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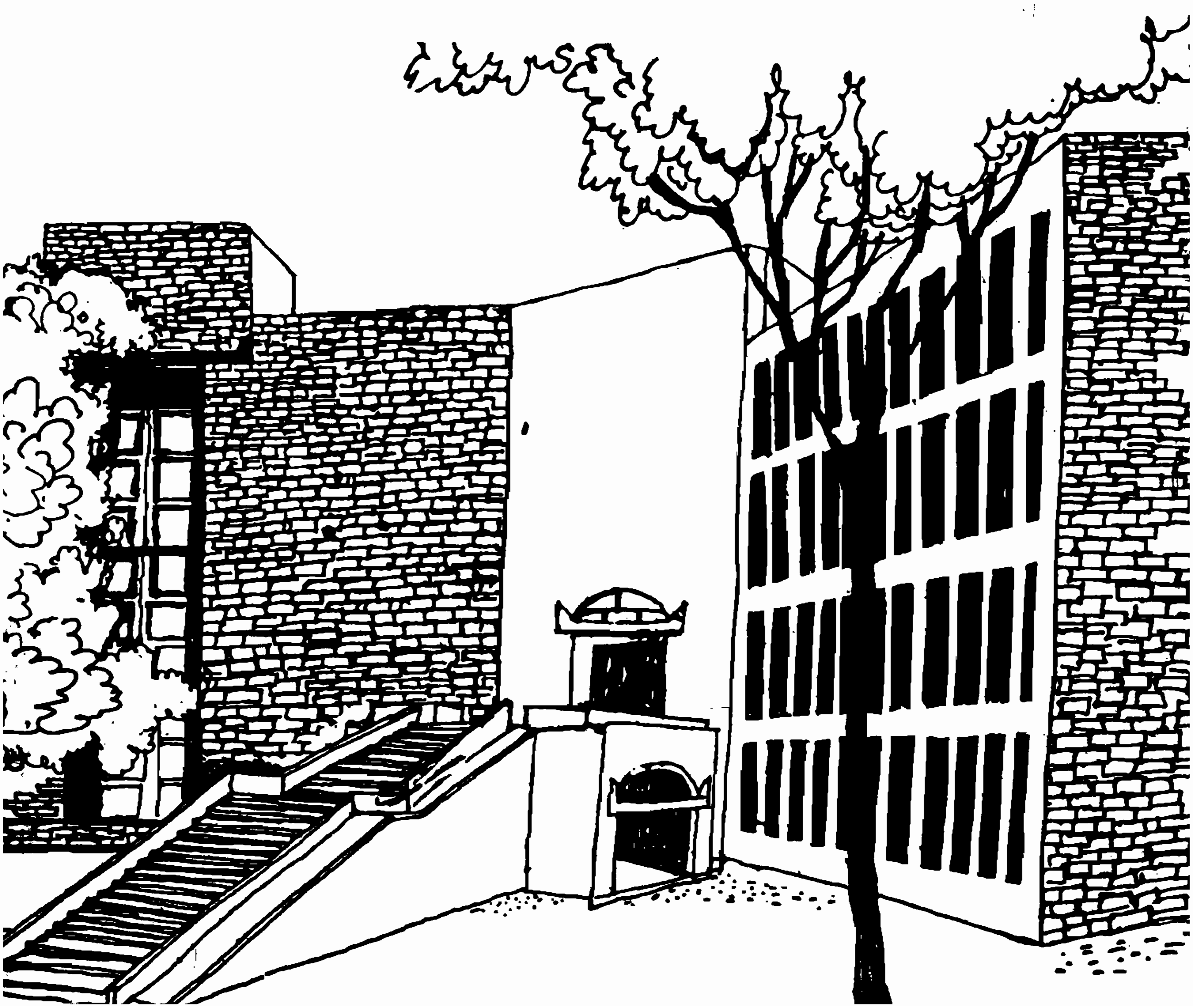

AVAILABILITY AND WORK TARGETS OF BULLDOZERS

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Availability and Work Targets of Bulldozers

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Abstract

Setting work targets for machines is an important task for engineering managers, especially where they operate large fleets with machines of different makes and ages. Setting uniform work targets is easier but it does not take into account operating characteristics of machines which could differ with make and change with age. It is suggested here that using analysis of availability of machines can provide an alternate basis to set work targets. Availability analysis of bulldozers is reported here which suggests the feasibility of achieving higher work targets compared to the present 1000 hours per season.

