Int. J. Production Economics 144 (2013) 383–396

Contents lists available at SciVerse ScienceDirect

Int. J. Production Economics

journal homepage: www.elsevier.com/locate/ijpe

Design and operations planning of municipal foodservice systems

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ARTICLE INFO

Article history:
Received 22 June 2011
Accepted 4 March 2013
Available online 14 March 2013

Keywords:
Foodservice sector
Integrated planning
Multi-skilled workforce

ABSTRACT

The foodservice sector is associated with a limited possibility of storing foods due to shelf life restrictions, a labor-intensive production environment with various skill requirements, low profit margins, and an extensive set of regulations and expectations regarding the quality of meal provision. Inspired by a municipal foodservice case in Denmark, we discuss the main challenges in the design and operations planning for the foodservice sector explaining the necessity of taking an integrative approach. Accordingly, a hierarchical planning methodology is developed focusing on integrating planning of the required multi-skilled workforce with the planning of production and distribution. Decisions are classified as design and operational depending on their aggregation level and formulated as generic mathematical models, which are applicable to similar cases. The developed models are subsequently solved in a case-tailored solution procedure. The numerical results presented in the paper show that our integrative approach results in lower total costs as well as a significant reduction in the number of necessary temporary staff. Further, it is shown that better results can be obtained when the integrative approach is combined with an extension of shelf life, a penalization of transhipments and a recruitment of staff with different types of skills.

1. Introduction

Delivery of meals from institutional kitchens is becoming more and more important, particularly for nursing homes, meals-on-wheels providers, schools and kindergartens. This is especially true in western societies where the demographic development is towards an increasing number of elderly who live in nursing homes. For instance, in Denmark, citizens of over 65 years of age or below 6 comprise about 21% of total population of Denmark (Statistics Denmark, 2010), and this figure is expected to increase to about 26% in 2023. Such significant growth indicates the potential role that prepared meal delivery plays in the daily food intake in the Danish society. Next to the growing quantity of meals delivered through institutional kitchens, concerns about the quality of the food provided through these centers are also increasing. On the level of generic food chains, Trienekens and Zuurbier (2008) analyzed the growing concern regarding food quality and stated that we may expect that quality assurance will dominate the process of production and distribution. Regarding foods that are particularly delivered through institutional kitchens, the growth in implementation of feedback routines among nursing homes on acceptability of food services from 1995 till 2003, reported by Mikkelsen et al. (2007), indicates an increasing concern about the quality of meals delivered to the elderly. In addition, further legislative incentives are recently put into action to increase the quality of served meals in these institutions.

With regard to the main production processes, meal production environments can be classified into conventional (cook-hot-hold), cook-chill, and cook-freeze production systems (Rodgers, 2005). In cook-chill and cook-freeze environments, the time between production and consumption of meals is extended, leading to a situation where meals are produced, stored, transported, and possibly stored again before they are consumed. Such considerations increase the need to integrate the planning of production and distribution operations.

Prepared meal delivery to nursing homes and kindergartens is usually carried out under limited public funding. Especially in today's aging society, the total budget to allocate to prepared meal delivery is an important political subject. In Denmark, the supply of food to the elderly and school children is organized on a municipal level. Therefore, each municipality has to decide on the budget it allocates to best design and operate its meal delivery system. Moreover, the elderly and school children are expected to receive high quality food despite the limited available funding. Therefore, optimization of the production and distribution operations, leaving a larger share of the budgets to invest in high quality ingredients, is essential in municipal foodservice operations. Besides, due to the broad range of required skills to perform different production operations in this industry, the production capacity is often limited by the availability of skilled labor.

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http://dx.doi.org/10.1016/j.ijpe.2013.03.004

As a result, hiring and assignment of skilled labor to production operations should be made in coordination with production and distribution plans.

The aim of this paper is to provide decision support models for the design and operations planning of municipal meal production and delivery systems. The contribution of our work is a planning approach integrating the planning of multi-skilled workforce with production and distribution operations in the foodservice industry. To this end, we first organize the related decisions into long-term and short-term decisions and then develop a generic hierarchical modeling approach for this problem. The developed models are subsequently solved through a solution framework, which connects the long-term and short-term decisions, and handling the potential infeasibilities and sub-optimalities. The solution quality of the framework is further strengthened by taking the customer order arrival process into account. Numerical analyses, inspired by a Danish case municipality, indicate the value of integrative planning approach for the foodservice industry.

