Integration of the dynamic health states in the production planning of manufacturing systems

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Abstract. This research treats the case of an unreliable manufacturing system whose machine's reliability depends on the random dynamic of the technician's health state. The technician's health state impacts on the production machine. This study integrates the technician's health state in the planification of the production of a manufacturing system. The option to replace the technician should be taken to meet the long-term demand. The objective is to minimize the total cost that includes inventory, backlog and replacement costs over an infinite planning horizon. We formulate the stochastic optimal control problem in the framework of Markov decision processes and develop the optimality conditions. Numerical methods are used to obtain the optimal control policies (production rate and replacement policy). Finally, a numerical example and a sensitivity analysis are presented in order to illustrate and confirm the structure of the obtained optimal solution.

Keywords: Manufacturing systems, Random process, Production machine, Replacement policy, Numerical methods

1. Introduction

A manufacturing system is built from production equipment, which are programmed, operated and maintained by human beings (see Bai and Gershwin (1994) for more details). Many manufacturing industries function as sociotechnical systems, where there is strong bond and a high interaction between people and machines. Sociotechnical systems are built upon production machines, which are subject to random failures. The presence of stochastic events such as random failures of the production machines in human-machine systems has become an important topic of research, which has drawn a lot of researcher's attention. For example Emami-Mehrgani et al. (2014) have modeled the human errors in dynamics of manufacturing system and verified the influence of human errors during maintenance and lockout/tagout activities on the optimal safety stock levels. However most of the researchers continue to treat operators and technicians as robots. They assume that the technician's health state is permanently good to repair production machines with a constant efficiency. But in reality, many times, engineering systems fail because of human errors rather than because of hardware or software failures (Dhillon and Yang (1994)). The dynamic of the technician's health states is one of the sources of the human errors. That is why Williams (1958) pointed out that human-element reliability must be conducted in the overall system reliability prediction; otherwise, such a prediction would not be realistic. The lack of realism observed in existing models causes production and maintenance problems. Those problems are related to the poor use of the production machines and the technician's poor performance during the maintenance of manufacturing equipment. The technician's performance has an impact on the quality of the manufactured products and on the reliability of the production equipment. In this study, the technician's health state defines his efficiency during the repair of the production machine.

The purpose of this study is to integrate the dynamic of the technician's health states into the existing production policies of manufacturing systems. The decision variables are the production rate of the machine and the replacement rate of the technician. Such a technician's health is subject to deterioration, due to the poor working schedule of the manufacturing system under study. In fact, the working schedule of the studied manufacturing system fails to alternate technicians between working hours and resting hours.

2. Problem statement

This paper integrates the dynamics of the human being into the management of the activities of a manufacturing system. This system is constituted by a machine treating a specific type of products. The machine is subjected to random breakdowns and repairs. When the machine breaks down, it is immediately repaired by a technician. The repair time of the machine depends on the state of the technician. This technician works permanently in the company and handles all the department of maintenance. It is assigned to the repair of the machine as soon as a breakdown arises. This technician is submitted to extended working days according to a production policy mainly based on the optimization issues. The performances of the technician depend on the sequence of the working days and on the number of workdays a week. When the number of breaks (resting time) is not adequate, besides a schedule of extended working days in a compressed workweek, the fatigue can accumulate and become harder and harder to support, until become insuperable. A machine repaired by a technician working in these conditions can be badly repaired or need more time to be repaired. We assume in this paper that the repair time of the machine increases with the degradation of the state of the technician and that the machine is repaired well (as good as new condition). The evolution of the machine repair tine is represented in figure 1 according to the duration of the working day.

The repair time is assumed to be constant during the normal hours of work (an 8-hour day) when the working breaks (resting time) are respected according to the standard. After 8 hours, the time of repair increases due to the degradation of the performance of the technician. Extra hours are paid to the technician after the normal work period; what increases the costs of repair of the machine. The machine is either operational or under repair. Three levels of degradation of the technician are considered and the percentage of the machine failure time is divided in three parts corresponding to 3 ranges of repair time.

Figure 2 illustrates a situation for which the machine is 65% in operation and 35% under repair. By considering the dynamics of the technician which degrades, figure 2 also illustrates an example in which 5 %, 10 % and 20 % are dedicated to operations of repair for three different modes of the state of the technician. The machine modes can be classified as operational and under repair, while the technician modes can be classified as perfect condition, degraded condition and under replacement status.

The dynamics of the system is described by a continuous time Markov process, with control dependent transition rates from one mode of the system to another.