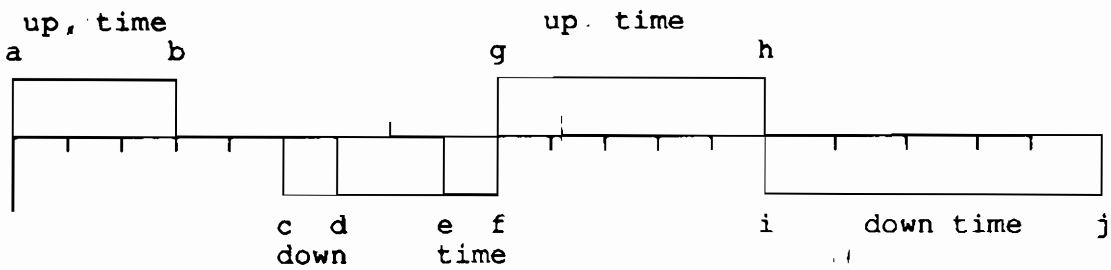
Introduction

A public corporation, undertaking soil and water conservation works, operates a large fleet of over 90 bulldozers and a few large tractors. Bulldozers to which this study relates, were of three makes--BEML, Komatsu and Caterpiller. Presently each machine is expected to log 1000 hours of work in a full season which consists of 189 days or 1890 hours of 10 hour work days. Logging larger work hours will result in better utilization of the fleet and increased incomes. It may also permit appropriate changes in pricing. Setting realistic work targets for the fleet is therefore an important task for engineering managers. Presently the target for each machine is set uniformally at 1000 hours per season. While the present approach has the merit of being simple, it is more an exercise in goal setting, ignoring the age and make of the machines, their breakdown patterns and efficiency with which breakdowns are attended to. There is therefore a need to have an alternate basis that takes these into account.

Availability analysis appears to be of relevance in this regard. Availability is defined as the probability that a machine or a system is operating satisfactorily (or is up) at any point in time given that it was up to start with. It is one of several possible indices that is usually used to measure the performance of a system or machine. It promises to yield another basis for setting targets of work, which could be used either as an alternate or supplementary to the present method.

Fig (1) shows a definitional diagram to illustrate availability and related terms [Kapoor and Lamberson(1)]. As the season begins, bulldozers are transported to the site and work starts. Work is stopped when a break-down occurs. Depending on its nature it could be set right, by the field staff or it may be necessary to call in a mechanic from headquarters. If the breakdown is more serious, it may even be necessary to transport the bulldozer to the workshop. Latter situation would require requisitioning a trailer for transport. The span of time (ab or gh) in which machine is working is called up-time or operating time. The duration for which machine is not available is called down-time (cf or ij). Down-time will include active repair time (de) and the time spent in arranging for repairs, logistics etc (cd and ef).

Fig. 1 Definition Diagram



$$\text{Availability} = \frac{\text{up time}}{\text{up time} + \text{down-time}}$$

Method

A sample of each of the three makes of bulldozers was selected.

(a) First, the up-time and down-time patterns of this sample of bulldozers were studied. Statistical distributions underlying these were developed.

(b) Possibility of getting an analytic expression of availability was explored. As it proved difficult, simulation was resorted to.

(c) Simulated results were used to analyse availability.

(d) Work targets based on availability were determined.

Sample

A sample of eight bulldozers was selected from among 64 operated by one of the divisions of the corporation. The sample consisted of two BEML, four Komatsu (Kom) and two Caterpiller (Cat) machines. Table (1)-column 2-shows the hours of work logged till 1990 by each of these machines. We shall refer to this as work-age of machines. Chronological age of BEML machines was 9 years each, of Komatsus 19 years each and of Caterpillers 28 years each.

Long spans of consecutive log book data were used to develop down-time and up-time distribution. In case of two BEML machines 9 year data was used. In case of Kom-1 6 years, Kom-2 9 years, Kom-3 9 years, Kom-4 10 years, Cat-1 10 years and Cat-2 9 years data were used.

Analysis

Down-time and Up-time Distributions

Frequency diagrams of down-time data of all the eight machines were plotted. These broadly appeared similar. Visual inspection suggested the possibility of gamma distribution being the underlying pattern. There could be other candidates and indeed some were tried. But the fact the bulldozers are mechanical systems--with components subject to wear, tear and fatigue --added to the preference for gamma. Gamma was found to be a good fit in all cases except one (Komatsu-3). The down-time data of two BEML machines, when individually analysed did not fit gamma. But when pooled, it did fit gamma. Pooling was justified in view of the fact that both machines are virtually of equal work age. Lognormal was found to be a good fit for up-time for all machines.

