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Product Wheels for Scheduling in the Baking Industry: A Case Study

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Abstract: This paper illustrates current challenges and suggests solutions within the area of scheduling in the baking industry. The analysis applies the product wheel heuristic approach of King (2009) and tests the production cycles generated using actual sales and production data from a manufacturer of frozen baked goods. The product wheel method showed to be a suitable method for application at the baked goods manufacturer and generated a 23% reduction in setup and inventory cost at the case company. Despite the benefits, the product wheel method proved difficult to apply in a high variety setting, where an operations research model may have achieved more significant results.

Keywords: Production planning, scheduling, product wheel, process industry

1 Introduction

Rising labour costs, increased price competition, and higher demand for customised products and quick delivery times are just a few of the pressures placed on the modern baked goods manufacturer (Higgins, 2013). Bread, a staple in the diet of the Western world, has multiplied its forms through the years, spanning from baguettes to buns and flatbreads and assorted sweet treats. Behind the increased variety on the store shelf are manufacturers struggling in a competition to maintain their low-cost infrastructure while accommodating a higher product mix. Producing a wider array of products can require investment in technology in manufacturing, but can also require adjustment of operational procedures for tasks like production scheduling. It is a common goal for production scheduling to maximise service level towards the customer while minimising costs for the company (Christou et al., 2007). In doing this, the production schedule acts as a critical link between the needs of the market and the physical output of a manufacturing system in the baking industry, helping a company achieve greater flexibility (Nakhla, 1995).

Production scheduling is a decision-making process whereby the lot sizes, start and end times, and order sequence for a production operation are determined (Lütke Entrup, 2005; Stadtler & Kilger, 2005). Additional factors determined by plans and schedules include which products to produce, which machines to make the products on, which machines to overload, when to schedule maintenance, and which demands to satisfy (Fordyce et al., 2015; Pinedo, 2009). Factors such as the complexity of the production process, the number of products being produced, and the variability of product demand all influence the planning and scheduling process.

Aspects of the baking industry that complicate production scheduling are the multi-stage fermentation process, the presence of active yeast in the dough, handling of allergens and organic ingredients, and the use of large, capital-intensive production equipment which often requires lengthy setup times (Akkerman & Van Donk, 2009a; Modal & Datta, 2008). Additionally, production scheduling can be a cost driver for a company if the batch sizes, sequencing and finishing times are not optimal. Due to the broad range of effects of

planning and scheduling on overall business performance and given the increasing demand for flexibility from customers, research around scheduling in the baking industry is needed to help baked goods manufacturers gain and maintain a competitive advantage.

The food industry is an essential component of the European and global economies, accounting for roughly 13% of the turnover in the manufacturing sector in the EU in 2014 (Statistical Office of European Communities, 2017). Manufacturers of baked or farinaceous products are one of the principle niches within the broader food industry and have shown steady growth in revenue since 2010 in major European markets such as Germany (12%) and Italy (8%) (Statistical Office of European Communities, 2017). Despite this, the academic literature offers limited research on scheduling methods within the food sector and, more specifically, the baking industry.

When discussing the industrial landscape of Europe, it is necessary to consider small to medium-sized enterprises (SMEs) which employer fewer than 250 people and, yet, account for over 99% of the number of enterprises, 57% of total value added, and over 66% of employment in the EU (European Commission, 2016). SMEs in the food sector require a different approach for operations management due to the capabilities of management and limited resources (Dora & Gellynck, 2015; Rymaszewska, 2014). However, scheduling tools discussed in the literature have primarily catered towards large enterprises, focusing on the installation of software systems and optimisation models and algorithms (Van Donk & Van Dam, 1994), both options which can be out of reach for an SME in the baking industry.

This article, therefore, addresses the following research question: *how can scheduling techniques be applied to improve production in the baking industry?* This question is explored using a literature review of planning and scheduling methods in various food contexts, including baked goods manufacturing. Next, the product wheel methodology of King (2009) is selected for application and testing at a small to medium-sized baked goods manufacturer. The product wheel is a heuristic method for gaining economies of repetition while simultaneously responding to needs for increased variety and flexibility towards the end customer (King, 2009; Wilson & Ali, 2014).

This paper contributes to research by testing the product wheel in a food context, an industry with a documented need for better scheduling and which to date as seen limited research (O'Reilly et al., 2015). The paper contributes to practice by using a real-life case, hence illustrating the practicability of the approach.

The paper is structured as follows: first, a literature review is carried out exploring the baking industry, food sector, and scheduling methods. Second, the research methodology and empirical data are described. Third, the findings from the case study are analysed and theoretical and practical implications are described. Finally, conclusions and notes regarding further research are outlined.

2 Literature Review

A preliminary look at the literature revealed an absence of studies focusing on scheduling in the baking industry. Therefore, the literature search was expanded to explore scheduling methods in the broader food industry.

