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Competence-based performance model of multi-skilled workers ☆

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ABSTRACT

Effective human resource management requires an individual approach to worker appraisal in order to be able to make accurate analyses and to make informed decisions. In this paper we develop a competences-based analytical model of the performance of multi-skilled workers undertaking repetitive tasks. The aim is to build an analytical tool that better describes the capabilities of workers to perform repetitive tasks by binding together hierarchical competences modeled as a weighted digraph and learning curves to express individual learning rates. An illustrative example based on an assembly line using a discrete-event simulation model is provided. As a result we get an approach that calculates how work experience on one working post translates into performance on other posts, thus enabling better workforce scheduling. Incorporating competences-based modeling into planning and scheduling results in a more precise estimation of actual and future workforce performance.

1. Introduction

A competent workforce is a source of competitive advantage for a company (Liker & Convis, 2011). Machinery, equipment and tooling can now be purchased by anyone with the appropriate resources, all of them are readily available. The factor that differentiates companies is the know-how of its employees, which also forms the company's main asset. With the knowledge and intelligence of its employees, a company is able to effectively manage its own resources, take actions to improve its performance and innovate.

One noticeable megatrend for many years has been mass customization, wherein customers look for personalized products tailored to their requirements and fully meeting their expectations. This trend can be observed in the automotive, consumer electronics, textile, fashion and many others industries (Fogliatto, Da Silveira, & Borenstein, 2012). Mass customization requires manufacturing systems that are flexible, while keeping continuous price/cost pressure. A traditional approach to flexible manufacturing systems, which originated in the early 1980s, is to rely on production using automated CNC machines, automated material handling systems and central computer control. CNC machines are very sophisticated, can perform many different technological operations but are quite expensive. Automated materials handling systems are flexible, yet only within a certain predefined range. In theory computer integrated manufacturing was an excellent idea but in reality again these kinds of system were very expensive and were not as flexible as expected. For these reasons, among other things, lean management became widespread in the production world, a set of common-sense practices from the experience of many manufacturing practitioners.

Mass customization, flexibility and agility are built into the lean management approach, which stresses the very important role of the workforce, seen as a main asset and a source of competitive advantage (Liker & Convis, 2011). One of the fundamentals of lean management is the multi-skilled employee, having the competences, experience and knowledge to perform many different simple and complex tasks. Employees are a source of flexibility as they are capable of seamlessly changing their roles according to the company's needs (Womack & Jones, 2010). This facilitates adapting to a changing environment and customer requirements. A company with multi-skilled workers can function with a lower number of staff. Workers who are single-skilled may sit idle waiting for work to become available. Multi-skilled workers are assigned to work, and do not wait for work to come to them. In a company with a multi-skilled workforce, planning focuses on the needs of the customer, not on the capabilities of the staff. This leads to a reduction in the number of idle hours. Multi-skilled workers are familiar with consistently learning new skills and adapting to changes. Employee satisfaction improves morale in a business, which leads to increases in productivity and employee retention rates. An experienced and well-trained multi-skilled workforce translates directly into higher productivity, better quality and lower costs.

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In this paper we will focus on a competence, performance, learning and experience modeling and analysis of multi-skilled workers, who perform repetitive operations in their daily work. Apart from the purely manual skills, workers must also often have some kind of theoretical knowledge, domain specific knowledge and experience. Sometimes they also independently solve small problems or make simple decisions. Workers therefore have specific skills and a level of flexibility, which are highly individual qualities. The treatment of all employees as identical in terms of their manual skills, ability to learn and ability to cope with difficult situations is a major simplification, leading to inefficient human resource management. Effective management of the process should therefore take into account the human factor in an individual way in order to perform accurate analysis and make informed decisions. In this context, human resources and humanization can be seen as a natural source of flexibility and responsiveness and play a similar role as automation and central planning approaches did in the past decades (Boucher, Bonjour, & Grabot, 2007). This approach requires a re-definition of those processes that had been analyzed mainly in terms of technology (technology-centered).

In literature, the arbitrarily defined human factor affecting organizational performance is referred to as 'competence' (Boucher et al., 2007). This concept has an official definition in ISO standards (International Organization for Standardization). For example ISO 9001 (2008) defines 'competence' as "the ability to apply knowledge and skills to achieve intended results". This definition is highly versatile and can therefore be used at different levels of organizational management and in the analysis of various processes.