Table (1) : Down-time pattern

Machine	Work age (hrs)	Down-time distribution	Mean (days)	SD (days)
BEML-1	9410	G (0.27 , 7.19)	1.94	3.74
BEML-2	9665			
Kom-1	10933	G (0.28 , 4.88)	1.37	2.58
Kom-2	12837	G (0.40 , 6.17)	2.47	3.90
Kom-3	14421	no fit	2.60	5.01
Kom-4	14740	G (0.32 , 8.05)	2.58	4.55
Cat-1	16773	G (0.24 ,29.85)	7.16	14.62
Cat-2	17521	G (0.26 ,37.59)	9.77	19.17

Note : G (a,b), Gamma with parameters 'a' & 'b'
Test : Kolmogorov-Smirnov
Fit significant at 5% level

Table (2) : Up-time pattern

Machine	Work age (hrs)	Up-time distribution
BEML-1	9410	LN (28.09 ,30.59)
BEML-2	9665	LN (32.58 ,47.72)
Kom-1	10933	LN (36.33 ,64.76)
Kom-2	12837	LN (27.06 ,49.08)
Kom-3	14421	LN (26.95 ,44.54)
Kom-4	14740	LN (35.36 ,52.76)
Cat-1	16773	LN (25.50 ,51.86)
Cat-2	17521	LN (31.03 ,50.89)

Note : LN (a,b), Lognormal with mean 'a' days & standard deviation 'b' days.
Test : Chi-square
Fit significant at 5% level

Figs (2) and (3) show the down-time and up-time distribution for Caterpiller-1 as illustration. **Tables (1) and (2)** show some statistical features of down-time and up-time distributions. It is seen that mean down-time bears some relationship to age of machines. Caterpillers, the oldest machines have the highest mean down-time. Among the Komatsus, the older ones show a slightly higher mean down-time.

Fig. 2 Down-Time Distribution (Cat-1)

