Aquaforest TIFF Junction Evaluation

On Marine Radar Reliability

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Summary: Presentive maintenance and other reliability practices are studied and compared with previous results.

1. Single Units

1.1. Introduction and comparisons with [1] and [2] .

Our information has been contributed by Machinery Co. Ltd., the Finnish importer of Raytheon radars, and Mr. N.Forsström from the Electrotechnical Dep. of the H.Q.All statistics deal with Raytheon 1660 TM in 1972-75 if not otherwise mentioned. Raytheon sets operated by the administration of maritime affairs and Finland Steamship Co.Ltd. cover a quarter of all commercial marine radars in Finland. Moreover, S-band radars seem to have gained popularity in contrast to the situation some fifteen years ago. The proportion of transistorized radars has grown from virtually zero to 90 %.

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The mean time between failures is 780 hours of operation, the sample size SS being 104. The word 'before' is used in most reliability models. The effect of this difference is neglible, as will be seen. An average total of 9.9 work hours is required to radar renewal (repair) in port, SS=235. Repairs at sea are most rare in contrast to [1] and [2]. It is not difficult to explain this: only 2.3 % of the ships in [1] and none in [2] had two sets, while 60 % of the ships (SS=75) in our radar files are endowed with a pair of radars. Combined with transistorization, this has created a vast reliability growth (and a need to study the theory of couples). Indeed, hardly any skipper bothers to keep radar logs. As an unfortunate consequence, we do not know the mean sea-time a radar is unserviceable. We assume it is 173 h as in [1]. Radar is intended to operate roughly two thirds of sea-time so that 115 h is actually lost. Thus the uptime ratio = MTBF/(MTBF+MTTR) = 0.8715.

We proceed to show how to find confidence intervals for UTR. Let $d(t)$ denote the total time-to-repair during $[0,t]$, T_0, T_1, σ_0 and σ_1 the first two moments of failure and repair times respectively. These are: 780, 9.9, 830 and 6.87 h. According to [3, p 231]

(1) $$\lim_{t\to\infty} \Pr\{d(t) \leq f(t)x + g(t)\} = N(x)$$

where N stands for the cumulative standard normal distribution and fuctions f and g depend on the above moments.

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In the limit we have PR $\{UTR \geq p\}$ = Pr $\{d(t) \leq (1-p)t\}$. Thus confidence intervals are obtained by using well-known properties of N. By taking t=50000 h, i.e. less than most lifetimes, the 95 % confidence interval is (0.9836,0.9913), the midpoint being 0.9875 which happens to equal $T_o/(T_o+T_1)$ = UTR if no more decimals are written down. The corresponding intervals for t=1000, 10000 h are (0.960,0.985) and (0.9788,0.9961). We conclude that interval availability and its condensation, point availability, approach rapidly UTR, i.e., a radar soon reaches a stationary state.

The ability to use asymptotically correct formulas facilitates surveys of economical importance. For instance, according to [4,104] the number of failures occures with 95 % probability in the intervals (25,52), (104,152) during the first 30000, 100000 h respectively. An average repair costs 3-5 % of the acquistion price.

F.J.Wylie [1, Tables 2&3] decided against trend on the one hand between fault incidence and qualifications of a radar officer and on the other hand between age of radar and fault incidence. With the aid of the non-parametric Mann test [5,378-81], we re-established these conclusions. Various combinations of years were applied to expose any effect of statistical insignificance, aging or burn-in. In the latter case, the standard and Spearmann correlational

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coefficients of [1, Table 3, columns 1&4] are 0.073 and 0.171. The null hypothesis of no trend cannot rejected with a 5 % level of significance in either case. Furthermore, the 84 % confidence interval of standard correlation, (-0.320,0.467), falls outside the range of rejection.

It should be noted that hazard functions of individual units need not be exponential, although the author believes in a nonincreasing failure rate.

Conclusions about effect of switching on failure incidence seem to be the opposite in [1] and [2]. We are of the opinion that radar should be operated continiously with as little switching as possible. A utility investigation could be made as follows: The first and most difficult phase is to determine the gain (function) for safety and economy per time unit of radar use. This naturally depends on the proportion PP of sea-time a radar is intended to operate. Failures break patterns randomly provided that meteorological conditions are somehow adjusted. By norming this function f to unity over the whole of sea-time, an ideally chosen PP results in 1/PP as upper bound for f, while the lower bound is 1, if we exclude the possibility of a skipper systematically erring as to whether his radar should be switched. Next, find out the percentage of failures due to switching. This is given in [1] as 967/2950, the absence of which would in our case raise PP from 0.667 to 0.868.

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Thus a policy of operational continuity is worth advising if $f(0.667).0.667 \leq 0.868$, i.e., $f(0.667) \leq 1.30$. Analogously it is found in the case of [1] that the criterion is $f(0.25) \leq 3.02$. In general, I as a policy determining the switching pattern is strictly preferable to II if and only if

$$PP_I \; f(PP_I) > PP_{II} \; f(PP_{II}).$$

1.2. On Preventive Maintenance

Perspectives of maintenance have drastically changed in recent years. Let us reveal the first complexity by considering the nature of the hazard function. The Weibull distribution of failure time $1 - \exp(-ct^a)$ with $a, c > 0$ has the property that failure rate decreases whenever the form parameter a is not more than unity. Unity itself means exponentiality, i.e., a constant rate. Estimates $\mathring{a}$ of a, as well as confidence intervals, are given in [6, p 188,217 & 240]. The probability that a is less than unity is 99.99 %. Two possible explanations can be offered. To start with, the average age of our sets is three years, so that burn-in effects may exist. In addition, it is stated in [5] that complining data from several units with different exponential distributions may yield a strictly decreasing resultant rate. Extensive statistics, with individuals carefully separated, from several airforce radars, the age of which is at least

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ten years, have, however, confirmed the above result. Sample sizes range so far between 139 and 425. There is, in any case, wide agreement that the hazard function is nonincreasing. Suppose that a repair or preventive maintenance is at the utmost capable of restoring original reliability behavious. It is then clear that scheduled maintenance both increases expenditures and decreases reliability, thus representing the worst characteristics.

