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New Extension For Inspection And Age Based Policy For Heterogeneous Components Considering Imperfect Inspections And Delay Time

Victor Hugo Resende Lima, Augusto José da Silva Rodrigues, Rafael Gomes Nobrega Paiva, Cristiano Alexandre Virginio Cavalcante

Department of Engineering Management, Universidade Federal de Pernambuco, Recife, Brazil

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Maintenance planning for industrial systems involves various policies, including age-based, block-based, and inspection-based strategies, applicable across different sectors like wind turbines and steel factories (Lee and Mitici, 2023; Shafiee and Finkelstein, 2015; Li et al., 2015). Regarding inspection-based policies, they can be categorized into several types, for example, randomic, periodic and aperiodic (sequential). In the realm of non-periodic inspections — initially explored by (Barlow et al., 1963) — several maintenance policies have been developed. In the realm of non-periodic inspections, which is essential for industries facing highly variable operating conditions or wear rates, the applicability of non-periodic inspection policies is particularly significant in industries such as oil refining and aerospace, where equipment conditions can rapidly change due to operational demands or environmental factors. Notable developments include (Kitagawa et al., 2016) non-periodic inspection policy for one-shot systems using a Simulated Annealing algorithm and (Hajipour and Taghipour 2016) use of a Genetic Algorithm for k-out-of-m systems. Moreover, the delay-time model, integrating periodic and random inspections, allows varying inspection intervals, which can be crucial for optimizing maintenance schedules in complex industrial settings (Yang et al., 2016).

The delay time concept (Sinisterra et al., 2023) posits that each failure is preceded by an identifiable defect. Noteworthy within this framework are the hybrid KΔT policy of inspection and age-based replacement (Scarf et al., 2009) and (Okumura et al., 1996) model, where Δ, the time interval between inspections, is constant. However, strictly applying this fixed interval can lead to suboptimal outcomes. (Wang, 2012) notes that varying the intervals can be crucial, an issue explored in this study to determine the benefits of flexible inspection scheduling.

In the context of the delay-time concept, literature on non-periodic inspections is scarce. (Wang, 2000) examined a maintenance policy where each inspection type has a distinct Δ value but with consistent intervals between the same type of inspections. In contrast, (Alberti et al., 2022) presented the only known study where intervals between inspections vary, although they must follow a monotonic trend of either increasing or decreasing. In our research, we treat each inspection as an independent variable, allowing for dynamic variations in intervals within a single solution to accommodate both increases and decreases.

This study introduces a new maintenance policy for single-component systems based on the delay-time concept with non-fixed inspection intervals. Commonly known in the literature as sequential or aperiodic inspections, we refer to them as non-fixed in this study. The policy also considers imperfect inspections, allowing for defect misclassification. Termed the $K\Delta kT$ policy, it diverges from traditional methods by treating inspections as 'free' variables.

In this study, we are examining a single-component system that follows the delay time concept. This system can exist in three states: operational, defective, or failed. The occurrence of a defect is denoted as X, and the delay time, H, represents the duration between the arrival of a defect and system failure. These variables are statistically independent. The components come in two types, and their probability density function for defect arrival is expressed $f_X(x) = p.f_1(x) + (1-p).f_2(x)$, where p signifies the mixture rate of each component type, and f_1 and f_2 are the probability density functions for defect arrival.

The inspection process is imperfect, meaning that during an inspection, a defect may be erroneously detected with probability β, and a defect may go undetected when it exists with probability α. Consequently, if a defect is identified during an inspection, whether it truly exists or not, a preventive replacement is initiated with a cost of *CR*. If a system failure occurs, a corrective replacement is executed with a cost of CF. Each inspection is associated with a cost *CI*, and *CI* < *CR* < *CF*. The variables under consideration include the number of inspections to be conducted (*K*), the moments for each inspection (ΔK with i = 0,1, ..., *K* and $\Delta 0$ = 0), and the moment for preventive replacement based on age (*T*).

To assess the impact of this new policy, we compared its optimized outcomes with those of the policy proposed by (Scarf et al. 2009), using the input data from this article. We varied the input parameters representing the occurrence of false negatives in inspection and the cost of failure. It can be observed that in all cases, the policy with non-fixed inspections yields better results. The arrangement of inspections is another characteristic of this new policy, where they are organized in groups early in the component's life to prevent failures due to the possibility of weak components. Additionally, inspections are placed near preventive maintenance to mitigate the risk of failure in strong components. These results are illustrated in Table 1.