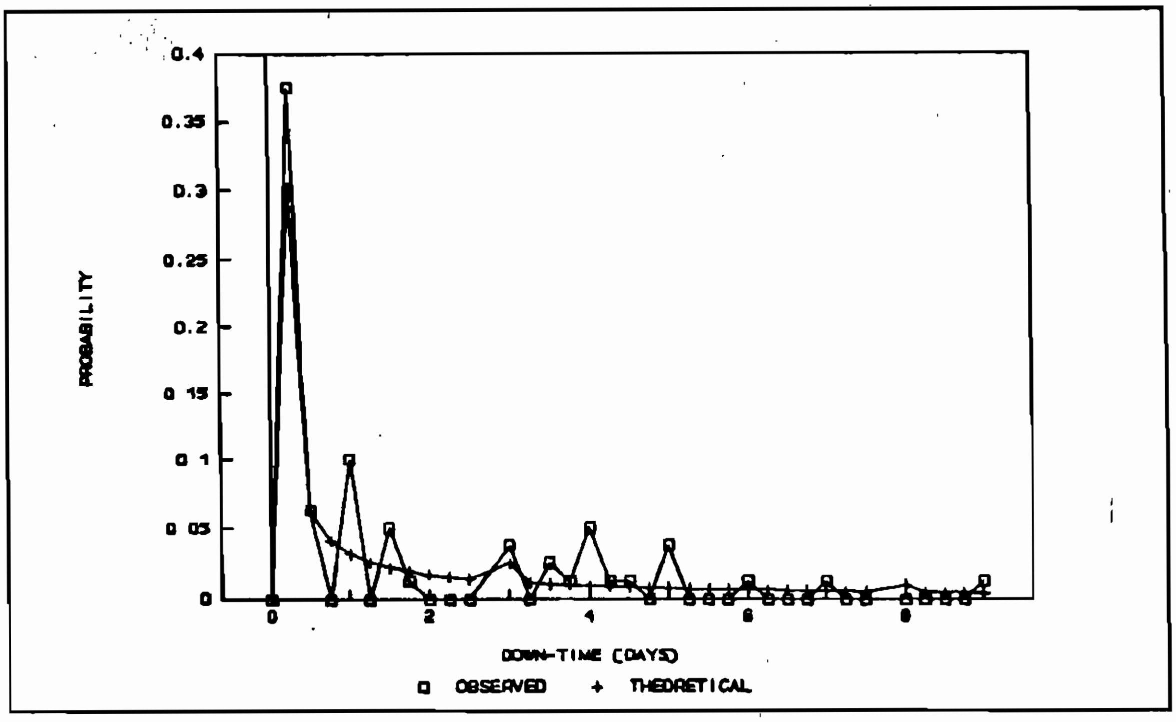
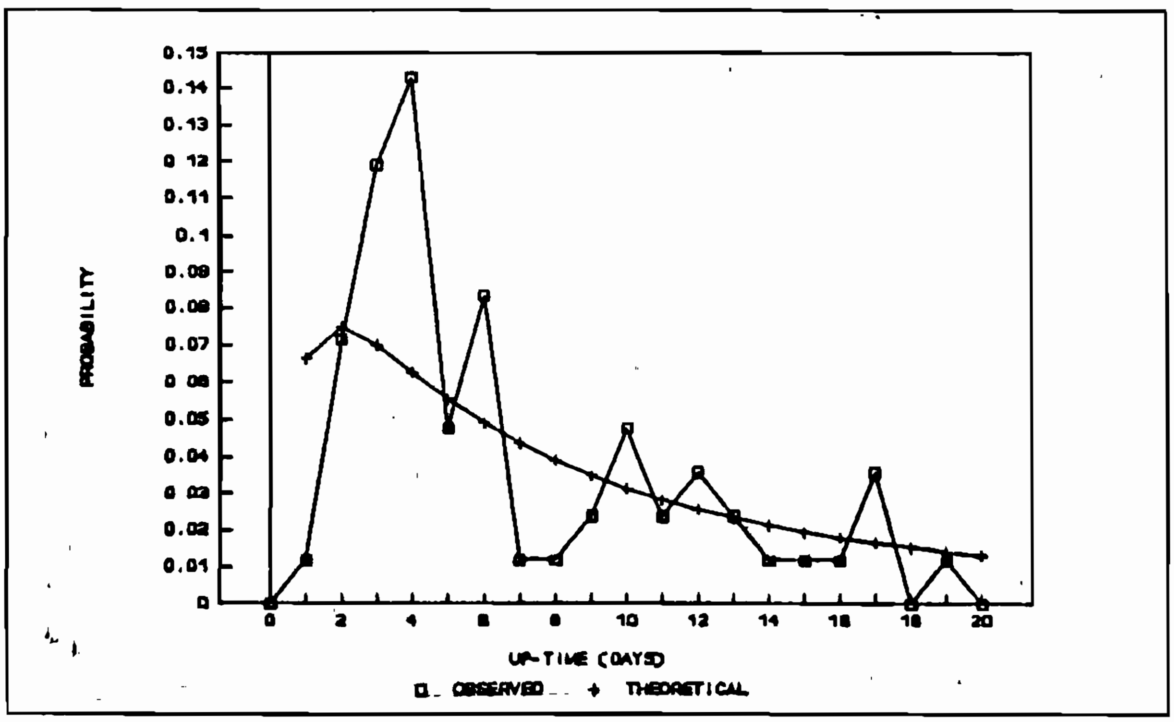


Fig. 3 Up-Time Distribution (Cat-1)



Alternating Renewal Process - Availability

All machines are up at the beginning of the season. Work is started. In due course breakdowns occur. A machine remains down until repairs are completed and machine returned to field. The two states--up and down - alternate. Accordingly, an alternating renewal process is generated. As stated earlier, availability is the probability of machine being up at any time, given that it was up to start with.

Let

t	time
u	up-time, lognormal variate
d	down-time, gamma variate
$E(u)$	expected value of up-time
$E(d)$	expected value of down-time
$A(t)$	availability at time t
$A^*(s)$	Laplace-Stieltjes transform of $A(t)$
$F_u(t)$	distribution function of time to breakdown (same as up-time)
$f_u^*(s)$	Laplace-Stieltjes transform of $F_u(t)$
$G_d(t)$	down-time distribution
$g_d^*(s)$	Laplace-Stieltjes transform of down time distribution

An important theorem of renewal process [Medhi (2)] states that

$$A*(s)=\frac{1-f_u^*(s)}{s\left[1-f_u^*(s)g_d^*(s)\right]} \quad .....(1)$$

When the distribution functions $F_u(t)$ and $G_d(t)$ are such as can be easily transformed - for instance, negative exponential, gamma etc. - one can invert (1) and obtain closed-form expression for $A(t)$. But when this is not the case - as at present with lognormal being the difficult one - closed-form expression is difficult to obtain. However, it turns out that steady state value of $A(t)$ is easily obtained without the inversion of (1).