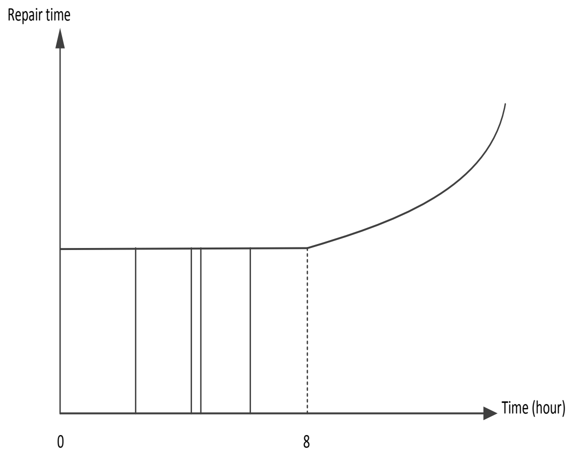

Figure 1. Evolution of the repair time

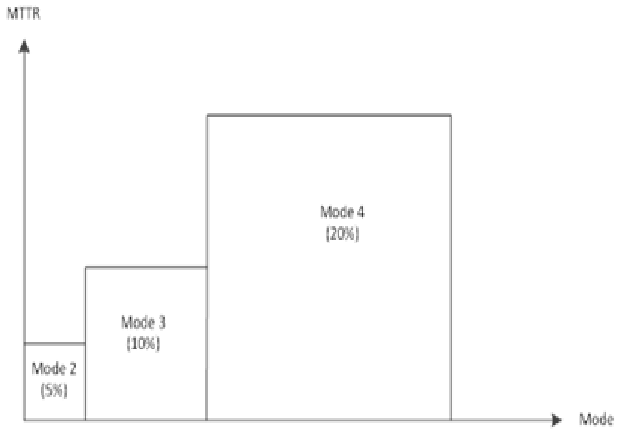

Figure 2. Ranges of the repair time

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In order to increase the system capacity, we control the transition rate q_{41} from replacement status mode to operational mode as illustrated by the state transition diagram depicted in figure 3.

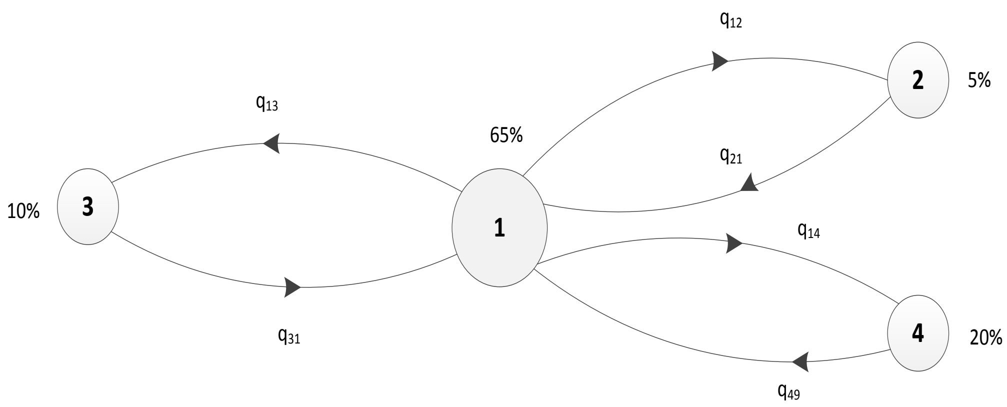

Figure 3. State transition diagram

Hence, the transition matrix depends on the replacement rate. The dynamics for the system are in a hybrid state comprised of a discrete state (the machine's state) and a continuous state (stock level). When the machine is operational, it produces parts and when it is under corrective maintenance, it does not produce anything. The surplus may take either a positive value, called an inventory, or a negative value, called a backlog. Our objective is to control the production and the technician's replacement rates so as to minimize an expected discounted cost including inventory holding, backlog, repair and replacement costs.

3. Results analysis

The study of the production rate of the machine, in its operational mode shows that the computational domain is divided into three regions where the optimal production control policy consists of one of the following rules: (i) if the stock level in the system is less than the optimal stock level, the production should be at a maximum rate to reach the optimal stock level; (ii) once the stock level in the system is equal to the optimal stock level, the production should be at the demand rate; (iii) if the stock level in the system exceeds the optimal stock level, then we do not produce. Such a structure is illustrated in figure 4.