2.1 Baked Goods Manufacturing

Manufacturers of baked goods make products such as bread, cakes, and pastries that are baked in an oven (Oxford Dictionaries, 2015). Baked goods manufacturers can vary from large-scale to small-scale and may deliver either fresh or frozen products. Fresh bread products typically are provided to markets daily to ensure the product is of the acceptable quality level when purchased (Zhou & Therdthai, 2006) while frozen products are often held in cold storage and delivered with longer lead times (Ribotta et al., 2006). These manufacturers may also make semi-processed baked goods such as refrigerated dough, frozen dough, and partially baked dough (Ribotta et al., 2006). A yeast bread-making process typically consists of the following stages: dough making,

dividing, proving, baking, cooling, slicing, and packaging (Zhou & Therdthai, 2006). Characteristic production systems for baking and other food processes are flow shops, a configured set of dedicated machines which process all jobs in a fixed order (Dewa et al., 2013; Gupta & Kumar, 2016).

2.2 Scheduling in the Food Industry

The current needs of the market and technological constraints of food manufacturers require production planners to consider several factors when scheduling jobs in production. These factors include the use of both batch and continuous processes within one production line, processing of perishable goods, sequence-dependent setup times, and high variability of yields and process duration (Akkerman & Van Donk, 2009b). For the larger context of consumer goods manufacturers, recent trends in operational scheduling have included grouping products into families which use a comparable production setup, the use of regular production schedules for high running products to increase customer responsiveness, the change of emphasis from low production cost to fast delivery and logistics performance, and the shift from make-to-stock (MTS) products to make-to-order (MTO) products (Bilgen & Günther, 2010). Products with a shorter shelf-life will often be scheduled with an MTO strategy since the products cannot be stored in inventory for prolonged periods (Akkerman & Van Donk, 2009b). In contrast, products with a longer shelf-life (i.e. frozen baked goods) are made with an MTS strategy as they have a longer shelf-life in inventory. Complicating the scheduling task further is the growing variety of products within the food industry (Nakhla, 1995).

2.3 Product Mix Flexibility

The flexibility literature has been around since the 1980s and aims to define and measure how organisations can adapt to quickly to changes in the market. The flexibility of a production line directly impacts the production scheduling practices which can be used. Given the level and uncertainty of customer demand, a manufacturer may respond by building flexibility capabilities within volume, product mix, quality, new product introduction, and delivery (Slack, 1983). Product mix flexibility has been defined as the "ability to manufacture a particular mix of products within the minimum planning period used by the company" (Slack, 1983, p. 9). The process technology used, the design of the products, and the scheduling of the products are known to affect product mix flexibility (Slack, 1983). Product mix flexibility is inversely proportional to the difficulty to change between products on a manufacturing line. Changeover time can be defined as the time needed to transition from producing one product to another. Often, changeover time includes the time to turn the line on or off, time for the system to adjust to temperature or pressure, and time to remove material from a previous production run (King, 2009). Changing between products on a food production line is a critical task since food safety, allergens, production line arrangement, packaging type, and labour utilisation all must be considered. Equipment changes and cleaning procedures must be executed thoroughly to avoid contamination and endangering end customers. From a cost perspective, changeovers should be as short and infrequent as possible since they pose a significant cost for companies in waste product generated and reduced speeds during the start-up phase of a new product (Akkerman & Van Donk, 2008).

One method used in the food industry to improve mix flexibility is natural sequencing, a technique where similar products are scheduled in succession to minimise overall changeover time (Bilgen & Günther, 2010). When applying natural sequencing, sequences of products are often developed based on product families and consolidated into schedule blocks which are then arranged to minimise changeover time. A product wheel, like a schedule block, is a method for natural sequencing which uses a flexible scheduling sequence for production that is based on demand, changeover times, production rates, and inventory carrying costs (King, 2009). Product wheels can also serve

as a tool for continuous improvement whereby reducing the duration (or lot size) of a product wheel allows greater flexibility and responsiveness to customers (King, 2009).

2.4 Existing Scheduling Models for the Food Industry

Several operations research models and heuristics have been generated for specific food production industries, including the baking industry, as shown in Table 1. Since there were limited articles on planning problems in the baking industry, the literature search was expanded for those involving a food industry application. Food process applications represented among these models range from producing candy to baked goods to beverages. Different modelling formulations in the literature describe the specific production systems which vary depending on the number of production stages, the number and size of inventory locations, the presence of bottleneck resources, as well as the perishability of the products made. One model by Hecker et al. (2013) includes a no-wait constraint for a baked good production line to model the time-sensitivity of the fermentation process. This model was the only one to incorporate such a constraint specifically for the baking industry.

2.5 Literature Summary

This literature review shows that scheduling in the food industry is challenging and requires consideration of several factors. Furthermore, it shows that research into planning and scheduling in the baking industry is limited. The models currently developed and in use within the food industry are operations research models, heuristics, and lean scheduling methods, such as the product wheel. These models and tools vary depending on the nature of the production system being scheduled and are often customised to incorporate the specific constraints facing the food industry, such as perishability of the products and sequence-dependent changeover time.

