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A superimposition based approach for maintenance and quality plan optimization with production schedule, availability, repair time and detection time constraints for a single machine

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ABSTRACT

Performance of a production system significantly depends upon the effective planning of its shop floor level operations like, production scheduling, maintenance and quality control. These three functions have an interaction effect on each other; hence a combined operational policy of these functions can improve the system performance. The objective of this paper is to develop a methodology for optimizing maintenance and quality plan with the constraint on schedule, availability, repair time and detection time, for a single machine. The approach includes the selective maintenance and a sampling procedure based on the economic design principle. Cost models developed for the problem at hand are presented along with their detailed explanation. Two solution methodologies namely, Simulated Annealing (SA) and Genetic Algorithm (GA) are used for obtaining the near optimal solution. A computational experiment to compare the performance of SA and GA is presented. Results indicate a better performance of the proposed approach over the conventional approach of independent planning.

1. Introduction

Competition for business in the global market is increasing very fast and companies are facing challenges to meet several unending customer demands like quick response, high product quality, low costs, timely deliveries and better customer service. In today's dynamic business environment, companies need to improve the performance of their manufacturing systems through effective utilization of resources and efficient planning of shop floor activities. Maintenance, quality control and production scheduling are the three important shop floor operations whose effective planning can lead to an excellent manufacturing performance. These three activities have an interaction effect in the operational context, for example, production scheduling assumes that machines are continuously available for processing. However, a machine may become unavailable during certain periods like failure, maintenance, etc. Similarly, lack of proper maintenance is usually among the most common causes of quality defects. The interdependency between these shop floor activities has gained the interest of researchers to develop approaches for integration between the three activities [1–8].

The present paper provides a methodology for integrating the three shop floor functions namely, maintenance, quality control and production scheduling, with an objective to minimize the expected total cost of system operation of these functions. An integrated model of the three functions is developed by superimposing the combined maintenance with quality control decision on the production schedule. Two solution approaches namely, simulated annealing and genetic algorithm are used for optimization of the decision parameters. Optimization procedure of the proposed model results in selecting one of the three maintenance actions namely, repair, replace or do-nothing for each system component, values of parameters like, sample size, acceptance number and time between samples for the sampling procedure, considering the optimal production schedule on the machine. The performance of the proposed approach is compared with the conventional methodology that treats these issues independently. A computational experiment is performed to compare the performance of the SA and GA.

The rest of the paper is organized as follows:

Section 2 presents a brief literature review related to the integrated approaches for production scheduling, maintenance and quality control. In Section 3, the problem structure for developing

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Nomenclature

A_{Req}	Required system availability
α	Age reduction factor for component
β	Weibull shape parameter for component
η	Weibull scale parameter for component (h)
CC	Cost of component (Rs)
C_f	Failure cost for component (Rs)
C_{LP}	Cost of lost production (Rs)
C_{LM}	Labour cost of maintenance (Rs/h)
C_{sp}	Cost of sub-components and consumables (Rs)
C_R	Replacement cost for component (Rs)
C_r	Repair cost for component (Rs)
CRL	Cost of loss of residual life (Rs)
$E[N_f]_{\mathrm{FC2}}$	Expected number of failure of the machine during the operating period leading to FC2
$E[\mathrm{DT}]_{T_{\mathrm{PMS}}}$	Expected downtime in next operation period (h)
$E[\mathrm{TC}_M]$	Expected total cost of selective maintenance
ML	Mean life (h)
MRL	Mean residual life (h)
MTTrA	Mean time to repair for component (h)
MTTRA	Mean time to replacement for component (h)
MAT	Maintenance action time (h)
PR	Production rate (units/h)
R_i	Reliability of i^{th} component
$R(t\|T)$	Conditional reliability having survived up to time T
$\Re_i$	Index of i^{th} component undergoing replacement
r_i	Index of i^{th} component undergoing repair
RF	Restoration factor for component
T_{PMS}	Time between the current maintenance and next expected opportunity (h)
T_{Avl}	Time available to carry out maintenance work
$E[C_{\mathrm{Restore}}]$	Expected total cost to restore the process (Rs)
$E[\mathrm{TC}_{\mathrm{PQC}}]$	Expected total cost of process quality control (Rs)
$E[C_{\mathrm{PQC}}]_{\mathrm{cycle}}$	Expected cost of process quality control per cycle (Rs)
$E[C_{\mathrm{Rework}}]$	Expected total cost of rework (Rs)
$E[N]_{\mathrm{cycles}}$	Expected number of cycles
$E[T]_{\mathrm{cycle}}$	Expected cycle length of process control
$E[T]_{\mathrm{false}}$	Expected total time for investigation of false alarm (h)
H_s	Time between samples (h)
N_s	Sample size
P_1	Average proportion of defectives during in-control
P_2	Average proportion of defectives during out-of-control
S_{in}	Expected number of samples in in-control state
T_{LM}	Time elapsed between the previous maintenance and current opportunity (h)
TC_f	Total cost of failures (Rs)
TC_R	Total cost of replacement (Rs)
TC_r	Total cost of repair (Rs)
v_i	Effective age of i^{th} component at the end of any period (h)
$(v_i)_o$	Effective age of i^{th} component at the opportunity
$(v'_i)_o$	Effective age of i^{th} component after maintenance at the opportunity (h)