Table 1. Sensitivity Analysis

η1	κ1	η2	κ2	p	λ	α	ß	Ci	Cr	Cf	KDkT				KDT				
											K	Δ0,...,ΔK	T	CR	K	Δ	T	CR	% worsening
2,5	3	5	18	0,1	0,5	0,1	0,2	0,05	1	10	4	[2.9822, 4.4487, 9.9019, 11.0136]	12,0573	0,1949	3	3,4630	11,7712	0,1988	2,00%
2,5	3	5	18	0,1	0,5	0,1	0,2	0,05	1	8	4	[3.0048, 4.4638, 10.3222, 11.5460]	12,59577	0,1783	1	3,7075	11,45545	0,1791	0,46%
2,5	3	5	18	0,1	0,5	0,1	0,2	0,05	1	12	4	[2.8863, 4.2887, 9.5604, 10.7747]	11,7933	0,2107	3	3,3380	11,42416	0,2167	2,85%
2,5	3	5	18	0,1	0,5	0,1	0,1	0,05	1	10	5	[2.8540, 4.3785, 9.6796, 10.9595, 11.8615]	12,66606	0,1890	3	3,4847	11,88811	0,1937	2,49%
2,5	3	5	18	0,1	0,5	0,1	0,3	0,05	1	10	2	[3.0341, 4.3497]	11,12276	0,2025	1	3,6647	11,11963	0,2034	0,44%

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References

Alberti, A. R., Neto, W. F., Cavalcante, C. A., Santos, A. C. J. 2022. Modelling a flexible two-phase inspection-maintenance policy for safety-critical systems considering revised and non-revised inspections. Reliability Engineering & System Safety 221, 108309.

Barlow, R. E., Hunter, L. C., Proschan, F. 1963. Optimum checking procedures. Journal of the Society for Industrial and Applied Mathematics 11(4), 1078-1095.

Hajipour, Y., Taghipour, S. 2016. Non-periodic inspection optimization of multi-component and k-out-of-m systems. Reliability Engineering & System Safety 156, 228-243.

Kitagawa, T., Yuge, T., Yanagi, S. 2016. Periodic and non-periodic inspection policies for a one-shot system with minimal repair. Journal of Japan Industrial Management Association 66(4E), 387-395.

Lee, J., Mitici, M. 2023. Deep reinforcement learning for predictive aircraft maintenance using probabilistic Remaining-Useful-Life prognostics. Reliability Engineering and System Safety 230, 108908.

Li, P.; Wang, W.; Peng, R. 2015. Age-Based Replacement Policy With Consideration of Production Wait Time. IEEE Transactions on Reliability 65 (1), 235-247.

Okumura, S., Jardine, A. K. S., Yamashina, H. 1996. An inspection model policy for a deteriorating single unit system characterized by a delay-time model. International journal of production research 34(9).

Scarf, P. A., Cavalcante, C. A., Dwight, R. A., Gordon, P. 2009. An age-based inspection and replacement policy for heterogeneous components. IEEE Transactions on reliability 58(4), 641-648.

Shafiee, M.; Finkelstein, M. 2015. An optimal age-based group maintenance policy for multi-unit degrading systems. Reliability Engineering and System Safety 134, 230-238.

Sinisterra, W. Q., Lima, V. H. R., Cavalcante, C. A. V., Aribisala, A. A. 2023. A delay-time model to integrate the sequence of resumable jobs, inspection policy, and quality for a single-component system. Reliability Engineering & System Safety 230, 108902.

Wang, W. 2000. A model of multiple nested inspections at different intervals. Computers & Operations Research 27(6), 539-558.

Wang, W. 2012. An overview of the recent advances in delay-time-based maintenance modelling. Reliability Engineering System Safety 106, 165-178.

Yang, L., Ma, X., Zhai, Q., Zhao, Y. 2016. A delay time model for a mission-based system subject to periodic and random inspection and postponed replacement. Reliability Engineering & System Safety 150, 96-104.

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