This literature review reveals a lack of literature exploring both the quantitative and qualitative aspects of scheduling in the baking industry. There are limited applications of quantitative scheduling models made for the baking companies, with only three instances identified in Table 1. Also, lacking in the literature was the application of the heuristic methods, the product wheel more specifically, within the baking industry. Given the limited work in the food industry to meet the needs of food SMEs in Europe, the product wheel heuristic is selected for application in this study. This heuristic approach offers an approach to improve scheduling that is within the resources of a typical SME and accommodating the product mix flexibility required in the baking industry. The contribution of this paper is a map of literature on the scheduling practices and research in food companies as well as a real case application.

3 Methodology

A mixed methods approach was used to frame the empirical study of how scheduling methods can optimise performance in the baking industry. Both qualitative data and quantitative data were gathered from a case company to understand the scheduling process, schedule performance and productivity. Different data sources were also used for triangulation purposes. The explorative nature of the research question allows for an in-depth understanding of the research area, suitable for the qualitative work in this project, while the performance of the scheduling methods can be assessed using quantitative methods (Creswell, 2014).

The case company, here called Baking Company, is an SME located in Denmark with approximately 200 full-time employees. The company was selected as it produces a wide range of baked goods with over 200 products serving the convenience bread market (also known as “bake-off” market). Baking Company qualifies as being an SME per the definition of the European Commission (European Commission, 2016). All products are either fully baked or partially baked in the process and all are frozen before being sold. The company was also selected as their production

Table 1. Operations Research Models and heuristics for Scheduling in the Food Industry

Author	Model and Objective	Case	Solution Method and Findings
Silva, et al. (2014)	Model a flow-shop problem with parallel production, setup times, batch production, due date and include transport capacity.	Baking company	Apply a greedy heuristic and genetic algorithm to solve the problem.
Hecker et al. (2013)	MILP for Hybrid flow-shop. Uses no-wait constraints to model time-sensitivity with dough fermentation. Objective: Min. total makespan or idle time.	Bakery (Germany)	Solve for local optimal (not global) using Particle Swarm Theory and Ant Colony Optimisation programmed in MATLAB.
Dewa et al. (2013)	Finite capacity scheduling system applied to flow shop tested with 5 heuristics. Objective: Min. cost of earliness & lateness.	Bakery (Zimbabwe)	Simulate 5 heuristics in Arena including Earliest Due Date, First Come First Served, First In System Last Served, Shortest Processing Time First, and a random procedure. EDD heuristic gave the optimal schedule.
Mehrotra et al. (2011)	MILP for creating production patterns in the processed food industry. Objective: Minimise setup and inventory costs.	ConAgra Foods	Two-stage heuristic which groups and assigns products to lines and sets sequence of each group. Use a heuristic-based planning tool which reduces the cost of setup and inventory by 15% with a 4-week long cyclic schedule.
Bilgen & Günther (2010)	MILP applied to multi-site production and distribution. Objective: Minimise setup, inventory and transportation costs.	Fruit juice, 3 plants (Germany)	Uses block planning to model natural sequencing of products using randomly generated demand data. Solve models to optimality.
Christou et al. (2007)	IP with 3 levels of scheduling granularity for aggregate planning on multi-product lines. Objectives: maximise customer service level and minimise extra labour costs and inventory costs (maximise freshness).	Beverage manufacturer with 3 plants (Greece)	Solve to optimality using LP relaxation and a custom two-part optimisation for solving the shift allocation first and the scheduling second. Code programmed in ANSI.
Doganis & Sarimveis (2007)	MILP to optimise production, customised for sequencing of yoghurt products. Objective: Minimise changeover, inventory, and labour costs.	Yoghurt production line (Greece)	Solve MILP using CPLEX to global optimality in less than 15 seconds. The output is a daily production schedule and resulting inventory levels
Soman et al. (2007)	Short-term batch scheduling heuristic using economic lot-sizing for MTO/MTS products. Objective: Minimise overall makespan while meeting demand.	Three-stage food manufacturer	Apply heuristic within a hierarchical planning framework. Suggest using the heuristic alongside detailed manual scheduling.
Mendéz & Cerdá (2002)	MILP application to two-stage make-and-pack production with unlimited intermediate and final storage. Objective: Minimise total makespan.	Candy producer (theoretical)	Solved to optimality using CPLEX. Applied pre-ordering rules (e.g. Shortest Intermediate Processing Time, General First Processed First Served) to reduce problem size.
Tadei et al. (1995)	Two model approach: (1) Medium planning using an LP to allocate labour and (2) short-term planning using an IP to determine shift schedule. Objectives: Min. inventory, meet demand.	Alimentary preserves (Portugal)	Solve using a decomposition heuristic was implemented using C++. The method proved as a consistent tool to evaluate what-if scenarios. Evaluate schedules based on average stock levels.
Randhawa et al. (1994)	Scheduling heuristic for a multi-stage system with parallel machines. Uses Shortest Processing Time First on bottleneck resources. Objective: Min. average flow times/ lateness.	Freeze-dried food producer (USA)	Solve with a computer model which creates a schedule for each stage along with KPIs (% utilisation, % idle time, time in the system, etc.)
Claassen & Van Beek (1993)	MILP model with two tiers (tactical and operational planning) applied to a flow shop with n-jobs and m-machines. Objective: Minimise penalty for lateness, setup, overtime, and costs.	Packaging line (Netherlands)	Solved to local optimality using a decomposition heuristic. Implemented programs into a decision support tool which generated higher quality schedules than the manually generated ones.