The remainder of this paper is organized as follows. In the next section, related research will be discussed. Then, Section 3 presents the problem description in more detail through explaining the case study. In Section 4, the modeling framework and the mathematical representation of the problem are discussed. The solution approach is explained in Section 5 followed by the numerical analysis. Finally, the paper concludes and the future research directions are presented.

2. Related research

Coordination of production and distribution operations often leads to significant improvements especially for industries where the possibility of inventory storage is quite limited due to product or market characteristics. Chen (2010) reviewed and classified integrated production and distribution studies on the basis of their modeling and solution algorithm characteristics. Such integration is very important in the food industry, due to the specific characteristics of food products, especially shelf life considerations. Regarding agro-food industry, Lowe and Preckel (2004) and Ahumada and Villalobos (2009) extensively reviewed planning problems focusing on production and distribution of crops. As one of their key findings, they concluded that the literature suffers from insufficient research on integrated planning problems in the agro-food industry. Later, Rong et al. (2011) showed the benefits of effectively integrating food quality depending on time and temperature with production and distribution planning in a general food supply chain framework. As one of their main findings, they concluded that setting temperature appropriately in different stages of supply chain, as opposed to considering it as a given parameter, has a significant influence on products quality as well as costs. A thorough review of quantitative approaches in food distribution management is presented by Akkerman et al. (2010), also including integrated production and distribution problems. They focus on the activities after the provision of food ingredients, and conclude that the available studies have mainly focused on retail applications apart from a few exceptions.

Among the limited research in the foodservice industry, integrated meal production and distribution planning is first analyzed by Chen et al. (2009). They considered a centralized single-resource production environment with stochastic demands. Their aim is to maximize the expected profit including a quality-related cost component. Later, Farahani et al. (2012) and Amorim et al. (2012) investigated the benefits of integrating production and distribution operations for perishable food products with more focus on quality improvement in two different supply chain contexts. To ensure applicability of their models to different cases, they considered a general production setting with multiple production resources and setup costs, employed the block planning concept, previously investigated in food production scheduling by Günther et al. (2006), and developed heuristic methods to solve the resulting production and distribution problem. They illustrated that using an integrative approach a considerable improvement of the quality of food products can be obtained without a significant increase in the total costs.

The previously discussed work considers production capacity in terms of physical production equipment. In the foodservice industry, labor is however often the key capacity factor. Due to the broad range of skills required to perform different operations, hiring the correct number and mix of employees to be assigned to different production operations is an important and challenging task. Such a planning problem can be identified as one classes of workforce planning and scheduling.

Workforce planning and scheduling encompasses a wide scope of well-researched academic problems ranging from strategic decisions on the number of required employees over a long horizon studied as early as Abernathy et al. (1973), to recent studies of the short-term scheduling of individual employees, *e.g.*, Stolletz (2010). In our study, we deal with two tactical and operational level workforce planning decisions. On the tactical level, we make staffing decisions related to the optimal number of staff to be hired as well as their potential training requirements. On the operational level, a sufficient number of available staff is assigned to different production activities on the basis of the activity requirements and the skills of the staff. Also, extra temporary workers can be hired on the operational level on an as-needed basis. However, the detailed scheduling of individual workers is not considered in this paper.

As presented in Ernst et al. (2004), several authors (Love and Hoey, 1990; Loucks and Jacobs, 1991; Goodale and Thompson, 2004; Thompson and Goodale, 2006) researched workforce planning and scheduling in the foodservice industry. However, all these studies focus on the operational problem of developing tour schedules for individual staff. Among the related studies on planning workforce with multiple skills in other industries, the following prominent articles share more similarities with our problem definition. Grunow et al. (2004) investigated the problem of planning and scheduling multi-skilled workforce for running the clinical studies in pharmaceutical industry through developing a two stage hierarchical model. Fowler et al. (2008) extended the work by Wirojanagud et al. (2007) through developing heuristic algorithms for general workforce planning problem with worker differences focusing on the influence of cross-training programs on increasing workforce flexibility. Bhulai et al. (2008) developed a two-step method for determining the staffing level and scheduling shifts in a multiskill call center environment. Rong and Grunow (2009) investigated the problem of planning permanent and temporary workforce in air cargo terminals.

This paper takes a quantitative approach to re-structuring and optimizing foodservice operations. To do this it takes an integrated approach to the planning of workforce, production and distribution operations. As such, our work contributes to the literature on foodservice management by analyzing this problem for a typical foodservice case representing a multi-site, multi-stage meal production and distribution system, serving a variety of different customers.

3. Problem description

In defining this problem, we got inspired by a foodservice case in a Danish municipality. The case exhibits several characteristics that are typical for the foodservice sector. The municipality in our