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A non-zero integer non-linear programming model for maintenance workforce sizing

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ABSTRACT

This paper formulates a non-linear integer programming model to solve a maintenance workforce sizing problem with a productivity improvement goal. This problem is modelled in a bi-objective framework that minimises the number of maintenance personnel while maximising their productivity levels. Inputs into the optimisation model include monthly and routine maintenance periods, volume of production, contingency maintenance time, use factor and priority factor among others. The model has been validated with real-life detergent factory data, demonstrating its potential usefulness. A principal novelty of the model is the inclusion of use factor, which captures how often maintenance technicians are busy on the job with respect to assigned tasks, including unanticipated high maintenance workload. The model has been solved using a branch and bound algorithm. The impact of workforce structure and workers' salaries on model's performance has been studied and sensitivity analysis carried out to investigate the changes to the optimal solution as a result of changes in the input data. The results show a reduction in the number of maintenance workforce personnel in comparing values with and without use factor in the model. The model's ability to obtain global optimal result depends on the value of the minimum routine maintenance time within each maintenance section. Also, the model is shown to be sensitive to priority factor, which captures the appropriate ratio of full- and part-time workers under the same category. The model provides both an easy-to-use practical tool for maintenance managers and supervisors as well as a scientific tool for determining optimal maintenance workforce size for a manufacturing plant.

1. Introduction

Workforce sizing in manufacturing industries (Duffuaa and Raouf, 1992; Mosely et al., 1998) across the globe has received more attention than before in recent times due to the turbulent business environment, which generated stiff competition among industries and the purchasing power of customers that has declined, thus leading to reduced purchases of companies' products. Consequently, organisations are unable to keep large workforces and need to downsize for survival and the maintenance of business profitability (Naveh et al., 2007; Hargaden and Ryan, 2011). This development, which requires a careful planning for the workforce has also spread to service systems such as retailing, aircraft (Al-Sugair, 1994; Alfares, 1997, 1999), hospital buildings (Al-Zubaidi and Christer, 1997), information technology (Dixit et al., 2009; Chouhan and Goyal, 2010). The research scope brought about by the need to downsize, restructure or re-engineer the workforce system has gone beyond engineering to take advantage of other fields (i.e. psychology) for maximum benefit to the workforce and the system. In engineering systems, especially in maintenance engineering, different studies sought to address maintenance workforce problems (Roberts and Escudero, 1983a, b; Galpio et al., 1993; Al-Sugair, 1994; Alfares, 1997; Mosely et al., 1998). An important attribute of these studies is that they were conducted in developed countries where government policies are usually consistent over long period. In these studies the data used in testing models are usually obtained in environments where they are conducted with special attributes of such environments. However, since environments are different in developing countries, some of these data may not be applicable. Human factors (Dorn, 1996; Shepherd and Kraus, 1997), training policies (Iraturi et al., 1995; Brusco and Johns, 1996; Shepherd and Kraus, 1997), decision support systems (Dixit et al., 2009) and motivation (Maloney and McFillen, 1987) are the major considerations in modelling workforce problems and may largely be at variance in developing countries.

Over the years, several factors and influences have affected workforce considerations and one event that has significant effect on this experience/trend is the last global economic meltdown in 2008, which had catastrophic effects on business survival. This

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occurrence led to drastic reduction in the number of employees maintained in small-medium- and large-scale organisations world-wide, particularly in economies that depend on the importation of raw materials for their industries. This reduction has been aided using multi-skilled approach (Williamson, 1992a, b; Brusco and Johns, 1996; Bechtold, 1988; Stanley, 1997; Burleson et al., 1998; Gomar et al., 2002; Bamber et al., 2003). Williamson (1992a) considered the optimisation of maintenance of AIDE facilities using multi-skill approach. Varying productivity and training policies as they affect multi-skilled workforce were examined by Brusco and Johns (1996). Stanley (1997) investigated benefits, impediments and limitation of multi-skilled workforce utilisation strategies in construction. The strategies involved in the use of multi-skilled workforce with respect to the construction sector were the focus of Burleson et al. (1998). All these multi-skilling studies are also having their problems (Van den Beukel and Molleman, 2002); they fail to address prioritisation and use factor in workforce assignments.

Research and practice on workforce sizing is further encouraged due to a number of factors, including heightened workers absenteeism, poor product demand, poor machine utilisation, poor skilling attitudes, technological discontinuity and turnover of staff that are experienced in industries during this current turbulent business experience. The use of scientific workforce sizing tools may result in a reduced need for downsizing by organisations. The remaining sections of this paper are organised as follows: Section 2 presents the literature review, Section 3 deals with the model development while Section 4 presents model application and the discussion of results is presented in Section 5. The conclusion of this study is in Section 6.