*Integer Programming (IP) using only integer variables, Linear Programming (LP) uses continuous variables, and Mixed-Integer Linear Programming (MILP) which uses both integer and continuous variables.

system was seen to be typical for the baking industry, consisting of two automated, flexible flow shop production lines.

Based on the research question and findings from the literature review, a research framework was taken from the product wheel heuristic from King (2009). The method includes 10 steps which assess various aspects of the production system and scheduling practices. The steps are:

1. Decide which assets would benefit from product wheels.
2. Analyse product demand variability.
3. Determine the optimum production sequence.
4. Calculate the shortest wheel time based on time available for changeovers.
5. Estimate the economic optimum wheel time based on Economic Lot Size (ELS) model.
6. Determine the basic wheel time and determine which products are made on every cycle and the frequency for other products.
7. Calculate inventory levels to support the wheel.
8. Repeat Steps 3-7 to fine-tune the design.
9. Revise all scheduling processes, as appropriate.
10. Create a visual display (heijunka) to manage the levelled production.

These steps are shown graphically in Figure 1.

Steps 1 to 7 of the method will be applied to the data set from one production line at Baking Company and the appropriateness of the approach will be assessed. The high-volume production line was selected as it is the production line with the highest capacity and is often running at full utilisation, therefore showing potential to benefit from further optimised production planning.

The primary methods of data collection were company visits, interviews, presentations by the senior staff, product documentation, sales records, and data from the manufacturing execution system. Production data used to create the product wheels is from the full year 2014. The product wheels generated will be tested using a simulation built in Microsoft Excel and four months of actual sales data from 2014 to see the impact on delivery service to the customers. The effect of the product wheel on delivery service to customers was measured as days with stock outs per product.

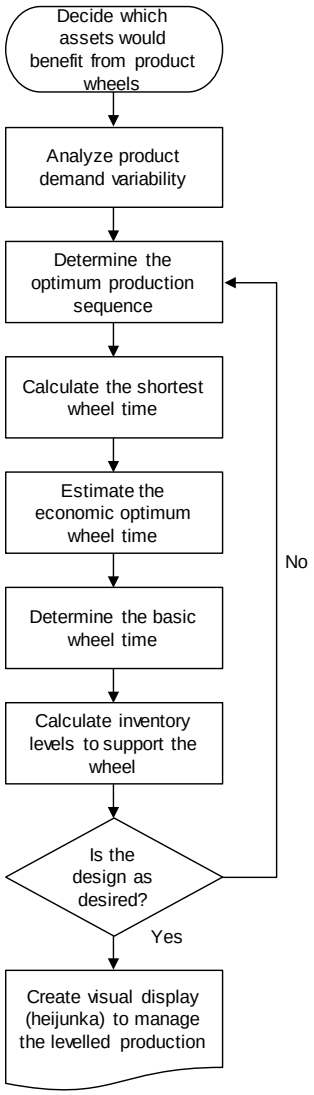

Figure 1. Steps in the product wheel method. Adapted from (King, 2009)

Two days were spent on site in production observing the system and gaining an understanding of the process flow. During these visits, the production manager was interviewed for 30 minutes to understand the production data. Qualitative data on the planning process was gathered through two, one-hour semi-structured interviews with the

production planner to gain deeper insight and supplement the quantitative data. The questions focused on how schedules were created, rules for production sequence, and interactions between the planner and production team when creating the schedule.

The proposed research methodology allows for exploration of the gap in the literature regarding the impact of the scheduling via the product wheel in an SME in the food industry by using quantitative methods such as the ELS model and production cycles. The qualitative aspects are addressed by analysing the scheduling process of the production planner. This research methodology will also address the lack of the application of the heuristic scheduling methods within the baking industry with the development of production cycles at the case company.

4 Findings

Observations collected during the on-site visits at Baking Company revealed that the company uses a batch production system that is available for production approximately 90 hours per week, operating from Monday to Friday (i.e. maintenance time excluded). The product assortment at Baking Company consists of six major product groups: sausage rolls, Danish pastries, focaccia bread, buttermilk horns, pastry bars, and pastry rolls. Each product is assigned to a specific line for production as the preferred line. The production line selected for study produces mainly sausage rolls and buttermilk horns. All products at Baking Company are frozen and then baked at the retail location for final sale.

