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Competences-based performance model of multi-skilled workers with learning and forgetting

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ABSTRACT

The relationship between performance and experience is non-linear, thus planning models that seek to manage workforce development through task assignment are difficult to solve. This gets even more complicated when taking into account multi-skilled workers that are capable of performing a variety of tasks. In this paper we develop a competences-based analytical model of the performance of multi-skilled workers undertaking repetitive tasks, taking into account learning and forgetting. A learning curve can be used to estimate improvement when repeating the same operation. Inverse phenomenon is forgetting, which can occur due to interruption in the production process. The Performance Evaluation Algorithm (PEA) was developed for two cases: fixed shift duration and fixed production output. The aim was to build a tool that better describes the capabilities of workers to perform repetitive tasks by binding together hierarchical competences modeled as a weighted digraph together with a learning and forgetting curve model (LFCM) to express individual learning rates.

1. Introduction

Workforce planning and scheduling had became a manager's central point of interest since the onset of the lean revolution lead by Toyota and its followers (Liker & Hoseus, 2008). Great potential for improvement lies in underutilized human resources. It is not merely enough to optimize the use of machinery and logistics procedures, as a company is in the first instance the people working in it. The employees are the most competitive advantage and a source of continuous improvement. While for many companies the cost of labor is the major direct cost component, optimal workforce scheduling could be employed to reduce this cost. Workforce planning is still one of the most complex problems faced by managers. As a company grows in size, these problems also become increasingly difficult. In broad terms, workforce planning encompasses the problems of: hiring and dismissing, staffing and scheduling, and shifting policies (De Bruecker, Van den Bergh, Beliën, & Demeulemeester, 2015; Van Den Bergh, Beliën, De Bruecker, Demeulemeester, & De Boeck, 2013). Personnel scheduling problems are usually NP-hard ones and can be formulated as integer linear programs. For some small sized instances, LP-solvers can be used, complex problems can be solved by heuristics, which combine local search and network flow techniques (Brucker, Qu, & Burke, 2011).

Lean management promotes the idea of multi-skilled (cross-trained) workers that are prepared to operate on many working posts (Liker & Meier, 2007). Multi-skilling has many positive effects like: improvements of communication among workers, increase of job satisfaction and self-motivation, less boredom, less repetitive stress and less fatigue (Wang, Sowden, & Mileham, 2013). An experienced and well-trained multi-skilled workforce translates directly into higher productivity, better quality and lower costs. Workers are able to fill in for absent employees and work in an area requiring increased manpower at any time, and for any duration. This allows maintaining production levels under many circumstances that would otherwise leave workers idle or profits lost. 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 change. Multi-skilling can be developed through a variety of techniques: coaching and mentoring, job-rotation, job-shadowing, self-learning, or team-based cross-functional projects.

A multi-skilled worker, because of the wide range of competences, is often transferred from one task to another depending on client demand and the organizational needs of the company. As a result, periods of intensive work will be interspersed with idle periods for a particular task. Over the working time, proficiency in executing the task will increase and during the idle periods the proficiency is expected to diminish. When the skills of a worker are not interrelated between tasks, i.e. experience in

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Nomenclature

i, j	the competence index
k	the multi-skill worker index
n	the working post index
m	the schedule index
G	the competence graph
G_i	the compound competence graph for competence c_i
C_i	the set of compound competence for competence c_i
c_i	the competence
R_i	the set of relations between competences for competence c_i
$r_{i,j}$	the relation between competences c_i and c_j
Γ_i	the competence relation force set for competence c_i
$\gamma_{i,j}$	the competence relation force between competences c_i and c_j
p_k	the multi-skill worker
w_n	the working post
$\lambda_{i,n}$	the strength threshold for required competence c_i at working post w_n
$l_{i,k}$	the learning rate for worker p_k performing a task requiring competence c_i
$f_{i,k}$	the forgetting rate for worker p_k for competence c_i
$u_{i,k}$	the number of executed task repetitions requiring competence c_i by worker p_k (experience level)
$\tau_{i,k}$	the time competence c_i was last used by worker p_k
$\tilde{\tau}$	the current time
$T1_i$	the theoretical time required to execute a first time task requiring competence c_i
$tB_{i,k}$	the production break duration to achieve total forgetting of competence c_i by worker p_k
$tb_{i,k}$	the production break duration (since it was used last time) for competence c_i by worker p_k
Tw	the time for performing operations
s_m	the schedule task
$y_{i,k}$	the theoretical production output as a result of use of competence c_i by worker p_k