The analysis of worker performance based on competence requires a more precise formalization of the concept in order to determine its impact on a specific technological operation (Boucher et al., 2007). Literature is rich in studies devoted to modeling and analysis of knowledge-based organization. Competences have mainly been analyzed in the context of knowledge industry workers, i.e. software developers or engineers involved in project-based activities (Loufrani-Fedida & Saglietto, in press), which differs from the mainly repetitive character of production activities. But there is a lack of works with a precise description of the relationship between the competence and the performance of workers. Apart from classical learning curves and simple optimization models, usually with ordinal scale parameters, literature lacks studies that employ a more complex and precise formalization of worker competence in a repetitive work context.

A combination of competence models together with learning curves in one analytical tool would facilitate taking into account, when building schedules, individual worker competence levels and the changes over time as a result of acquiring experience through work. The novelty of this paper is thus threefold.

- First, we have developed a performance model of multi-skilled workers by combining, for the first time, two concepts: learning curves and competence sets. As a result we get a tool that can precisely enumerate worker competence, and then use it in performance estimations, while taking into account that worker performance changes with experience, as described by the number of repetitions. The reasons behind this idea are from observations that competences are hierarchical and interrelated, and that learning curve models completely neglect this fact.
- The second novelty is a competence update algorithm, which keeps track of current competences of workers. This algorithm takes into account the competence structure (described as a competence weighted digraph) and the number of executed task repetitions.
- The third novelty is in combining the competences-based performance model of multi-skilled workers with a discrete-event simulation that permits precisely defining a moment of change in competence strength even in complex circumstances for large groups of workers and multi-stage production systems. The simulation permits scenario testing, looking for optimal solutions or for conducting sensitivity analyses.

This paper is further organized as follows. The following second section presents a summary review of literature. The competence model may be found in the third section, followed by a specification of the competence update algorithm in section four. In the fifth section a computational example of an assemble line, with results and a discussion are presented. The final sixth section concludes the paper with a summation and further issues to be taken into consideration.

2. Literature review

2.1. Learning curves

The first to describe the "learning curve phenomenon" was Wright who in 1936 provided the first equations for use in obtaining cost estimates based on repetitive assembly production. Since then the learning curve approach has gained popularity and has been applied to many industries: automotive (Wang, Sowden, & Mileham, 2013), machine (Tanimizu, Ishii, & Yokotani, 2014), electronics (Weber & Fayed, 2010), construction (Jarkas, 2010). Repetition causes workers to take less time to perform such tasks due to increasing familiarity with the operation and tools. Dependent variables (performance measures of workers) in learning curve models could be: number of units produced per time interval; time to produce a single unit, costs to produce a single unit, or percentage of non-conforming units (Anzanello & Fogliatto, 2011).

When working with learning curves it is very important to precisely determine the theoretical first unit time or cost, learning curve model and curve slope (Stewart, Wyskinda, & Johannes, 1995). In literature, guidelines have been echoed for various industries (Smunt, 1999), manual labor versus machine work (Stewart et al., 1995). Learning curve models could incorporate prior experience (Cherrington, Lippert, & Towill, 1987) and forgetting (Grosse, Glock, & Jaber, 2013; Heimerl & Kolisch, 2010b). Depending on how many dependent variables are taken into account, univariate or multivariate non-linear models could be applied. The most popular models are based on: log-linear, exponential, hyperbolic or sigmoid functions (Anzanello & Fogliatto, 2011).

2.2. Multi-skilled workers assignment

Multi-skilled workers, also called cross-trained, can competently perform technological operations on more than one workstation. Multi-skilled workers can be assigned more easily to a job, depending on the requirements of the current organization. Cross-training increases the flexibility of labor to deal with fluctuating demands. High workload imbalances require more extensive cross-training to improve job performance. The very popular lean management approach in the manufacturing world requires that all workers are multi-skilled (Liker & Meier, 2005). Some kinds or production arrangements are impossible to realize without multi-skilled workers. This is true for U-shaped production lines where the number of workers on a production line depends on the workload (Miltenburg, 2001). In the case of a low workload, a worker has to operate a higher number of workstation, i.e. has to have more skills. If there is a lack of cross-trained workers, even