Figure 2 shows the primary process stages on the line. In mixing phase, the wet and dry ingredients for the dough are weighed and mixed. The mixed dough is then placed into a hopper and guided through an extruder and onto a conveyor to the lamination stage where the dough is rolled flat and layered. After lamination, the dough moves via conveyor to the makeup stage where it is cut and formed into the final shape with additional ingredients, such as sausages, cheese, and cream filling. The formed products are placed on trays and then moved to a proofing step where the dough can rise before either being frozen or baked. The products which are fully or partially-baked can cool before being frozen. Once frozen, all products are placed in boxes and palletised before moving into cold storage. The products have a one-year shelf-life in cold storage.

Figure 2. The production process at Baking Company

4.1 Creating the Master Production Schedule

To assess the qualitative nature of the planning tasks, a task decomposition of the production scheduling process at Baking Company was created. At the highest planning level, a master production schedule (MPS) is created by the production planner which shows the aggregated volumes of each product to be produced on both lines. Each week, the production planner develops the MPS for a six-week planning horizon and then revises it based on rush orders and orders for MTO products. MTS products are selected for production based on their inventory levels and expected demand. MTO products are scheduled with a lead time of 3-4 weeks while MTS products must be delivered in one day due to the competitive nature of the convenience bread market. With such short lead times, the MTS products must have a sufficient stock level to cover demand with an acceptable level of service.

4.2 Creating the Detailed Schedule

Once the aggregate planning values are determined in the MPS, the planner generates the detailed production schedule with a one-week planning horizon. A minimum run length is set to 3 hours and a target run length is 7.5 hours, which is the approximate length of one shift. The planner uses a combination of rules of thumb along with

the planning interface of the ERP system to determine the run length and achieve the desired volume in the MPS. Once the planner determines the run lengths, she assigns the products to the line, sequences the products based on scheduling rules and then estimates the changeover time. These tasks are often executed in parallel as the planner attempts to make the schedule fit demand while complying with capacity constraints.

As is common in the food industry, many planning rules are used to create schedules for Baking Company to reduce production costs. The following list contains a set of planning rules that are currently used at Baking Company to form the MPS and the detailed production schedule:

- Organic items are scheduled as the first of the week to avoid contamination.
- Light-coloured doughs are scheduled before dark-coloured doughs to avoid colour mixing.
- Items with sauce are scheduled after items without sauce and toward the end of the week to avoid excessive cleaning.
- Products with allergens (i.e. sesame or almonds) are run as the last product for the week.
- Fully-baked products are scheduled separately from partially-baked products.
- Chicken products are always made before pork products to reduce the risk of cross-contamination.

Once the schedule is made for the week, the planner reviews the schedule with the production team leader for feasibility. The planner requests feedback on the planned changeover time, sequencing, time for new products, and other factors before updating the schedule and releasing it to production. During on-site visits, it was seen that the production planner at Baking Company maintains daily communication with the production workers and is seated in an office that is close to the factory operations.

4.3 Production Volume

A Pareto method called the Glenday Sieve was applied to production data with a summary shown in Table 2 to visualise the distribution of the production volume among the products at Baking Company (Glenday, 2005). The Glenday Sieve reveals that half of the production time was spent making only 19 products on both lines at Baking Company in 2014. These represent the high running products such as a Danish pastry product and various products from the sausage roll group. The Glenday Sieve also shows that 27 products contribute to the red category which accounts for only 1% of production time at the facility. With the highest concentration of stock keeping units (SKUs) residing in the yellow group, it appears that the company is spending 95% of its time making only 65% products. The Glenday Sieve reveals a clear distinction between the products that are “high runners” and those that are “low runners” at Baking Company. Furthermore, the production time is unevenly distributed amongst the products with a moderately long tail taking only limited capacity.

Table 2. Glenday Sieve for products in 2014

Product Colour	Cumulative % Production Hrs	Number of Products	% of Products
Green	50%	19	12%
Yellow	95%	88	53%
Blue	99%	31	19%
Red	100%	27	16%
Total	100%	166	100%

5 Analysis

In the following sections, the first seven steps of the heuristic presented by King (2009) is applied to the 2014 production and sales data to test the applicability of the method to the baking sector. The details of the implementation are listed in the following sections.

1. Decide which assets would benefit from product wheels.

The asset at the Baking Company selected for study is a high-volume, flow shop production line (Gupta & Kumar, 2016). The production line is scheduled as a single unit since all machines connect via a conveyor system with low work in process inventory between machines.

2. Analyse product demand variability.

An analysis of the variation of monthly demand for a full year of sales data from 2014 was performed for products at Baking Company based the method of D'Alessandro and Beveja (2000). In this method, the average monthly demand and coefficient of variation (CV) of monthly demand are calculated for 86 products produced on the line and graphed to segregate the products into MTO and MTS categories. The findings for Baking Company are presented in Figure 3.

