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A case study on using evolutionary algorithms to optimize bakery production planning

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ABSTRACT

The production of bakery goods is strictly time sensitive due to the complex biochemical processes during dough fermentation, which leads to special requirements for production planning and scheduling. Instead of mathematical methods scheduling is often completely based on the practical experience of the responsible employees in bakeries. This sometimes inconsiderate scheduling approach often leads to sub-optimal performance of companies. This paper presents the modeling of the production in bakeries as a kind of no-wait hybrid flow-shop following the definitions in Scheduling Theory, concerning the constraints and frame conditions given by the employed processes properties. Particle Swarm Optimization and Ant Colony Optimization, two widely used evolutionary algorithms for solving scheduling problems, were adapted and used to analyse and optimize the production planning of an example bakery. In combination with the created model both algorithms proved capable to provide optimized results for the scheduling operation within a predefined runtime of 15 min.

1. Introduction

Many bakery goods contain yeast (*Saccharomyces cerevisiae*) as a proofing agent. This form of proofing is a fermentation performed by microorganisms in which sugars are metabolized to CO_2 (among other components), as can be seen in Fig. 1. Due to this fermentation process the production of such goods is not highly but strictly time sensitive from the point on, where the microorganisms get in contact with water and substrates under preferable conditions of temperature and humidity, as happens in the dough production process.

The upmost shown metabolism is the most influential and most common in yeast containing doughs. Due to the common existence of lactic-acid bacteria in dough the lactic fermentation also occurs but rather influences the aroma than the texture of dough. The retention of CO_2 produced by yeast is given by the dough matrix surrounding the gas bubbles and leads to a desired volume increase. Over time the amount of CO_2 increases due to yeast activity and thus the gas pressure in the gas bubbles increases likewise. Up to a certain degree the dough matrix can withstand the structural stress induced by the increasing gas pressure, but after exceeding the maximum gas retention ability the dough matrix and thus its structure collapses more or less complete with respect to the present gas pressure and thus as a function of fermentation or proofing time.

Cooling can be used to regulate or slow down the fermentation speed of yeast but is costly and sometimes accompanied with negative influence on the product quality. Due to this and the decrease of product quality (up to the total loss of marketability) induced by a too long unregulated fermentation process, the time dependency of the processing of yeast containing doughs has always to be considered in the production scheduling.

Focusing on the German baking industry, the production planning is almost completely based on the practical experience of the responsible employee(s) instead of the usage of mathematical methods like in Scheduling Theory. Combined with the high diversity of the product range that includes around 100 different products in a common German bakery and the high complexity of the scheduling task induced therein, the performance of bakeries is often sub-optimal.

The baking industry in Germany consists of approximately 14,000 producing companies, reaching business volume of almost 13.4 billion Euros per year and employs over 290,000 employees (Zentralverband des Deutschen Bäckerhandwerks e. V., 2012). Based on this general framework the increase of companies' efficiency in respect of energy consumption or staff allocation and man working hours comprises high potential to decrease production costs in this industry.

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The use of evolutionary optimization algorithms like Particle Swarm Optimization (PSO) or Ant Colony Optimization (ACO) to solve the scheduling task might increase the efficiency of baking companies by calculating an optimal production plan and therefore determine the exact time schedule and capacities of devices needed to reach the production goal. Thus idle times of machines can be reduced or completely erased which leads to a reduction of energy consumption or the decrease in the makespan which leads to a reduction of man working hours needed.

Kennedy and Eberhart (1995) invented PSO as an adaption of the movement and behavior of bird flocks or fish schools. As a swarm intelligence algorithm it mimics the behavior of such swarming animals and iteratively searches the search space of a given optimization problem for the optimal solution. Since its invention PSO was widely used to tackle numerous scheduling or optimization problems in many different industry branches (Bank, Fatemi Ghomi, Jolai, & Behnamian, 2012; Eberhart & Shi, 2001; Li & Deng, 2012; Lian, Gu, & Jiao, 2008; Liao, Tjandradjaja, & Chung, 2012; Liu, Wang, Liu, Qian, & Jin, 2010; Pan, Tasgetiren, & Liang, 2008; Tang & Tang, 2012; Tasgetiren, Liang, Sevkli, & Gencyilmaz, 2007; Wang & Yang, 2010).

Another animal behavior inspired and frequently used algorithm (Ahmadizar, 2012; Li, Baki, & Aneja, 2010; Tzeng & Chen, 2012; Yagmahan & Yenisey, 2010) is the Ant Colony Optimization, initially proposed by Dorigo in his Ph.D. thesis (Dorigo, 1992). ACO follows the mechanisms that help ants to find the shortest and thus optimal way between a food source and their formicary.