For process quality control

α_s	Type 1 error of sampling procedure
β_s	Type 2 error of sampling procedure
τ	Expected time of occurrence of assignable cause
$\mathrm{ARL}_{\mathrm{In}}$	Average run length in in-control state
$\mathrm{ARL}_{\mathrm{Out}}$	Average run length in out-of-control state
C_s	Acceptance number
C_{ins}	Cost of inspection (Rs)
C_{ac}	Cost of investigating the assignable cause (Rs/h)
C_F	Cost of investigating the false alarm (Rs/h)
C_{Rej}	Cost of rejection per piece (Rs)
C_{Res}	Cost of restoring the process (Rs)
C_{Rew}	Cost of rework (Rs per unit)
$E[C_{\mathrm{sampling}}]$	Expected total cost of sampling per cycle (Rs)
$E[C_{\mathrm{False\ Alarm}}]$	Expected total cost of false alarms per cycle (Rs)
$E[C_{\mathrm{Rejection}}]$	Expected total cost of rejections (Rs)
$E[C_{\mathrm{ACD}}]$	Expected total cost of assignable cause detection (Rs)
T_F	Time required to investigate false alarm (h)
T_S	Time required for sampling (h)
$T1$	Expected time to search the assignable cause (h)
$T2$	Expected time to restore the process (h)

For production scheduling

P	Processing time of a batch (h)
W	Penalty cost for the batch (Rs/h)
CT	Completion time of a batch (h)
DD	Due date for a batch (h)
$E[\mathrm{TC}_{\mathrm{PS}}]$	Expected total schedule penalty cost
$E[\mathrm{TC}]_{S+M/Q}$	Expected total cost of integrated model ($S+M/Q$ (Rs))
LT	Lateness of a batch (h)
LT_F	Lateness of a batch due to component failure
T_d	Delay time due to component failure (h)

the proposed approach is described. The mathematical model for integrating the three functions is developed in Section 4. The proposed approach is presented in Section 5 and the solution approaches are presented in Section 6. Details of the numerical example for demonstrating the applicability of the integrated approach are given in Section 7 and optimization results in Section 8. Finally, the conclusion and the future research scope are outlined in Section 9.

In the next section, a brief literature review related to the integrated approaches is presented. To the best of our knowledge, literature on the combined approach for all the three functions is very limited. Hence, the literature related to integrated approaches of two activities is also presented.

2. Literature review

Scheduling problems combined with maintenance have received increasing attention by researchers, considering the interdependency between these functions. The integrated approaches for maintenance and production scheduling related to single machine, mostly consider two types of preventive maintenance; deterministic and flexible maintenance. In the deterministic case, maintenance periods are determined before the jobs are scheduled [4,9], while the latter means that the schedule of maintenance periods is also determined jointly with the schedule of jobs [10,11]. Chen [12] solved a scheduling problem with periodic maintenance to minimize the total flow time. Ji et al. [13] considered a single machine scheduling problem with periodic maintenance activities, where each maintenance activity is scheduled after a periodic time interval. Sbihi and Varnier [14] studied a single machine scheduling problem with several fixed and flexible maintenance periods with non-resumable jobs, with an objective to minimize the maximum tardiness. Low et al. [15] investigated a single machine scheduling problem with both, deterministic and flexible maintenance