Using final value theorem,

$$\lim_{t \to \infty} A(t) = \lim_{S \to 0} S\,A(s)$$

$$\lim_{s \to 0} S\,A(s) = \lim_{s \to 0} \frac{1-f_u^*(s)}{1-f_u^*(s)\,g_d^*(s)}$$

If E(u) and E(d) exist and are finite,

$$A(\infty) = \frac{E(u)}{E(d) + E(u)} \quad \text{......... (2)}$$

Table (3) shows the steady state values of availability of sample machines using (2). It is seen that the availability of Caterpiller is markedly less than those of others. Again, this is because these machines are older, breakdown more frequently and remain in that state longer.

Availability - Simulated

Steady state values of availability can be used as reference for long term fleet use. It would be useful however to investigate how long does it take to reach steady state. In absence of closed-form expression of availability, we shall make use of simulation to get an approximate idea of this.

Table (3) : Availability - Steady State Values

Machine	Work age (hrs)	A (∞)
BEML-1	9410	0.93
BEML-2	9665	0.95
Kom-1	10933	0.93
Kom-2	12837	0.91
Kom-3	14421	0.91
Kom-4	14740	0.93
Cat-1	16773	0.78
Cat-2	17521	0.76

Given the distributions of up-time and down-time, it is possible to generate the renewal process using synthetic values. If a long enough sequence is generated, and availability computed at suitable epochs (instants of time), one can observe when the magnitude begins to settle down. This will be illustrated for one machine of each make--BEML 1, Komatsu 4, and Caterpiller 1. A string of some 700 random observations of time to breakdown and down-time were generated by computer, using their respective distributions.

The alternating renewal process was simulated by picking the up-time and down-time observations alternatively from the sequences. Computations of availability were made at the end of each cycle.

Figs (4), (5) and (6) show the computed value of availability as time advances for BEML-1, Komatsu-4 and Caterpiller-1. As expected, in all three cases, A(t) does tend to approach a value close to the steady state values computed earlier. Transient phase appears to last well over 600 days for

BEML, over 900 days for Komatsu and over 800 days for Caterpiller. This will imply that to use steady state value of availability as a reference, three to five seasons, would be a suitable span.

This also means that steady state is unlikely to be reached in a normal work season of 189 days. Further examination of availability in a normal season of finite length is desirable.

Availability in Season of Finite Length

In order to examine availability in a season of a finite length, 189 days in particular, we constructed a large number of synthetic seasons. This was done by truncating the (simulated) alternating renewal process exactly at 189 days from start. Nearly a hundred seasons were constructed for each of the three machines. Overall availability (operating time/length of season) was computed for each of these. This may be termed season-end availability. For example, **Fig (7)** shows the frequency diagram of season-end availability values for Caterpiller-1 obtained through simulation. Others were broadly similar. **Table (4)** shows some summary features of the simulated seasons.

Table (4): Season End Availability - Simulated

Machine	Work age	Number of seasons simulated	Season-end availability			Mean number of break downs per season	Mean down time	Mean up-time
	(hrs)		Min.	Mean	Max.	(no)	(days)	(days)
BEML-1	9410	97	0.82	0.92	0.99	6.2	2.3	28.9
Kom-4	14740	111	0.68	0.93	0.99	5.3	2.8	36.7
Cat-1	16773	96	0.28	0.75	1.00	6.5	8.5	25.7

Feasible Work Targets based on Availability

We used the relative frequency distributions of each of the three machines to construct graphs of probability of operating times of various lengths in a normal season at a given assurance level. These are shown in fig (8). If we choose 90% as the assurance level, it is seen that BEML-1 can be expected to log at least 160 days of operating time in a season, Komatsu-4 170 days and Caterpiller-1 102 days. These values could be indicative of targets that can be achieved.

Fig. 4 Simulated Availability Function (BEML-1)