Since ACO and PSO both provide easy implementation, easy modification and the ability to solve complex scheduling optimization tasks in reasonable computational time, they are promising methods to solve bakery scheduling tasks. In the presented work both methodologies were adapted to investigate the scheduling of an example bakery.

2. Material and methods

The developments and investigations presented in this paper were performed on a "lenovo ThinkPad R500" with an "Intel Core 2 Duo" 2.26 GHz processor, 2 GB RAM and Microsoft XP 2002 as system software. The modeling and optimization were programmed and performed with MATLAB 7.1 (The MathWorks, Inc.).

The production data used in this work including products, processing times and production stages are listed in Table A.1 in Appendix.

3. Modeling and optimization

Due to the high diversity of products in a German bakery it is not possible to solve the scheduling task with exact methods, at least not in reasonable computational time prior to the production start. Using exact methods to calculate the parameters of all possible schedules would mean to calculate an enormous number of combinations given by the relation in Eq. (1), where n is the number of jobs (products) and m is the number of machines or stages used.

$$number\ of\ schedules = (n!)^m \tag{1}$$

It is obvious that this relation causes an unmanageable amount of combinations for the scheduling problem in German bakeries, where the normal range of products is commonly above 100 and the machinery in operation approximately between 10 and 50 (depending on the bakery's size).

From the scheduling point of view the production in a bakery can be described as a *hybrid flow-shop* according to the common definitions, e.g. in (Pinedo, 2008; Ruiz & Vazquez-Rodriguez, 2010). In a manufacturing facility where a product, a job, has to undergo a series of operations or processing steps related to specific machines set up in series and is processed on each of the consecutive machines, this manufacturing environment is referred to as a *flow-shop*. If a production step consists of several parallel machines, this particular production step is referred to as a stage. If jobs have to be processed on only one of those machines in a stage or can bypass it, as is the case in a bakery, the machine environment is referred to as a *hybrid flow-shop*.

The number of possible schedules can be reduced significantly by considering the scheduling task in a bakery as a *permutation flow-shop* instead of a 'normal' *hybrid flow-shop* by adding the constraint, that the order in which the jobs n pass through the production is fixed and does not change between production stages (Lian et al., 2008; Pinedo, 2008; Tasgetiren et al., 2007). Although the real process in a bakery does not fulfil this requirements entirely, this model can be used and modified to match with the real production processes, where products can bypass other previously started products and the sequence of products on the first production stage determines all subsequent process tasks, due to the aforementioned time dependence in bakery production. By doing so the number of possible combinations is reduced from $(n!)^m$ to $n!$ and each schedule is a permutation of n (Perez-Gonzalez & Framinan, 2010). Each of those permutations is used to determine

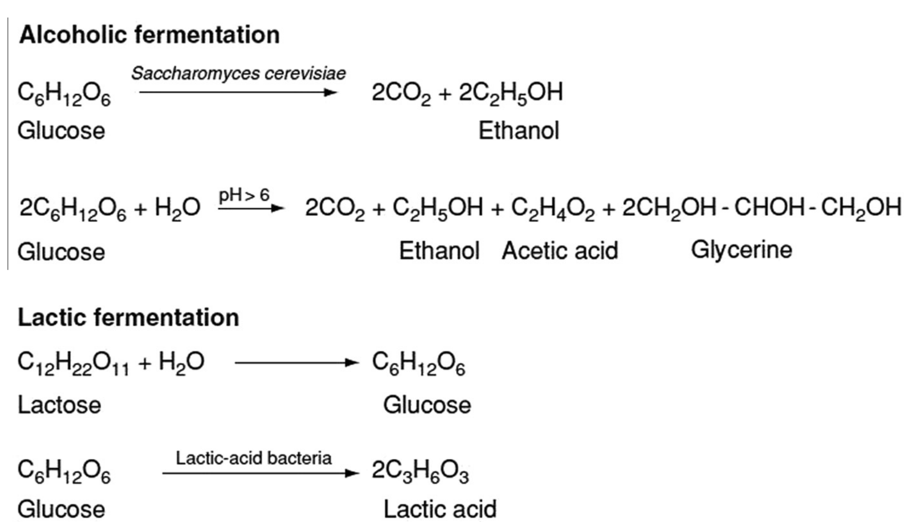

Fig. 1. Sugar metabolisms in dough. Modified after (Collado-Fernández, 2003).