It is interesting to observe that even an increasing hazard rate would not automatically justify preventive maintenance in the quest of maximazing uptime ratio. The reader is referred to [3,7.8] , and the common situation where time to perform repair is less than time to maintenance completion, 9.6 h vs 11-16 h in our case.

There are some indications that planned maintenance leads to a better than new state. Nothing of statistical significance can be said.

The present practice of radar overhauls during annual docking has neglible influence; the average number of such actions before first failure is 0.0002. We cite [3,229,(6.330)] . Considerable financial losses result if maintenance is carried out at fixed times T, 2T, 3T etc. instead of rescheduling after each failure. The number of actions is increased by some 40 % in periodic maintenance in comparison with the policy in [3,7.8] when T=90 days.

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In a thorough study of maintenance models, knowledge of renewal time distributions is often required. We divide our statistics into successive intervals of time and write down the number of observations and endpoint of each interval. The optimal amount of intervals is 1 + 3.322 log SS by H.A. Sturges. It is advisable to have about equally many observations in each interval to avoid any problems in Chi-square testing. Data of the cumulative distribution a radar is unserviceable at sea is given in [1, Table 1, columns 1&4] as follows: (24h,113), (48h,27), (72h,10), (96h,5), (120h,3), (240h,16), (480h,18), (1000h,2) and (zh,4). Weibull parameters can be estimated by feeding into a program of linear regression pairs (x,y), where $x=\ln t$ and $y=\ln\ln(1/\exp(-ct^a))=ax + \ln c$. Then $\mathring{a}=0.418$ and $c=0.229$. The exactness of fit up to 1000 h is remarkable as Chi-square 7.44 with five degrees of freedom has a significance level of 0.2. As a byproduct we get the coefficient of standard correlation $r=\mathring{a}\sigma_x/\sigma_y = 0.975$.

It is more difficult to fit repair times in port. In many cases a mixture of two or even three Weibull distributions has to be minimized with respect to Chi-square. Let us give two examples:

a) Total service time (travels included) in port: (2h,19), (3,17), (4,18), (5,17), (6,24), (8,23), (11,27), (14,23), (67,30) - $a_1=1.1, a_2=2, c_1=0.27, c_2=0.0081$ and $Q_1=1-Q_2=0.58$. The Chi-square is 7.55 with three degrees of freedom.

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b) Downtimes of several slightly different types of marine radar in military use (not necessarily by the navy): (0.667h,27), (1.017,27), (1.783,27), (2.25,27), (3.33,27), (4.883,28), (8.5,27), (20,27) and (1203.33,27)- $a_1=1.2$, $c_1=0.36$, $a_2=1$, $c_2 0.065$, $Q_1=0.65$ and the Chi-square is 15.47 the level of significance being 0.001.

Modern types of radar have less than six faults per year. The number is likely to fall below two in the near future, leaving very little ground for preventive maintenance.

2. Systems of Order 2

We consider only parallel structures of order 2 due to the following reasons: a) lower bounds of reliability measures are thus obtained for all two-unit standby systems; b) radars should be used as much as possible; c) asymptotically correct results can be applied without any restrictions to failure or renewal time distributions [4,333-4] . Thus (2) $R(t) = 1-\exp(-t/T)$ where $T=T_1((1+T_o/T_1)^2-1)/2$ stands for the mean time of failure-free operation of the system. The formula is based on the assumption that $D=(1+T_o/T_1)^2 \gg 1$. Let us compare (2) with the respective Markov (M) result [3,195,(6.56)] when $T_o=780$ h, $T_1=9.9$ h (i), 115 h (ii) and t=20,200,1000,3000 and 8766 h:

i) (2) D=6366,T=31510h,R(t)=0.9994,0.9937,0.9688,0.9092, 0.7571

(M) MTBF=31900h,R(t)=0.9996,0.9940,0.9694,0.9105,0.7599

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(2) D=60.6,T=3425h,R(t)=0.994,0.943,0.747,0.417,0.0077

(ii)

(M) MTBF=3815h, R(t)=0.999,0.967,0.782,0.458,0.098.

It is seen that Markov values are slightly higher as the mean time before first system failure is larger than T, essentially depending on D. As a major conclusion, we believe that any complexities of the nature of failure and renewal time distributions seem to have little influence on the reliability behaviour of radar pairs (and multi-radar systems). It is thus justified to apply easy-to-use Markov models.

Different availability measures can be found in [3,8.3]. Suppose both sets can be repaired simultaneously. Then system uptime ratio is $UTR=1-(1-UTR_{single})^2=0.9998,0.983$ when $T_o=780$ and $T_1=0.9,115h$. The same values result by applying [3,(8.69)].

The effect of the underlying assumption is minimal. Consider a service company having 200 radars as customers with an average $T_o=500h$ and five two-man repair crews, i.e.,$T_1=5h$. By applying [3,382],it is found that queueing probability is 2.2 %, and the average number and time of radars waiting for repair are 0.035 and 17.5h.

Thus far it has been tacitly assumed that both sets are identical. However, most pairs consist of one S-and X-band radar. This problem is solved by a simple trick: any model of a slightly loaded pair reduces to a hot stanby by observing that there is only a difference in failure, not in repair rates.

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