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Optimal spares and preventive maintenance frequencies for constrained industrial systems

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ABSTRACT

The research investigates the influence of an effective maintenance system on the efficient performance of any industrial system. The core concept of the research explains that the simultaneous focus on the spares inventory subsystem as well as on the preventive maintenance subsystem must be considered when developing a quality maintenance programme. Considering and developing such aspects separately will lead to suboptimal performance since there exists a trade-off between overstocking and undersupplying spares for preventive maintenance activities. Details on the technique chosen are discussed, namely simulation modelling as well as recent developments such as agent based modelling. Advantages of this technique are the flexibility in representing complex relationships within a system without knowing the exact form. The optimisation heuristic, a genetic algorithm, which was used to solve the research problem is explained. Finally a case study is used to demonstrate the aptness and success of the research approach, namely an annual 44% maintenance cost saving and 3% increase in production output.

1. Introduction

With the passage of time systems undergo wear and tear, deteriorate and eventually fail. The reliability of holistic systems decreases as evidenced by erratic, unreliable behaviour of the systems and individual components. Striving to improve reliability is fraught with increasing cost and capital investment in the short term. The long term benefit of a predictable stable process can prove to be more economical, not to mention safety implications of complex man–machine systems. The field of Industrial Engineering has traditionally endeavoured to analyse and understand the man–machine–money-and-method systems in attempting to improve the inner workings thereof. The proposal of harnessing maintenance to improve system reliability and productivity, while reducing operational cost, is merely a further example of an Industrial Engineering application.

1.1. System reliability

Definitions abound in the literature of system reliability, but all address three essential aspects as follows: Reliability is the ability (probability of success) of a system to perform a required function for a defined period under specified environmental conditions (Blanchard & Fabrycky, 2006). The primary focus of this study, however, is on the 'defined period' commonly known as uptime or availability. To ensure that a plant or operation is available to produce and deliver production, measures should be taken to attain availability for the system during periods of operation. The concepts of maintenance and reliability are inseparable, the one completes the other. Campbell and Reyes-Picknell (2006) state that maintenance can be seen as an investment in productive capacity rather than a necessary evil.

1.2. Maintenance systems

Sarker and Haque (2000) state that "*maintenance is a dynamic service activity which aims at smooth, cost effective operations of an enterprise*". In many instances maintenance is seen as a support function which is often neglected or classed as subservient to other functions such as production. The importance of maintenance is undermined since it is seen as wasting time, infringing on profits and incurring additional cost, yet the implications of inferior maintenance can be deleterious to keeping equipment running and safe to operate. To facilitate production of a range of products on a large scale, plant operations must be reliable and available to meet demand targets. Properly organised and operated maintenance services with necessary resources (human, equipment and spares) are an essential lifeline of production to meet targets. Properly developed maintenance strategies and policies must be implemented to gain optimum benefit of a reliable system while constantly decreasing downtime.

The majority of maintenance activities cannot be successfully carried out without the presence of spare parts. Without a proper

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inventory of spares, operations may remain idle and suffer production losses. Campbell and Reyes-Picknell (2006) motivate that spares are procured and kept at the recommendation of manufacturers and not usually by persons responsible for maintenance. Having spares available at start up and during operation of a system ensures that downtime is kept to a minimum. The question to be answered is ‘which spares should be kept and in which quantities to facilitate maintenance since there is a definite trade-off between overstocking and understocking?’ Investment in spare parts can range from 5% to 15% of the total operating costs, depending on the industry and operations, and reducing a surfeit of spares can result in substantial savings and reducing capital investment (Mehrotra, Natraj, & Trick, 2001).

Maintenance of equipment or system is an area that has been extensively studied. Many literatures are also available, and various reviews and paradigms of classifications of maintenance policies can be found in Dekker, Wildeman, and Van Der Duyn Schouten (1997), Wang (2002), Pham and Wang (1996), Valdez-Flores and Feldman (1989) and Nakagawa and Mizutani (2009) amongst others. In a broad sense, maintenance policies can be classified as corrective or preventive based on whether failure is allowable or not, or as single- or multi-unit systems based on the number of units of items involved. Within these broad categories, other sub-categories could include the maintenance interval, whether it is finite or infinite, the repair type, whether it is minimal, imperfect or perfect, or the maintenance cost structure, whether it is constant, a function of unit age, or of number of repairs, etc.