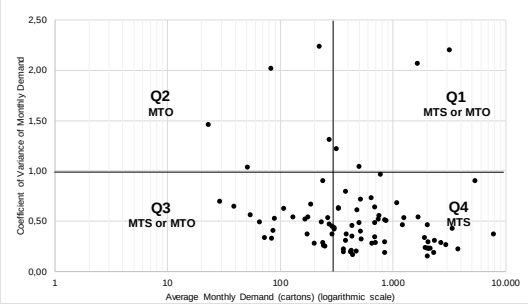

Figure. 3 Analysis of the Variation of Monthly Demand (Logarithmic Scale with Quadrants)

The threshold CV value was set to 1.0 since most of the green and yellow products (high volume products from the Glenday Sieve) had CV values between 0 and 1.0. The threshold value for average monthly demand was set to 300 cartons as this equates to roughly one 3-hour production run every two months for most products. As 3 hours is the minimum run length in production, making this quantity every two months was deemed to be "low running."

As is typical for this demand analysis, the products in Q2 are classified as MTO, and the products in Q4 are classified as MTS. The products in Q1 and Q3 can be classified as either MTO or MTS depending on the company sales and operations strategy. In this analysis, the Q1 and Q3 products are designated as MTS as the frozen nature of the food allows them to stay in inventory with a low risk of being scrapped. Table 6 shows a summary of the four quadrants including the number of products within each and strategies for scheduling them, where 81 of the 86 products classify as MTS. The 81 MTS products will be carried through the remaining steps of the product wheel heuristic since the 5 MTO products should be scheduled only when an order is received.

When comparing the results of the Glenday Sieve to the results of the demand variability analysis, all green products from the Glenday Sieve were designated as MTS based on the demand variability analysis as they fell within Q4 (high volume, low demand variability).

Table 3. MTO and MTS Segregation for Products

Q2 – Low volume, high variability Strategy = MTO # Products = 5	Q1 – High volume, high variability Strategy = MTS # Products = 4
Q3 – Low volume, low variability Strategy = MTS # Products = 26	Q4 – High volume, low variability Strategy = MTS # Products = 51

3. Determine the optimum production sequence.

Using the 81 MTS products as a basis and the scheduling rules gathered from the interviews production planner, the optimal production sequence was determined. The data from the interview was triangulated by an assessment of the planned changeover time between the product groups in 2014 since changeovers at Baking Company are sequence-dependent. A changeover time matrix was made on the product level but was not utilised since there were many missing combinations of products; therefore, the average changeover time between product groups was used. Both analyses showed that changeover time is minimised when scheduling items from the same product group next to each other.

4. Calculate the shortest wheel time based on time available for changeovers.

This step advises the user to place all products in a single production cycle and estimate the number times a changeover could be performed. Using equation (1) presented by King (2009), the maximum number of cycles of a product wheel in one year which contains all MTS products for the line is computed as 1.7 (see equation 2). This is calculated assuming the total available production time on the line is 4,320 hours (90 hours per week, 48 weeks per year), the total production time equals the production time from 2014 for the MTS products and that the product wheel changeover time is the sum of the average changeover time for the MTS products. The calculation shows that the production cycle should be run between one and two times every year if all products are made once in every cycle.

$$Max\ Cycles = \frac{Total\ Avail.Time - Product\ Wheel\ Time}{Product\ Wheel\ Changeover\ time} \quad (1)$$

$$Max\ Cycles = \frac{(4320\ -4232\ )}{53} = 1.7 \quad (2)$$

5. Estimate the economic optimum wheel time based on ELS model.

Continuing with the product wheel heuristic, the Economic Lot Sizing (ELS) analysis was performed to calculate the optimal batch sizes for production of the 81 MTS products on the line at Baking Company. The ELS calculates the cycle length x_j (the amount of time between production runs for each product j) and the lot size. Variables in the calculation were determined using the sales and production data from 2014. The inventory holding cost, h_j, was determined by taking the costs per carton for storage and handling finished goods at an external warehouse close to Baking Company. The calculation of lot size (cycle length multiplied by demand rate) is shown in equation 3 where:

j = product number
ELS_j = Economic lot size
D_j = Demand rate for product j in cartons per hour from 2014 sales data
Q_j = Production rate for product j in cartons per hour from 2014 production data
h_j = Inventory holding costs for product j in EUR per carton per hour
c_j = Setup cost for product j in EUR per setup

$$ELS_j = x_j D_j = \sqrt{\frac{2\ Q_j\ c_j}{h_j\left(1 - \frac{Q_j}{D_j}\right)}} \quad (3)$$

For each product, the optimal run length, lot size and production frequency were determined. The base units for volume and time in this analysis are cartons and hours. This model assumes a constant demand rate and production rate and utilises sequence-independent setup times in the calculations. While the production at the Baking Company experiences sequence-dependent setup times, the sequence-independent setup time was calculated by taking the average setup time for each product to simplify the model. Three of the MTS products had cycle lengths greater than once every year, which is not feasible given the one-year shelf-life of the products.

6. Determine the basic wheel time; determine which products are made on every cycle and the frequency for others.

Since there were 81 MTS products, a different strategy for generating production cycles was required. The basic wheel time is usually set by the high-volume products (King, 2009). A histogram of the cycle lengths for the line studied (see Figure 4) shows that most products have a 5-6-week cycle length, while most products have a cycle length of less than 11 weeks. No products had a cycle length less than 3 weeks. High volume, green products have cycle lengths from the ELS analysis which ranged from 3.3 – 6.2 weeks.