performing one task does not translate into performance in another task, the well-known learning forgetting models apply for these circumstances (Jaber & Bonney, 1997; Nembhard & Uzumeri, 2000). In reality these skills are often related, as they could be used for example in consecutive working posts on a production line. In this case learning forgetting models are not able to reflect the full experience gaining process.

There can be many reasons for interruptions in the production process, which results in forgetting:

- Several different products are produced alternately in the same factory's production line. The production period between two consecutive batches of the same product can be seen as the interruption resulting in forgetting (Globerson & Levin, 1987).
- Preventive maintenance or seasonal factory shutdowns resulting in turning off the machines and production lines.
- Fluctuations in demand. When demand for one product in high more workers are assigned to produce it and when the demand is low the workers are assigned to other products with higher demand.

To describe possessed skills of a worker and task dependent skills, we will use the concept of competence as it is broader than skills and thus allows embracing both hard (technical) and soft expertise. ISO 9001 (2015) defines 'competence' as "the ability to apply knowledge and skills to achieve intended results". This definition can be applied at the various levels of an organization and in the analysis of a variety of processes.

Analysis of worker performance based on competence requires precise formalization of the concept in order to determine the impact on a specific technological operation (Boucher, Bonjour, & Grabot, 2007). 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, 2016). Malachowski and Korytkowski (2016) have developed a model that ties competences with the performance of a worker in a quantitative way, based on measurement of the number of executions in repetitive tasks.

In this research we will focus on the estimation of worker performance as a function of competence and experience in performing similar and repetitive tasks. Estimation of worker performance is the bedrock for all planning and scheduling algorithms. They require as an input parameter a precise estimation of task duration. In the case of scheduling tasks carried out by machines, it is much simpler as the machine's working cycles are repeatable. When a worker performs a task, and assuming that the duration of the task is standard (or expected to be), then the duration is a source of variability and as a consequence we get a schedule, which, in reality, leads to results with poor repeatability.

The novelty of this research lies in developing a competence-based performance model of a multi-skilled worker with the learning and forgetting phenomenon. This was done with the use of the Learning Forgetting Curve Model developed by Jaber and Bonney (1996). That model, however, does not take into account that during breaks in executing task A, the worker could be utilized to execute task B with some similar features, and in the sense of experience could be beneficial later when returning to task A.

This paper is further organized as follows. The following, second section presents a summary literature review. The competence model is outlined in the third section, followed by a brief introduction to the Learning and Forgetting Curve Model. A Performance Evaluation Algorithm is developed in the fifth section. The sixth section contains computational examples, with results and discussion. The final section concludes the paper with a summary and notes on issues to be taken into consideration.

2. Literature review

In the literature review we will focus on the two basic concepts that constitute the core of the developed model: learning forgetting models and competence management systems.

2.1. Learning forgetting models

Learning forgetting models fall within a more general class of learning curve models initially proposed by Wright in 1936. A recent and comprehensive state of the art summary in this area is presented by Anzanello and Fogliatto (2011). Over the last eighty years, learning curve models have gained popularity and have been applied in many industries: automotive (Wang et al., 2013), machinery (Tanimizu, Ishii, & Yokotani, 2014), electronics (Weber & Fayed, 2010), and construction (Jarkas, 2010). 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, and percentage of non-conforming units (Anzanello & Fogliatto, 2011).

Dar-El (2000) presents a review of learning models with forgetting. Jaber and Bonney (1996), based on Wright's model, have presented the Learning Forgetting Curve Model (LFCM). Using LFCM it is possible to estimate the duration of a production batch knowing the worker's experience (number of executed repetitions) and duration of production breaks (which diminish experience).