Invited Review

Workforce planning incorporating skills: State of the art

Philippe De Bruecker [a,*], Jorne Van den Bergh [b], Jeroen Beliën [b], Erik Demeulemeester [a]

[a] KU Leuven, Research Center for Operations Management, Leuven, Belgium
[b] HUBrussel, Center for Informatics, Modeling and Simulation, Brussels, Belgium

A B S T R A C T

This paper presents a review and classification of the literature regarding workforce planning problems incorporating skills. In many cases, technical research regarding workforce planning focuses very hard on the mathematical model and neglects the real life implications of the simplifications that were needed for the model to perform well. On the other hand, many managerial studies give an extensive description of the human implications of certain management decisions in particular cases, but fail to provide useful mathematical models to solve workforce planning problems. This review will guide the operations researcher in his search to find useful papers and information regarding workforce planning problems incorporating skills. We not only discuss the differences and similarities between different papers, but we also give an overview of the managerial insights. The objective is to present a combination of technical and managerial knowledge to encourage the production of more realistic and useful solution techniques.

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1. Introduction

The planning of the workforce in a company is one of the most difficult problems managers face. As the size of the company increases, the problem tends to get more and more difficult. The workforce planning defines when and how many employees should be hired or dismissed and when these employees should work. Hence, it is a combination of staffing and scheduling decisions. Workforce planning problems entail some special features that are absent in all other types of resource allocation problems. When people are involved, the decision environment tends to get very dynamic and workforce planners face an extremely heterogeneous set of employees. One must not only take into account different employee preferences and union constraints, but also the different skills that workers may possess.

In this research, we define skills as the ability of a worker to perform certain tasks well. In certain problems, some tasks can only be carried out by personnel members who possess a specific skill and/or skill level. Other problems focus on the differences in performance of differently skilled persons and try to maximize some company specific performance measures like quality or speed of work. Sometimes, differently skilled persons entail different costs and the company wants to minimize the total labor costs. In these examples, the skills of a worker have an intuitive and direct effect on task restric-

tions, efficiency, quality or costs. However, incorporating skills in a workforce planning problem often involves some unexpected effects too that are not always easy to grasp correctly. Skill substitution and cross-training, for example, can have a positive or negative effect on performance depending on the situation. In addition, incorporating skills also entails learning effects, the effects of mixing different types of skills and the effects of teamwork.

On top of these complex consequences of different skills, finding a good solution technique appears to be even more difficult, especially when real-life problems are considered.

2. Research objectives

The objective of this paper is to provide an overview and classification of the literature to guide the operations researcher in his search to find useful papers and information regarding workforce planning problems incorporating skills. The unique feature of this approach is that we not only consider the relevant technical literature, but also the managerial literature. The main idea is that skill related workforce decisions actually belong to human relations management, but should be made based on sound technical methodologies. Unfortunately, only few papers succeed in combining both aspects. On the one hand, technical research regarding workforce planning usually focuses on the mathematical model and neglects the real life implications of the simplifications that were needed for the model to perform well. The inclusion of skills into the problem remains in many cases limited to the section of future research. Another problem that arises is that the formulated model is not yet applied or tested with real

* Corresponding author. Tel.: +32 472667543.
  E-mail addresses: philippe.debruecker@kuleuven.be (P. De Bruecker), jorne.vandenbergh@kuleuven.be (J. Van den Bergh), jeroen.belien@kuleuven.be (J. Beliën), erik.demeulemeester@kuleuven.be (E. Demeulemeester).

data in many papers (Van den Bergh, Beliën, De Bruecker, Demeulemeester, & De Boeck, 2013). On the other hand, many managerial studies give an extensive description of the human implications of certain management decisions in particular cases, but fail to provide useful mathematical models to solve the problem (Buchan & Dal Poz, 2002).

This paper first focuses on the managerial knowledge regarding skills in workforce planning problems. Next, the state of the art of the technical knowledge in operations management literature is reviewed concerning mathematical models for solving workforce planning problems incorporating skills. Many technical research papers do not consider all possible consequences of certain decisions regarding skills or make wrong or incomplete assumptions in their model. Such models do not represent a realistic scenario and are likely to fail in real life applications. In Section 3, we investigate the dynamics of different skill types that are used in the literature to obtain a good representation of reality. This is useful for the operations researcher to check the correctness and completeness of his model. In Section 4, an overview is presented of the techniques that are used to model and solve different skill related workforce planning problems.

To search for relevant literature on skill related workforce planning, we first looked for review articles. Unfortunately, no review papers exist that are dedicated to skills in workforce planning problems. Some review papers exist that focus on general workforce planning problems (Alfares, 2004; Burke, De Causmaecker, Vanden Berghe, & Van Landeghem, 2004; Ernst, Jiang, Krishnamoorthy, & Sier, 2004; Kohl & Karisch, 2004; Van den Bergh et al., 2013), but none goes into detail regarding skills. The collection of articles reviewed in this research consists of the relevant articles presented by the previous general review papers (Alfares, 2004; Burke et al., 2004; Ernst et al., 2004; Kohl & Karisch, 2004; Van den Bergh et al., 2013) and the articles resulting from our direct search as well as references therein. We limited our search to papers published after the year 2004 and the cut-off date is December 2012. Exceptions were made for interesting older papers that were cited multiple times.

