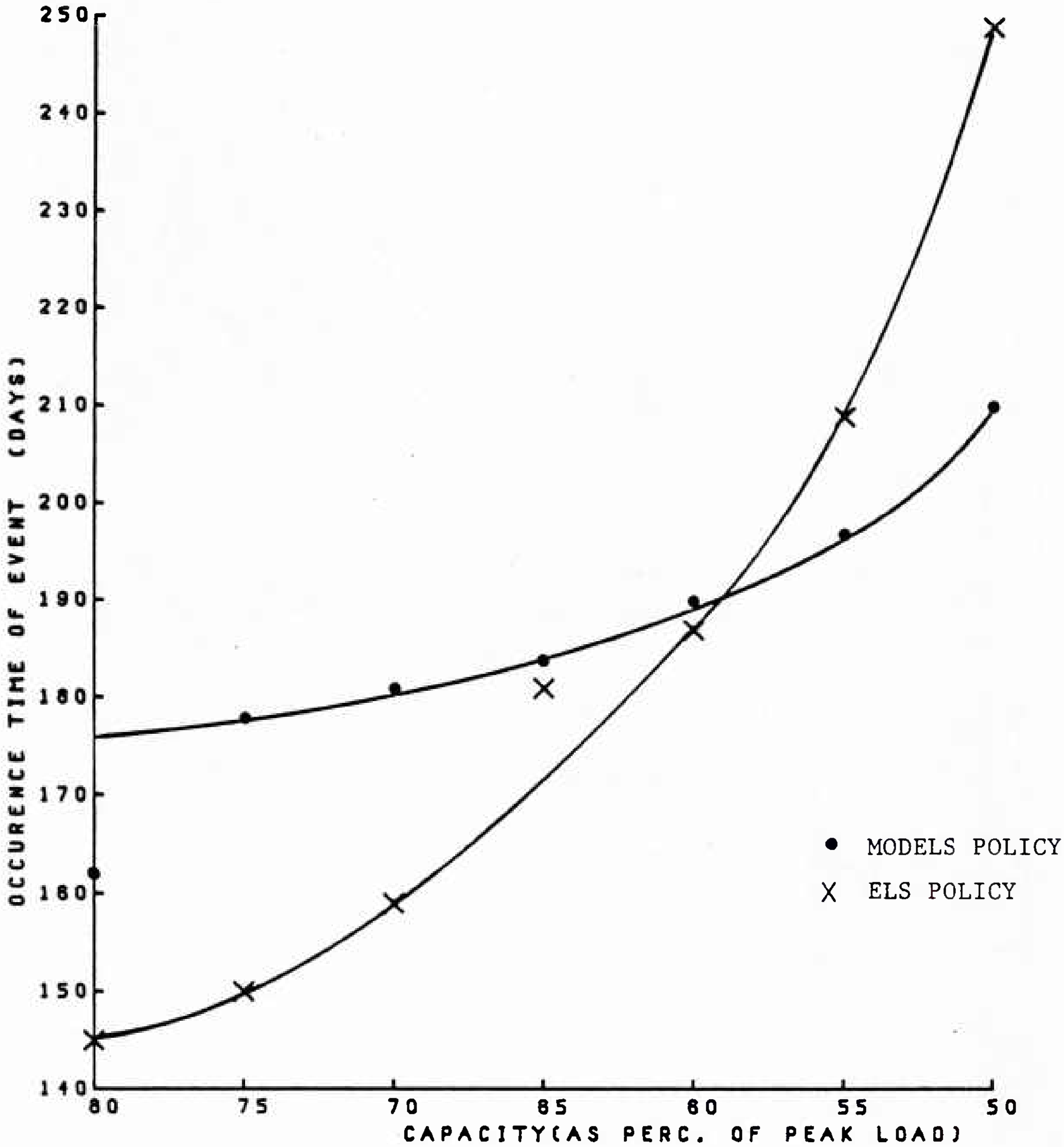


Chart 10

Effect of Shop Capacity Change - Event 604



5. SUMMARY

Several topics emerge from this experimental study:

First, the computer modeled scheduling of shop man hours to the various Type 1 activities merits further study. The two policies used show differences with respect to the three milestones, indicating that scheduling needs to take into account the location of work relative to the milestone being reached. The activities leading to undocking (604) are largely parallel to those leading to "ready engine room for tests" (606), and the activities following these two milestones are largely tests, which involve quite different work packages. Also, the statistical variation of these packages is likely to be quite different in comparison to the other activities of production.

Second, the apparent stability of the simulation results indicates that with a larger number of simulations (easily obtained), one may estimate probability distributions for time to reach each of the three milestones for any given shop capacities available, subject to the scheduling policy used.

Third, the impact of shop capacity limitation upon time to reach the three milestones is quite pronounced, indicating that this input should be handled nonuniformly, depending upon activity involved in comparison to other demands in the shipyard. The analysis was made by not allowing increases or decreases over time of the fraction of daily shop man hours available to the overhaul project. Modification of the scheduling policy is required to allow this variability in work conditions.

The random variations of shop hours to serve the activities were largely hypothetical in this study. For practical purposes it will be important to distinguish these statistical properties according to the kind of activity being served. At the very least, testing activities should be so distinguished and a serious attempt made to determine the ranges of variation of service times. Conservatively, one may use uniform distributions to characterize the statistical distributions, if ranges of variation are well determined.

Fourth, the analysis was made by preallocating shop capacities available for the project. In a yard with several projects, the pre-allocations to projects can be made by aggregate planning as described in OR Center Report 82-2.

REFERENCES

[1] Shephard, Ronald W. et al., QUANTITATIVE WIRTSCHAFTSFORSCHUNG FESTSCHREFT VOLUME, Wilhelm Krelle Zum 60 Gebertstag, edited by Horst Albach, Ernst Helmstädter, Rudolf Henn, J. B. C. Mohr, Tubingen, (1977).

[2] Leachman, R. C., "Aspects of Dynamic Production Planning," ORC 79-8, Operations Research Center, University of California, Berkeley, (July 1979).

[3] Shephard, Ronald W., "Dynamic Production Networks," ORC 81-7, Operations Research Center, University of California, Berkeley, (April 1981).