PREVENTIVE MAINTENANCE OF THE DIGITAL SYSTEMS FOR SELFDIAGNOSIS EQUIPMENTS CONTROL

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This work analyses the concept of minimising the cost and maximising the probability of detecting the faults in the context of the reliability of the selfdiagnosis systems. The present paper addresses the issue of optimal analyse of system preventive maintenance, that can be performed, wherein failed (or not failed) units are replaced on a scheduled basis. Optimisation of maintenance scheduling, replacement policies, evaluating the reliability of systems subject to preventive maintenance are described. Also, the influence of the link between reliability, maintainability, availability and durability of this type of systems is presented.

1. Optimisation of maintenance scheduling

Systems, which have to work at or below a maximum acceptable failure rate, should be maintained at predetermined points such that the failure rate does not exceed the acceptable level. Preventive maintenance (PM) policies [1] classify failures into two types: i) SPM: simple preventive maintenance; ii) PR: preventive replacement After each SPM the system is in a state which is between *good as new* and *bad as old*. The post-maintenance failure rate of the system after a PR-maintenance is *good as new* [2].

Studies of maintenance types SPM and RP have been considered in [3]. Nakagawa [4] developed a model for imperfect PM in which the effective age of the system is reduced by x time units at each PM. Canfield [5] discussed a system in which PM at time t restores the failure rate to its value at $(t-x)$, while the level remains unchanged.

Malik [6] relied on an expert judgement to estimate the improvement factor γ and Lie & Chun [3] proposed a set of curves (for the improvement factor) as a function of cost for SP-maintenance and the age of the system.

Jayabalan & Chaudhuri present a cost model, which considers inflationary trends over a finite time horizon. The service contract can be made for a finite period during which service per call is constant. Hence cost of a SP-maintenance is non-zero and constant until the system is replaced. It was established an algorithm that determines the number of SP-maintenances to be performed before each RP-maintenance in order to minimise the total cost during a finite time period.

a) Let the system (and the parent node) be L . Start from the initial node. Create m_1 offspring nodes and compute their total cost and absolute time. Enter them into set I, which contains the active nodes and the total number of nodes created. Set $N = m_1$.

b) Let the node in set I having least total cost be C_L. If $T_L \geq T_{\max}$, then go to step I ;

$T_{\max}$ planning period,
T_L time of RP-maintenance of system L.

c) Set $k = 0$.

d) Set $k = k+1$. If $k > m_L$, then go to step i. Otherwise, compute TC_k & T_k , (TC - total cost) :

$$TC_k = TC_L + C_L [1 + r_2(k-1)], \quad (1)$$

$$T_k = T_L + t_k , \quad (2)$$

t_k - time of SP-maintenance k intervention,
r_2 - maintenance-cost factor.

e) If $T_k \geq T_{max}$, then go to step h.

f) If $T_k + t_{m(k+1)} \geq T_{max}$, then note k is entered into set I. Set $N = n + 1$. Return to step d.

g) Dominance rules

Node α is dominated by node β if: $TC_\alpha \geq TC_\beta$ and $T_\alpha < T_\beta$, where α & β are any two nodes in set I.

g_1) If node k is dominated by node i, then return to step d.

g_2) If node i is dominated by node k, then node k is entered into set I and node i is removed from it. Set $N = n + 1$. Rèturned to step d.

h) If $TC_k = TC_l$, then node k replaces node i in set I. Set $N = N + 1$. Otherwise node k is inactive; return to step b.

i) TC_L and the number of SP-maintenances and PR-maintenances are the optimal solution. N is the total number of nodes created.

2. Replacement policies

Beichelt [7] gives a generalised approach in block-replacement policy.

Policy 1 (generalised block replacement)

Maintenance is carried out according to the mode of failure. At the moments T, $2T$, ... PM is performed.

Assuming $p(x) \equiv 0$ and $p(x) \equiv 1$, respectively, ($p(x)$ is fraction of PR mode failure at age x), special cases of policy 1 are seen to be the following two common maintenance polices:

Policy 2 (minimal repair-replacement)

PM is performed at age T. For failure only a minimal repair is done.

Policy 3 (block replacement)

The system is replaced at the time of failure. At times T, $2T$, ... Pm is performed.