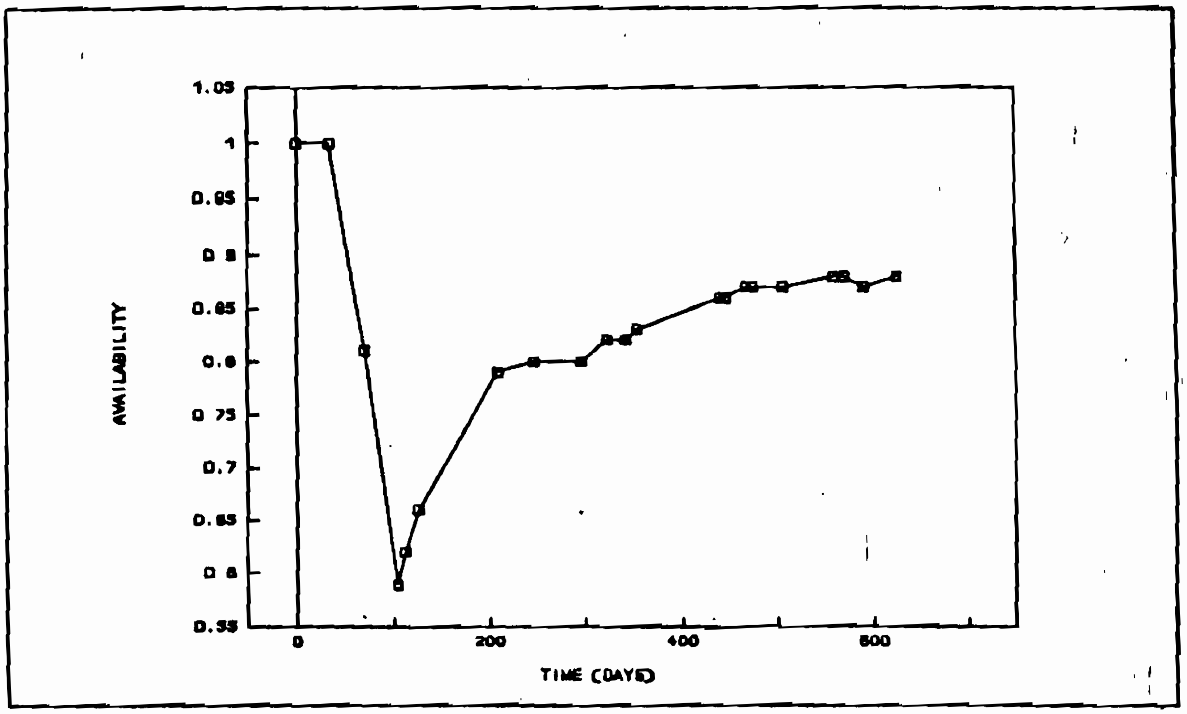


Fig. 5 Simulated Availability Function (Kom-4)

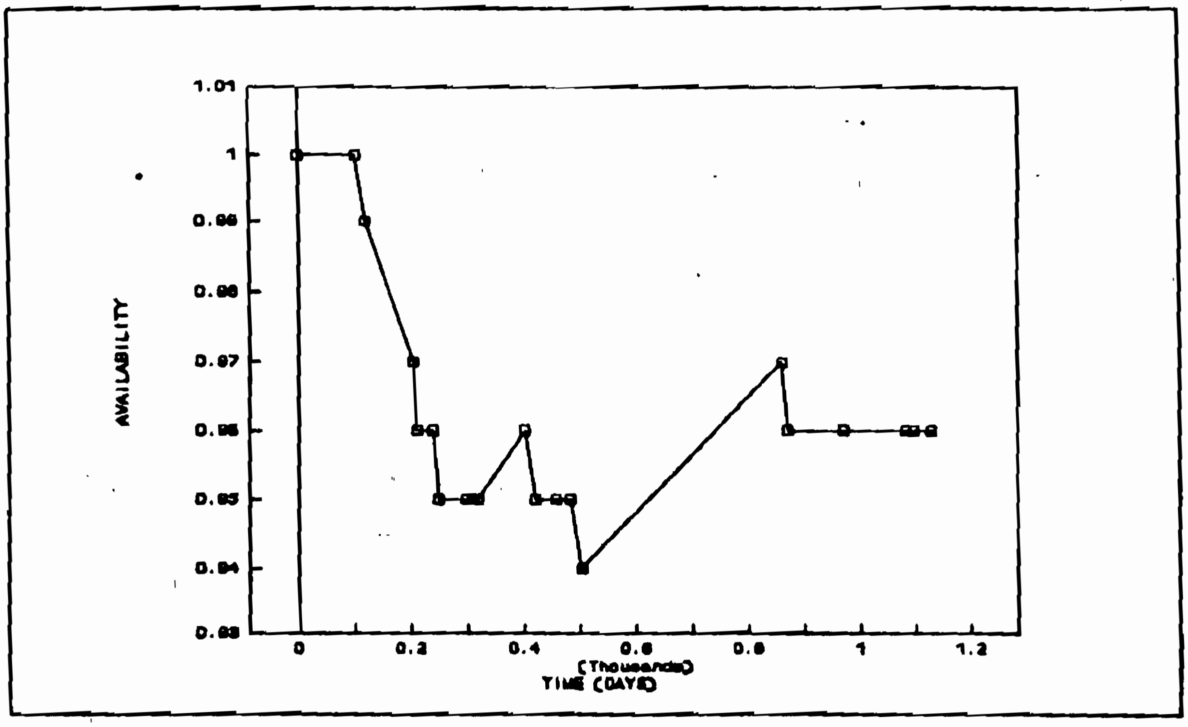


Fig. 6 Simulated Availability Function (Cat-1)