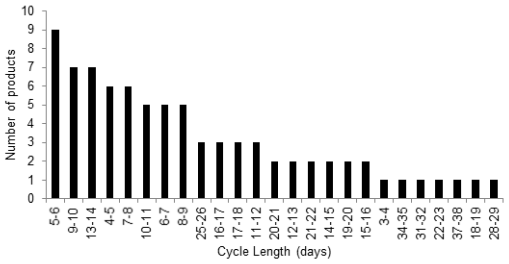

Figure 4. The economic cycle lengths for MTS products

For the first iteration, the product wheel uses a 4-week cycle time which repeats two times so that products are made every 4 or 8 weeks while other MTS products are made when the stock is nearly depleted. All product cycle lengths were rounded to the nearest multiple of four, and the lots sizes were updated. The product wheels generated are shown in Figure 5 and Figure 6. The green and yellow colours in the figures indicate the colour classification per the Glenday Sieve and serve as a reference for the high volume and mid-volume products.

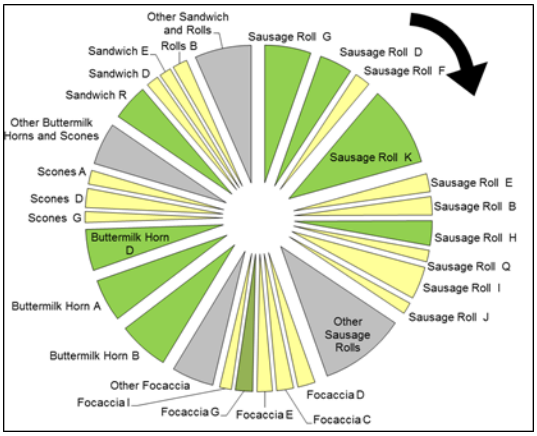

Figure 5. Product Wheel for weeks 1-4

The wheels were designed so that the product cycle always takes 70% of the production time for the week to allow room in the schedule for MTO products which have a lead time of 3-4 weeks. As suggested by King (2009), products which have a cycle length over eight weeks should be placed in empty grey spokes to accommodate both MTS and MTO production strategies. Only 35 products with an MTS strategy which had cycle lengths of less than eight weeks were included in the product wheel. Since products made every 12 or more weeks are made only 5 or fewer times per year, these are not included in the product wheel but are given space to be produced in time designated for "Other Sausage Rolls", etc. shown as one of the grey spokes in the wheels in Figures 5 and 6.

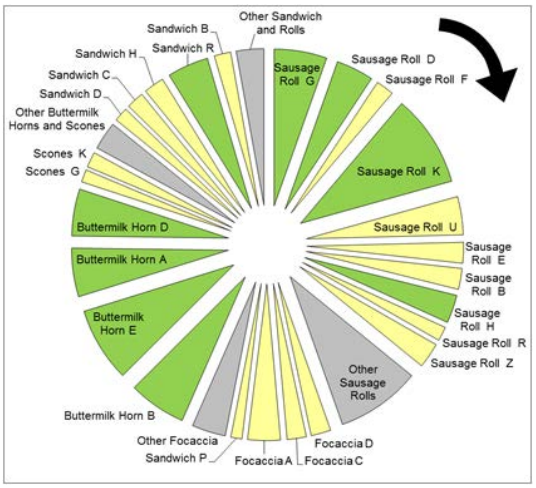

Figure 6. Product Wheel for weeks 5-8

7. Calculate inventory levels to support the wheel.

For testing the production plan, the safety stock levels were set at two weeks of the product demand which is the current safety stock target for high running products at Baking Company. Simulating the product wheels with actual demand data for four months (March 3, 2014 – June 25, 2014) at Baking Company was possible for the 32 products which were in the product wheel. Demand data was not available for three of the products in this time frame, so only 32 of the 35 products were assessed. The simulation demand period was selected to minimise the influence of seasonality in demand. In the simulation, stocks were initialised to be equal to the economic lot size plus the safety stock for each product. For each day in the simulation, the production quantities from the product wheels and demand quantities from the demand data were added or deducted from the stock in the previous day accordingly for each product.

The simulation of the first version of the product wheel showed that two products faced stock-outs over the four-month period: Scones G has 13 days without stock and Sandwich R has two days without stock. The lot sizes were increased and the simulation ran a second time where there were no stock-outs.

6 Results and Discussion

It is estimated that implementing the product wheels will lead to a 42-hour reduction (-18%) in changeover time on the line, which equates to roughly 2 days of additional production time per year. The impact of the product wheel on setup and inventory costs is also found and summarised in Table 3. As can be seen, implementing production cycles could potentially lead to EUR 103,600 (23%) decrease in annual setup and inventory costs from 2014. As this applies to the products that are already running in long production series, some of the benefits are overlooked. For example, if all products are scheduled in economic lot sizes, the company could potentially save EUR 145,000 in costs. Such results show that this manual heuristic did accommodate the need for mix flexibility and minimisation of production costs in Baking Company.