To the best of our knowledge, this paper is the first literature review that combines managerial insights and technical and mathematical knowledge to guide the operations researchers to solve workforce planning problems incorporating skills.

3. Managerial aspects of skill related workforce planning

As an operations researcher, it is important to identify all potential factors that may impact the workforce decisions. In this section, different types of skills are defined and we analyze the impact of different skill types on the problem formulation.

3.1. Definition of skills

In this literature review we define skills as the ability to perform certain tasks well. As this is a very broad definition, we identify two different skill classes to structure our analysis of the skill literature; the hierarchical class and the categorical class. Next, we consider six main skill determinants that are used in the literature to determine skills. Finally, we look at the performance measures used in operations research papers that are impacted by the skill level of the employees.

Defining different classes and types of skills facilitates the investigation of the different consequences and dynamics of including skills in a workforce planning problem. This is very helpful since many researchers, e.g., Buchan and Dal Poz (2002), Markes (2006) and Gibbs, McCaughan, and Griffiths (1991) complain about the haziness concerning the effects of skill decisions. Markes (2006) also mentions that there still remains some uncertainty concerning the impact of different ways to manage the skill pool. This section gives an overview of the dynamics and effects of skills presented in the literature in order to reduce the haziness surrounding skills.

3.1.1. Skill classes

By analyzing the technical and managerial literature concerning skills in workforce planning, we discovered two different skill classes: the hierarchical class and the categorical class. This classification is very useful because both classes appear to have different effects when skill substitution and cross-training is allowed (see Section 3.2).

In case of hierarchical skills, workers with a lower skill level can do less than workers with a higher skill level. Workers with a higher skill level are more educated or have more experience and can therefore perform more tasks, or they can perform certain tasks better or faster. When skills have a hierarchical nature, higher skilled persons can perform the tasks that are normally performed by a lesser skilled person. This is referred to as substitution. While substitution is always possible in this case, the company can decide whether or not to allow it. Hierarchical skills are usually defined on a continuous scale but are sometimes discretized in several skill levels. Some researchers even only use two levels: skilled or unskilled (Corominas, Pastor, & Plans, 2008; Fragnière, Gondzio, & Yang, 2010; Gordon & Erkut, 2004; Lagodimos & Leopoulos, 2000; Lagodimos & Mihiotis, 2006; Techawiboonwong, Yenradee, & Das, 2006).

In case of categorical skills, there is no difference in skill level and the skills of a worker determine which tasks he or she can perform. In this case, the skills of one person are not better or worse than the skills of another person. Hence, the different skills cannot be hierarchically ranked. When a person has a skill that allows him to perform more than one task, he actually possesses all separate skills to perform each single task. We refer to a worker who possesses different categorical skills as a cross-trained worker.

Table 1 shows the papers that make use of hierarchical and categorical skills. While most papers only consider one skill class in their problem, some researchers consider both classes at the same time (Bellenguez & Néron, 2005; Bhatnagar, Saddikutti, & Rajgopalan, 2007; Eiselt & Marianov, 2008; Eitzen, Panton, & Mills, 2004; Firat & Hurkens, 2012; Fowler, Wirojanagud, & Gel, 2008; Heimerl & Kolisch, 2010; Valls, Pérez, & Quintanilla, 2009) and talk about skill domains or categories and skill levels. In these papers, the authors assume that there exists a hierarchical structure in each skill category. Eiselt and Marianov (2008), for example, position each employee and each task in a skill space. Each dimension in this space represents a different skill and the position in each dimension represents the skill level. As is discussed in Section 3.2, different skill classes can have different implications. Therefore, the definition of the considered skill class is very important since it determines which dynamics will come into play. Fortunately, the number of papers that do not define the skill class is very limited (Batta, Berman, & Wang, 2007; Drezet & Billaut, 2008; Eveborn, Flisberg, & Rönnqvist, 2006; Günther & Nissen, 2010; Huang, Lee, Song, & Eck, 2009).

3.1.2. Skill determinants

In Table 2, we identify six different skill determinants and classify the corresponding papers according to the respective skill class. The skills of a person can be determined by the age or the experience of the employee, the degree of technical knowledge he acquired or the licenses and qualifications he received. The first three determinants in Table 2 (the age, the experience and the degree of technical knowledge) belong to the hierarchical class. The fourth determinant in Table 2 (licenses, qualifications or job title) belongs to the categorical class. Therefore, a worker with skills determined by the third determinant (degree of technical knowledge/capability) can perform a certain task better/worse than a worker with a lower/higher degree of technical knowledge. A worker with skills determined by the fourth determinant can do other things compared to a worker with other licenses/qualifications/job title. Note that for the second to the fourth determinant, some papers can be found in both the hierarchical