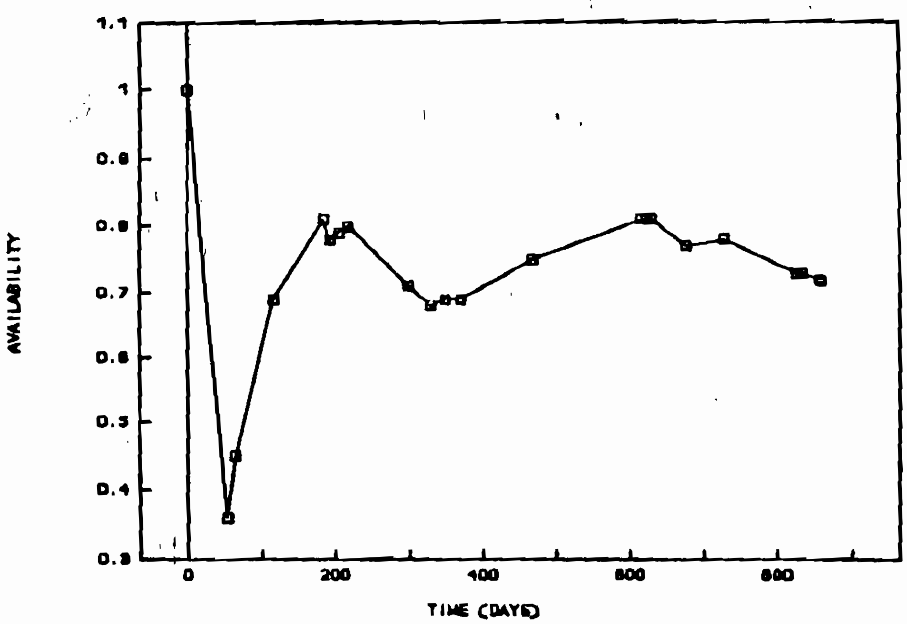


Fig. 7 Overall Availability - Frequency Diagram (Cat-1)