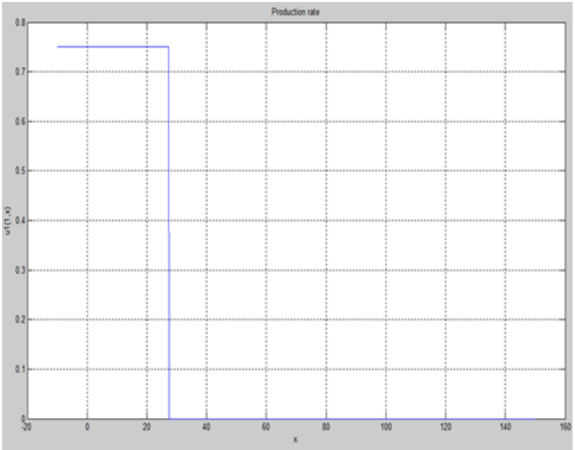

Figure 4. Production policy

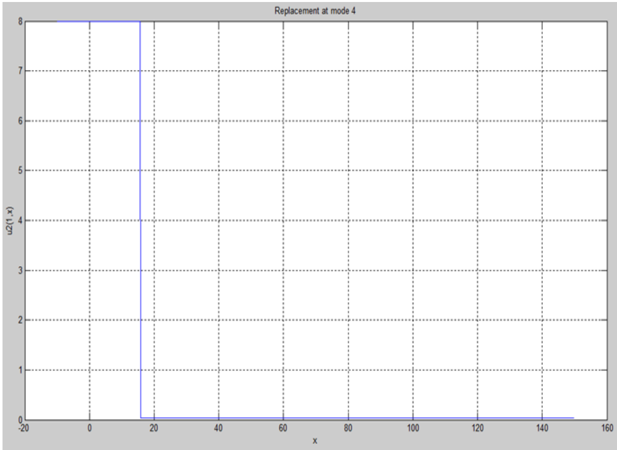

Figure 5. Replacement policy

The technician's replacement policy divides the computational domain into two regions where the replacement rate is set to its maximal and minimal values for backlog situation and for large stock levels respectively (figure 5). The reader is referred to Nodem et al. (2011) for more details on replacement policies. The obtained joint optimization of production and technician's replacement policies is an extension of so-called hedging point policy. By combining human factors in production, the optimal production and replacement thresholds (i.e., Z_1 and Z_2)

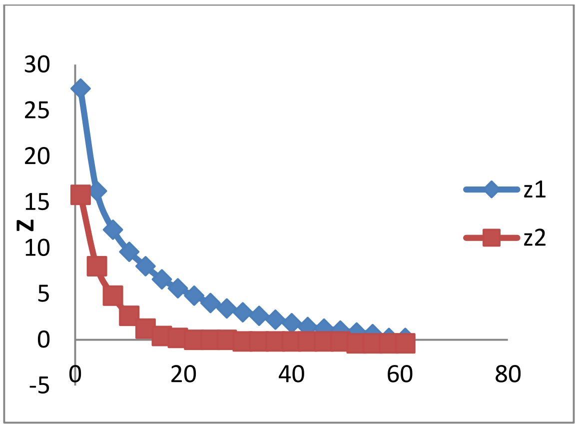

Figure 6. Variation of inventory costs

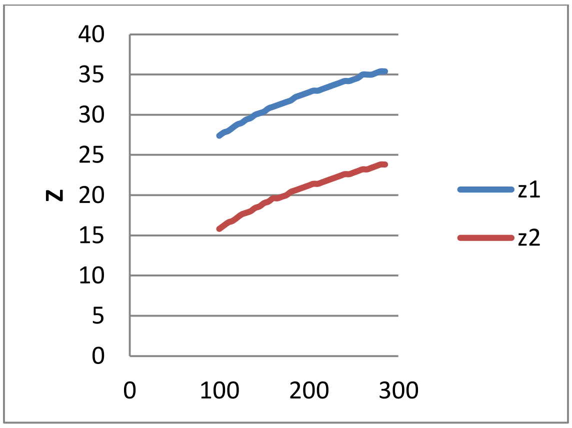

Figure 7. Variation of backlog costs

decrease when the inventory increase; conversely, they increase with the increasing of the backlog costs as shown in figure 6 and 7. These results illustrate the contribution of the proposed model.

4. Conclusion

This paper examined the impact of human factors for a single machine, and single product manufacturing system under uncertainties. The objective of the study was to determine how to produce while the machine is in operation and when to replace the technician in order to minimize the overall incurred cost. We developed a stochastic optimization model of the problem considered, with two decision variables (production rate and technician's replacement rate) and one state variable (stock level). By controlling both production and technician's replacement rates, we obtained a near optimal control policy of the system through the implementation of the policy improvement algorithm (numerical methods). We have shown that the number of parts to hold in inventory increases when backlog cost increase and decrease when the inventory cost increase. This analysis of sensibility shows the robustness of the approach proposed and so confirms the obtained results.

5. References

Emami-Mehrgani, B., Nadeau S., Kenné J.P., 2014, Optimal lockout/tagout, preventive maintenance, human error and production policies of manufacturing systems with passive redundancy, Journal of Quality in Maintenance Engineering, vol. 20, no 4, p. 453-470

Bai, S.X., Gershwin S., 1994, Scheduling manufacturing systems with work-in-process inventory control: multiple-part-type systems, The International Journal of Production Research, vol. 32, no 2, p. 365-385.

Dhillon, Balbir S, Nianfu Yang, 1994, Human reliability: a literature survey and review, Microelectronics Reliability, vol. 34, no 5, p. 803-810.

Williams, HL. 1958, Reliability evaluation of the human component in man-machine systems, Electrical Manufacturing, vol. 61, no 4.

Nodem FID, Gharbi A. Kenné J.P., 2011, Preventive maintenance and replacement policies for deteriorating production systems subject to imperfect repairs, International Journal of Production Research, 49 (12), 3543-3563