2. Literature review

In the following review, literature is searched for documented sources relevant to workforce sizing in maintenance systems but the paucity of such studies reveals some gaps that exist and this validates the need for the current study. The substantial body of theory on workforce has related linkages: workforce studies have been carried out in diverse areas such as workforce scheduling (Nanda and Browne, 1992; Greenwood and Gupta, 2000), workforce planning, workforce quality assessment, workforce allocation, and workforce utilisation. For workforce maintenance scheduling, Mosely et al. (1998) studied workforce maintenance scheduling and policies in water fabrication facility. Alfares (1999) investigated maintenance workforce scheduling in aircraft industry. Santos et al. (2009) as well as Chouhan and Goyal (2010) considered scheduling of IT workforce. For workforce allocation, Baker (1974) examined workforce allocation with respect to cyclical scheduling problems. Gomar et al. (2002) studied workforce allocation in construction firms. Gharote et al. (2012) worked on allocation of workforce in IT organisations. The workforce utilisation literature also includes Campbell (1999) that investigated the problem of cross-utilisation of workforce with ranging capabilities. Workforce planning involves studies such as Al-Sugair (1994) that presented a model for aircraft maintenance division. Manpower requirement for aircraft firms was described by Dahlman et al. (2002) while availability of maintenance workforce for aircraft maintenance was studied by Hecht et al. (1998). Workforce quality assessment was investigated by authors such as Vessely (1984) who examined the quality of workforce in nuclear power plants. Moore (2005) investigated maintenance workforce quantity in USAF aircraft maintenance system. Furthermore. Moore et al. (2007) studied impacts of manpower quality on aircraft maintenance.

In order to address workforce problems as mentioned above, several solution and analysis methods have emerged in literature: simulation (Barnett and Blundell, 1981; Duffuaa and Raouf, 1992; Ntuen and Park, 1999), stochastic programming (Duffuaa and Al-Sultan, 1999), supply chain optimisation (Gresh et al., 2007), heuristic techniques (Bechtold, 1988) and more. From the review of literature, the use of branch and bound as an optimiser in obtaining optimal solution has not been fully explored in relation to manufacturing systems maintenance workforce. Also, we noticed lack of maintenance workforce model for detergent industries. These knowledge gaps motivate the current study. Now, in all these investigations, there is a paucity of studies on workforce sizing in maintenance system and the challenges being faced by system managers in properly deciding on maintenance workforce size shows the need for the current study. Furthermore, Judice et al. (2005) formulated a workforce and lot-sizing model for mail processing companies using integer programming. The objective function of the model was minimisation of total salary of employees. The model was solved using branch and bound algorithm. The paper concluded that to obtain good solution within a reasonable time frame, the use of decomposition technique was necessary. Thompson and Goodale (2006) addressed the problem of workforce scheduling. The study extended a previous study on workforce sizing with respect to employee productivity by introducing non-linearity into workforce model constraint. This helped in solving the problem of non-linearity of time staffing functions for different categories of workers having varying productivity. Their work helps our study in the formulating one of the objectives of our work (i.e. productivity goal) and also providing a basis for the need to comparing the proposed model performance under different scenarios.

From the above further review, it was observed that workforce sizing problem has been treated as single objective. While all these literature documentation provide a strong basis for further work, the current treatment of problems formulated for maintenance function has been very scanty in the literature. Till date, it is surprising that despite the maturity of maintenance area, very sparse information are still available to stakeholders to properly model workforce sizing in maintenance. From the above review and literature observations, few studies conducted in the arena of maintenance workforce sizing have conspicuously omitted productivity and use factor issues in their analysis and such paper include Dietz and Rosenshine (1997), Ntuen and Park (1999) as well as Savser (1990). If nothing is done to increase our knowledge and understanding in this area, maintenance may still continue to be a “bottomless pit of expenses” that it is being viewed as by some. Also, there is need for proper scientific judgements for the placement of workforce in maintenance. Again, planning for the maintenance function should be on a pro-active basis to take maximum advantage of the economy and technology available. Techniques that employ goal programming approach in optimising the number of workforce with the associated costs in the maintenance function have not been documented in literature. Hence, a research agenda for developing a new methodology that will minimise man-hour losses is provided and has motivated the need for this paper that has addressed this problem.

The proposed model in this paper will help human resource and maintenance managers in controlling the excessive amounts of workforce that are assigned to carry out the maintenance function in their establishments. Additionally, the implementation of the proposed model will reduce the cost of maintenance staff and also ensures optimal distribution of available maintenance workforce in the establishment. To solve the above problem, this paper presents a non-zero integer non-linear goal programming model that minimises the number of maintenance workforce while maximising their productivity. The formulated problem was solved using the weightage method in the conventional solution of goal programming.