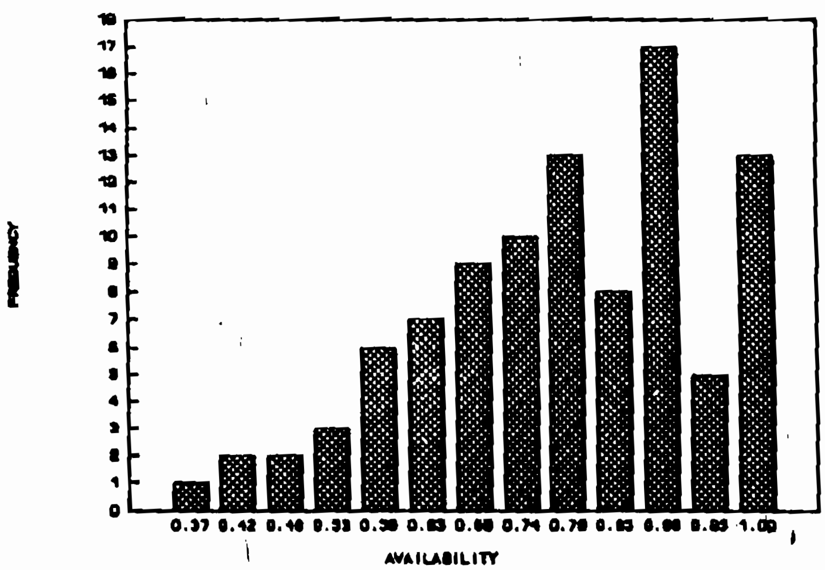
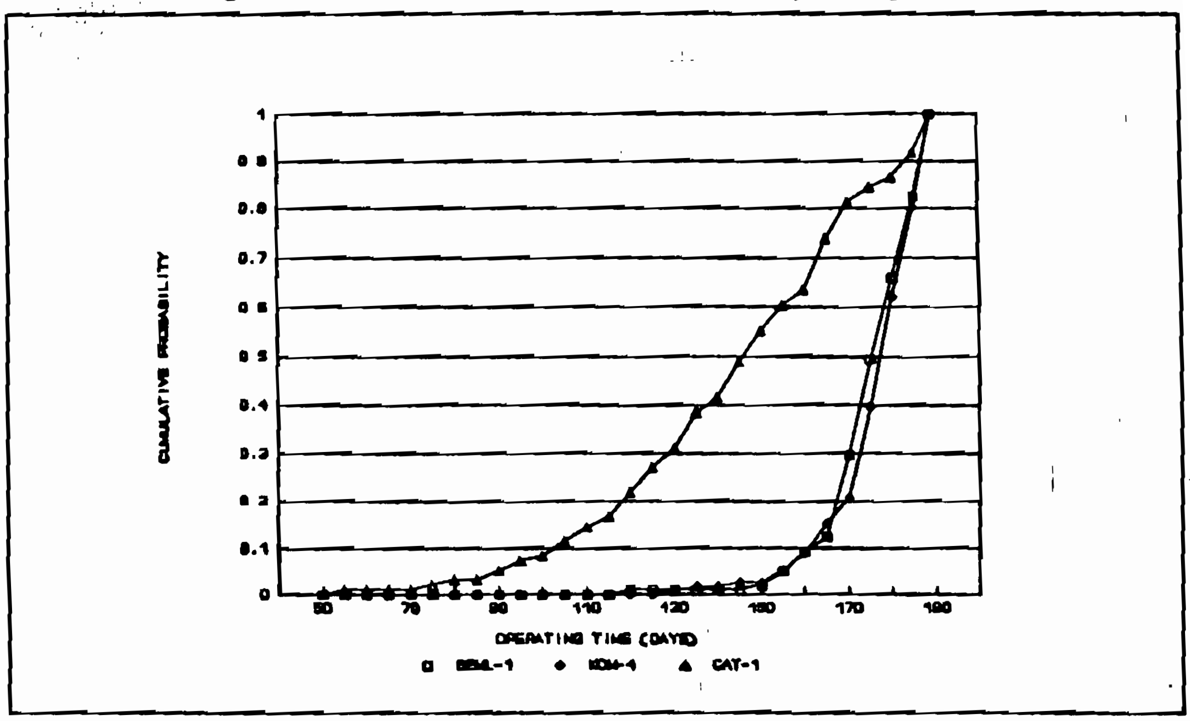


Fig. 8 Simulated Cumulative Probability of Operating Times



Thus, BEML can be expected to reach a target of at least 1600 hrs, Komatsu 1700 hrs. Caterpillers being much older, can be expected to reach a much lower target, 1020 hrs. These values are for an assurance level of 90% and under conditions of assured availability of work. Also it should be kept in view that time used in transport of machines between work sites has been ignored. This could be significant when transfer over long distances are involved.

Summary and Conclusion

Up-time and down-time distribution were built for BEML, Komatsu and Caterpiller bulldozers using a sample of log book data. The up-time was found to be distributed lognormal and down-time as gamma.

Availability in a season of given length (189 days) as also over many seasons was done using simulation. Long sequences (700) of observations were generated for up-time and down-time. These were used to generate a synthetic alternating renewal process. It takes time equal to 3 to 5 seasons before a steady state is approached. It was therefore concluded that 3 to 5 seasons would be an appropriate span of time if availability is used as a reference to judge actual long term fleet use.

Nearly a hundred synthetic seasons of 189 days were also constructed for one machine of each make. This was done by truncating the renewal process at 189 days. Examination of the variation of availability in a season of 189 days, revealed that BEML could log an operating time of 160 days, Komatsu 170 days and Caterpiller 102 days, with an assurance level of 90%. These values can be treated as achievable targets of work under condition of assured work availability and ignoring the time taken in inter-site transfers of machines. BEML can be expected to log in at least 1600 hrs of work in a full season, Komatsu 1700 hrs and Caterpiller 1020 hrs. Present targets (1000 hrs) for BEML and Komatsu can thus be increased.

Simulations carried out here could be used also to study machine interference problem that may occur when a large fleet having a mix of such machines is serviced at a common facility. This will however call for a separate analysis and has not been included here.

Availability analysis as illustrated in this paper can also be useful in situations where one or a group of machines, such as earth moving machinery and tractors work for long periods of time on custom works. It will not be useful however in situations where a machine is intermittently used such as a tractor on an individual farm.

Acknowledgement

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References

1. Kapoor K.C. and L.R. Lamberson (1977). Reliability in engineering design. John Wiley.

2. Medhi J. (1982). Stochastic processes. Wiley Eastern.

3. Cox D.R. and H.D. Miller (1968). The theory of stochastic processes. John Wiley.