Table 3. Impact of the product wheel on annual setup and inventory costs for 35 MTS products

	Changeover Cost (EUR)	Inventory Holding Cost* (EUR)	Total (EUR)
Original Schedule (2014)	226,400	217,100	443,500
Product Wheel	180,200	149,000	339,900
Savings	46,200	57,400	103,600

* Inventory cost includes the cost of safety stock
Note: costs and savings calculated only for the 35 products assessed in the product wheel.

The theoretical savings calculated for the production cycles at Baking Company are slightly higher than other research studies which used production cycles, such as the 15% reduction in setup and inventory costs found by Mehrotra et al. (2011) using their optimisation model. A study of product wheels in the process industry showed mixed results as to the impact of scheduling on changeover time, increasing the time in some cases and decreasing time in others (Wilson & Ali, 2014).

Where the product wheel had less favourable results in the case application was in the meeting demand requirements to the market for the MTS products. The lack of widespread stock-outs suggests that the inventory levels and batch sizes can be reduced slightly, but seasonality of demand should be considered. The stock out situation of Baking Company is comparable to the product wheel implementation at a chemical manufacturer (Wilson & Ali, 2014). It is worth noting that while making the product wheels in a real production scheduling scenario, the stock levels and corresponding lot sizes would need to be adjusted per the changing market needs and demand seasonality. However, the sequence of the production runs should remain the same since it is designed to reduce the total changeover time and inventory costs based on natural sequencing.

Looking beyond the production and warehouse impact, implementing the production cycles at the case in this study requires changes to the scheduling process, as well. In one potential redesign of the process, the product wheels are the first items to be planned when creating the MPS. The cycles are allocated across the weeks and production lines based on their cycle length. If there is capacity remaining in each week after production cycles have been allocated, the items are selected for production based on the original process. This process is expected to reduce the decision-making load of the planner.

The specific heuristic presented by King (2009) was difficult to apply to the case company for various reasons. The presence of sequence-dependent changeover times made the manual tasks in Step 3 of determining the optimum production sequence quite tricky. Step 4 of calculating the shortest wheel time was not readily applicable given the high product variety of the 81 MTS products. The heuristic assumes that all products are made in every cycle, which would mean that a

cycle would be developed for up to 81 products which would be scheduled over the course of 5-6 months, compared to the 35 products in the proposed 8-week product wheel set. This would be complicated and reduce the chances that the benefits of the product wheel, such as economies of repetition and making faster changeovers in production, would be realised. Running a production cycle twice per year will pose many practical challenges, such as very high batch sizes and stock levels for products. This shows that the product wheel method is not the best fit for production scenarios in the process industry which have a high number of MTS products. In a study on product wheels at a chemical manufacturer, only eight products were included in the product wheel design, so this was much simpler to generate the schedule for (Wilson & Ali, 2014). This suggests that the product wheel is more suitable for smaller scheduling problems.

Among the collection of scheduling methods tested in the food sector, the product wheel is an overly simplistic approach for the high variety company which was studied in this case. The product wheel offered an approach by which variety and sequencing could be addressed in the scheduling process in the baking company. However, based on the application example of Baking Company in this study, it can be concluded that the method should be reserved for small problems where few MTS items are required to be integrated into the product wheel. The other optimisation models presented in Table 1 which utilised operations research methods to solve the issues of natural sequencing via schedule blocks might be more suitable for solving applications with higher variety (Bilgen & Günther, 2010; Günther et al., 2006; Mehrotra et al., 2011; Mendéz & Cerdá, 2002; Pinedo, 2009). Just like the product wheel, the operations research production cycles aim to increase production efficiency by using pre-defined sequences of production orders. However, their solving ability for more complex problems makes them superior to the product wheel. Regardless of the issues with implementation, the simulation of the product wheel at Baking Company showed savings in changeover and inventory costs.

7 Conclusions and Future Research

Through a literature review and application of the product wheel methodology to a case company, it was found that the production cycles are a suitable scheduling method for improving the production performance in the baking industry, particularly at small to medium-sized enterprises. However, when testing the product wheel method proposed by King (2009) at a case company with high product variety, the method was found difficult to apply due to its manual nature. The results suggest that when scheduling production in a baking company with high variety, a more sophisticated technique for scheduling based on operations research methods should be utilised. Despite the drawbacks with the number of products, the product wheels generated in the study led to a 23% reduction in changeover and inventory costs for the products simulated at the case company.

This work contributes to the current gap in the literature aspects of scheduling in the baking industry by providing a case-based approach to show the applicability of production cycles as a scheduling method to a baked goods manufacturer and significant benefits of production cycles in this sector are estimated. This research study is limited in generalizability due to the nature of the case study. However, it is reasonable to assume that applying the product wheel in another food company with similar variety and seasonality would yield comparable results. The primary area of future work is to implement and assess the effectiveness of the proposed production cycles. Such research would provide the data needed to evaluate the actual performance of the cycles against the estimated performance and compare them to the simulated values.

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