Application of policy 2 is only possible if every failure can be removed by minimal repair. In reality this is usually nor true. If policy 3 is used, every failure is removed by renewal even if a minimal repair would be sufficient. In view of $c_1 < c_2$

(c_1, c_2 are the costs of a minimal repair, respectively renewal after a PR-mode failure) this cannot be economical. Hence policy 1 is a useful generalisation of policy 2 and 3.

Ebrahimi developed two replacement policies:

Policy 1_Local

Replace the system either at a time x (of breakdown failure), if $\alpha(x)$ is greater than some specific number α , or a designated age u (active replacement) whichever occurs first ($x < u$). Otherwise repair the system. This is equivalent to: Over a designated interval $[0,u]$, replace the system at its failure time x, if Pr{cost-rate of repair >cost-rate of replacement}$\geq \alpha$; Otherwise repair the system at age x.

Policy 2_Local

If either $D_1 \geq D_2$ or the system is at age u ($u > x$), whichever comes first, then replace the system at its failure x or at u respectively. Otherwise repair the system. This is equivalent to: Replace the system either at time x, if the average life-time per unit cost for replaced system is greater than the average life-time per unit cost for the repaired system at x, or if the system is at age u.

Policy 1_Global

Replace the system either at its failure time, if γ is greater than some specific number γ_1, or at age u, whichever comes first.

Policy 2_Global

If $D_1 \geq D_3$, then replace the system either at its failure time or at age u,

in which:

$$D_1 = \mathrm{E}\{T/C\} \quad (3)$$

$$D_2 = \mathrm{E}\{T(x)/C(x)\} \quad (4)$$

$$D_3 = \int_0^{\infty} \mathrm{E}\{T(x)/C(x)\}\, w(x)\, dx \quad (5)$$

$$\alpha(x) = \Pr\{(T/T(x)) \geq (C/C(x))\} \quad (6)$$

$$\gamma = \int_0^{\infty} \alpha(x)\, w(x)\, dx \quad (7)$$

- T life time of a new system
- $T(x)$ time between failure that occur at time x and the next failure time (excluding the repair time) after the system was repaired
- C cost of replacing a failed system
- $C(x)$ cost of repairing a system at age x
- $w(x)$ weight function
- u age limit

3. The link between reliability-maintainability-availability

Reliability of an item is primarily concerned with its ability to operate for a period of time without failure or serious degradation. This period is the uptime.

On the other hand, maintainability is concerned with item downtime. The parameter, which combines reliability and maintainability, called availability, is the proportion of time during which the system is available for use. Improvement in system availability could generally be made by decreasing the downtime of its components.

The component downtime can be classified into two parts:

a) the initial delay which is the period from the instant the component fails to the instant activity begins

b) the actual component repair time, which can further be classified as diagnosis time, replacement time, checkout time, etc. Assuming that the initial delay is negligibly small, it can be treated the actual repair time and determinated the sensitivity of system availability to component repair time. This sensitivity, defined Maintainability Importance Factor (MIF), is represented as the rate at which system availability improves as the component repair time is reduced.

4. Methods and results

We have developed a series of software applications to integrate the maintenance in the informatic system of the selfdiagnosis equipment. A maintenance activity is extremely hard to conceive in the absence of Computer-aided Maintenance Management System. *The MSQ Tech (Maintenance, Service, Quality & Technical) system* was designed as a flexible, modular and adaptable component of an integrated software system.