A corrective maintenance can be defined to be all actions performed as a result of failure, to restore an item to a specified condition. Preventive maintenance means all actions performed in an attempt to retain an item in specified condition by providing systematic inspection, detection and prevention of incipient failures. The importance of making this classification is important because of the possible tragic implication of breakdown maintenance on some systems, e.g. the aircraft. There could be many intermediate positions between these two extremes, and this was well articulated Barlow and Hunter (1959), which is a classic for preventive maintenance policies.

While Barlow and Hunter (1959) basically consider infinite maintenance horizon, the reality most system not operate in finite time space has led to the development of many models for finite interval. Nakagawa and Mizutani (2009) provides a good reading in this regards. The paper converts three usual maintenance models of periodic replacement with minimal repair, block replacement and simple replacement into finite replacement models. Also, optimal periodic and sequential policies for an imperfect preventive maintenance and an inspection model for finite time span are considered.

While the basic models have been those of single units, the fact that many systems are made up of many similar units operating in series or parallel has led to a whole new area in maintenance policies. This is particular important in situations where failure is unacceptable. Of particular importance is the concept of redundancy and standby units. Definitions of these terms, however, have some variants. Gnedenko, Belyayev, and Solovyev (1969) classified redundancy as either active, complete inactive standby or partially energised standby redundancies. Our definition is taken from Lewis (1994), that redundancy can be classified as active or standby. Active redundancy utilises extra units (or capacity) operating simultaneously, such that failure occurs only if both the required and the extra capacity fails. Standby redundancy is a case where the extra unit is brought to work after the original unit has failed. This is achieved by use of monitoring and switching systems that identifies failure of original unit and switches to the standby. He further noted that standby redundancy could be hot, warm or cold. In cold standby, the standby shuts down completely and needs to go through a warm up before it can bear load. A warm standby is kept on, but bears no load, thereby eliminating the warm up period. A hot standby bears a minimum load, but not as much as the operating unit. There are many articles addressing this type of system.

The fact that many items may not be assumed to have returned to their initially perfect state after repair, or that the failure rate may be dependent on the age of the system leads to many other models of deteriorating systems (e.g. Wang, 2002; Valdez-Flores & Feldman, 1989). More recently, the importance of the effect of random operating environment on the maintenance policy is being considered by researchers (Pham, 2005b; Persona, Pham, & Sgarbossa, 2010). Also, shock models are being considered. Aven (1996) presented a general framework for analysing condition based replacement policies for stochastically failing units in the presence of shocks. Chen and Li (2008) studied optimal maintenance problem with extreme shocks and repair times forming the geometric process. These area are becoming important because the hazard function of many systems may depend on the environment in which the system operates, many of which could be random, and that many failure systems are precipitated by shock events. Many articles have been published addressing these areas.

1.3. Maintenance spares

Managers and engineers often erroneously apply general inventory management techniques to spares. From a financial perspective they realise that there is a need to reduce capital investment in common spares as well as safety stock. Management and control over the inventory is improved at the same time. Huiskonen (2001), however, proposes that inefficiencies arise when general inventory management techniques are applied to maintenance spares. Control characteristics for maintenance spares are neglected, not to mention the influence thereof on the entire supply chain of a company. Spares inventory management must be treated as a special case of general inventory management. When determining maintenance critical spares, the following control characteristics must be addressed:

- *Process and control criticality* – Process criticality relates to the consequence of a breakdown (failure) due to a spare not being available. The value can usually be quantified as the cost of downtime. Control criticality regards the probability of failure, availability of spare parts, and repair times to mention but a few. It entails the quantification of reaction time.
- *Specificity* – Maintenance spares need to be categorised in terms of generic (standard) spares and unique (specialised) spares. Generic spares usually have multiple suppliers and supply is not a problem. Such spares are readily available and the risk of non-supply thus low. Specialised parts, however, usually come from a single supplier and lead times may be erratic.
- *Demand patterns* – Spares generally have erratic low volume demand. This type of demand pattern results in end users having to carry the financial burden of stocking the items, especially critical high priced items. This type of setup is in direct contradiction to general inventory management rules that state low volume items should be pushed back in the supply chain, i.e. stocked by the supplier.
- *Commodity value* – Though inventory value is a common characteristic in all stocked items, spares do not create value by stocking them. While finished goods will be sold and produce turnover, spares will simply, at best, prevent or reduce the cost of production downtime.