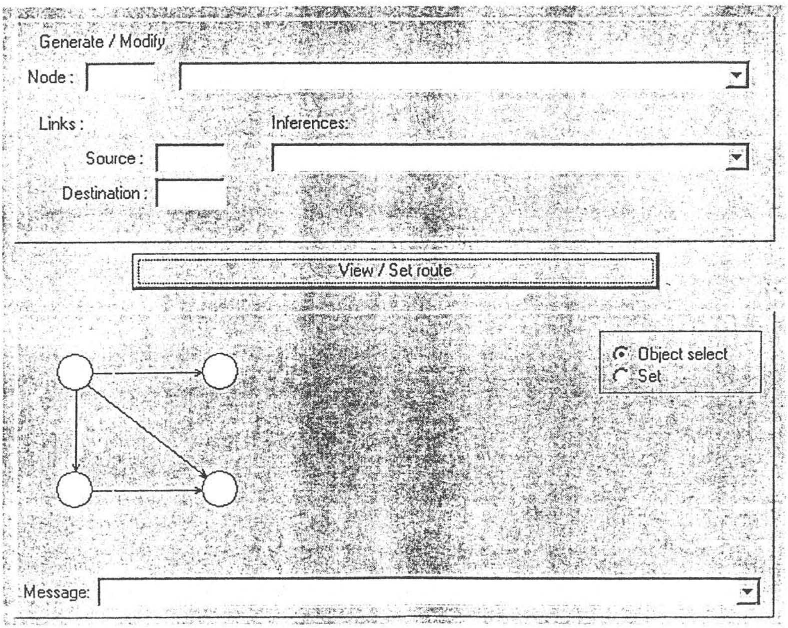

Fig. 1 Expert system for the maintenance monitoring

In the graph review (fig. 1), the nodes represent *solving problems*, and the arcs (as objects: oriented and labelled links) constitute *inferences (problem solutions)*.

The developed programs are remarkable due to:

- Object data positioning through functions with common structure for nodes and arcs.
- Program elements automatic set up (initialising, removing, saving/copying in/from files), once the functions from the previous paragraph being described.
- The possibility that these functions to return constant identifying values.

We have applied the new system since the second half-year of 1998. With a view to trace out the effects, we have monitorised a series of equipment's at which we had previous data too. The parameters of interest were:

- Non-operating time
- Total cost of the repairs
- Customer satisfaction

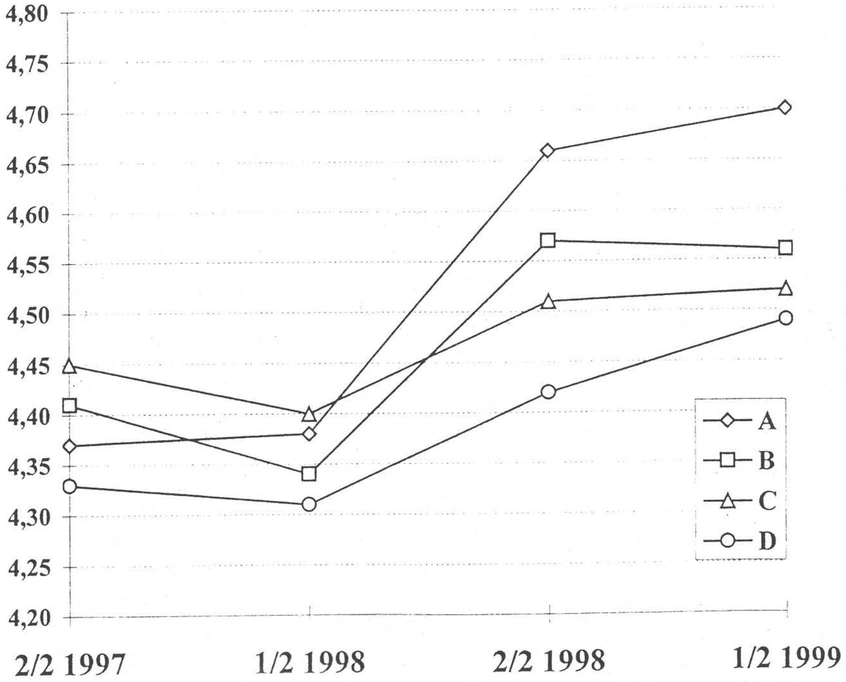

Fig. 2. Ratio Customer_Satisfaction / (Non_Operating_Time × Repair_Total_Cost)

The results, reflected by a complex parameter, indicate the effectiveness of the method.

5. Conclusions

From a maintenance-deterministic point of view, it must be assured that the system has a failure rate at or below a fixed value. As the system ages, the post-maintenance failure rate of the system drops to some newer one, but does not restore the system to the original state.

The replacement policies, which can be used in deciding whether one should replace or repair a system, have been developed on a variety of criteria: the life of a new system, the remaining life of the old system if it was repaired at time of failure, the cost of a new system, the cost of repairing the old system at time of failure, the average life-time per unit cost of repair, the hazard rate limits and tolerances. For each system, it can be considered a number of preventive maintenance models and chosen the optimum policy to maximise the availability.

We have developed a software package, *MSQ Tech,* for the maintenance integration in the informatic system of the firms that distribute equipment and supply also the service. A substantial improvement of the maintenance activity was registered.

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