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Changeability of the manufacturing systems in the food industry – A case study

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Abstract

Like other industries, the food industry currently faces increased demand for low-cost product variety. One potential response to this demand is increasing the changeability of the manufacturing setup. This paper has the purpose to explore how four changeability enablers (re-configurability, scalability, standard interfaces, and flexibility) impact four measures of changeability (changeover time, ramp-up time, ease of implementing minor product changes and ease of introducing radically new products) in the food industry. To do so, the paper conducts a nonparametric Kendall's tau correlation test using data collected from 18 production lines via questionnaires addressed at plant managers from six different plants part of the same industrial bakery. The results indicate that changeability enablers cannot support all outcomes simultaneously, and that trade-offs between certain enablers and outcomes may exist. In addition, the results indicate that perishability might play a crucial role in the degree and type of changeability enablers a food manufacturer can adopt.

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Keywords: Kendell's tau, questionnaires, food industry, mass custimization, and changeability

1. Introduction

In order to successfully compete in a market driven by global competition, manufacturers need to become able to efficiently develop and introduce new products at an increased pace [1, 2]. The food and beverage market is no exception and the market has become very dynamic, with rising competition, higher commodity prices, tighter profit margins and extensive new regulations [3, 4]. A challenge made even more complex due to the seasonal nature of demand and a general low customer loyalty [1]. Wiendahl et al. suggests firms to adopt changeability to successfully deal with these challenges [5], which is the ability both physically and logically respond to changes in product variety and volume [6].

Given the intense legislation and nature of the products in the food industry, manufacturers can have difficulties in adopting some of the more known techniques of increasing changeability, such as modularization and postponement. To some extent, the food manufacturers can produce partially cooked products such as frozen dough, cakes etc. and the consumer can customize the cooking with additional ingredients [1]. Thereby the customer order decoupling point (CODP) is postponed. However, this strategy of late customization has its limitations in respect to fully baked products [7]. A typical food plant produces a multitude of intermediate products in an even wider range of end packaging. However, the variety of the food products are often based on a relatively small number of raw materials. A product variant can be created by packaging, size, or print, labelling [9].

The food-processing industry, like the process industries, operates by mixing, separating, forming or chemical reactions; where these operations are applied on agricultural raw material in the form of a continuous flow or batch production [8]. To achieve a cost-effective production, large production batches are preferred, due to the typical long change-over times, due to the effort needed to clean, setup, and start-up the production system between product change-overs [10]. Especially planning flexibility is an issue in this environment, where, according to Van Wezel [10], the adoption of planning software would not be a sufficient standalone solution [9]. According to Gargouri et al. [4], efforts are need to address the monitoring and controlling of production systems, in order to better manage

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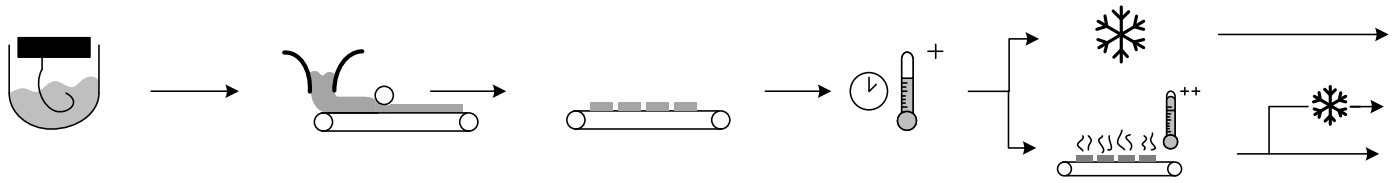

Fig. 1. A generic flow of the production with three end products.

low control problems. As the food industry, however, is characterized by unpredictable demand and a need for responsiveness and short lead times [10], the planning and control of production systems cannot solve the problem entirely. Instead, the production system design also plays a big role in determining how changeable the firm is, which is influenced by factors such as process flexibility, i.e. the ability of process equipment to manufacture variants with the same overall configuration [5]. However, within the food industry, the process flexibility is limited as manufacturers often utilize specialized equipment dedicated to processing a specific food product [11]. Although the equipment might have some degree of inherent flexibility, due to cost consideration, the manufacturers often are restricted in purchasing more flexible equipment.

Even though there is a need for cost-effectively producing a higher degree of variety and volume, the food industry has restricted changeability in their manufacturing systems, which is a challenge addressed by little literature. Further, literature from other areas may not be directly applicable to this industry, as previous research indicates that the drivers and enablers of changeable manufacturing are highly context dependent [12]. Therefore, the objective of this paper is to contribute with knowledge on how changeability can be implemented in the food industry. Specifically, this study addresses the following research question: how is the level of changeability in the food industry related to enablers of changeability.

2. Method

In section 1, it is established that there is a need for the food industry becoming changeable and thereby offer a product variety to the customer. Since this particular research area is immature, an exploratory single case study is used in order to determine if the theory on changeability applies to the food industry. In particular, a Danish food manufacturer producing bread and Danish pastry is chosen as case, as this industry is facing a challenging market environment. For instance, the price index of Danish bread manufacturing has declined from index 100 in 2010 to 85 in 2016 [14], meaning that the price on bread and cake has dropped with 15% in a mere six years. As a result, the case company's management recognizes the need for significant changes in the production setup in order to remain competitive. The case at hand is the Danish branch of an international company with more than 10,000 employees. The Danish Cluster has 1,400 employees and six industrial bakeries in Denmark and one in Germany, operates in the B2B and B2C marked, and provides bread, fast food products, and Danish pastry to both local and international customers. The product comes in three forms: ready to eat, ready to eat after defrosting or ready to bake after defrosting.

2.1. Questionnaire

In order to answer the research question, the paper uses questionnaires measuring the changeability of production lines, an approach also used by Andersen et al. [13]. In particular, the questionnaires measure the enablers and resulting changeability of 18 different production lines in the case company. These 18 production lines represent all the production lines at the case company, of which half are fresh and half are frozen. The frozen and the fresh production processes are highly similar and it is assumed that a comparison is possible. Each production line can produce several product variants but not the entire company's product portfolio. For a generic flow of the case company's production lines, see fig. 1, which includes the following activities: mixing and processing of dough, rise and relaxing of the products, and in some cases baking and/or freezing.

In order to adjust the questionnaire to the case at hand, the first author of this paper, who also is employed at the company as an industrial researcher, held prior meetings with the respondents. By limiting the enablers proposed by Andersen et al. [13] to those relevant to food industry, the researchers ensured that the enablers were understandable for the respondents. The questionnaire was sent by e-mail to all the respondents. A total of six production plant managers participated in this study, each responsible one of the company's industrial bakeries and representing one to five production lines. This also means that the respondents filled in between one to five questionnaires, i.e. one questionnaire per production line. Although this may introduce a bias as managers might compare their own production lines, which would enable dependent significant testing, this was deemed irrelevant since the managers have responsibility for very similar production lines, thus making the different intra-plant responses very similar.

The questionnaire is twofold, measuring the enablers of the changeability and resulting level of changeability on the production line. The unit of analysis is the production lines, and enablers are expressed on an ordinal scale from 1-5 was used, which corresponds to the study by Anderson et al. [13]. Moreover, it was indicated in the questionnaire that 1 the scale

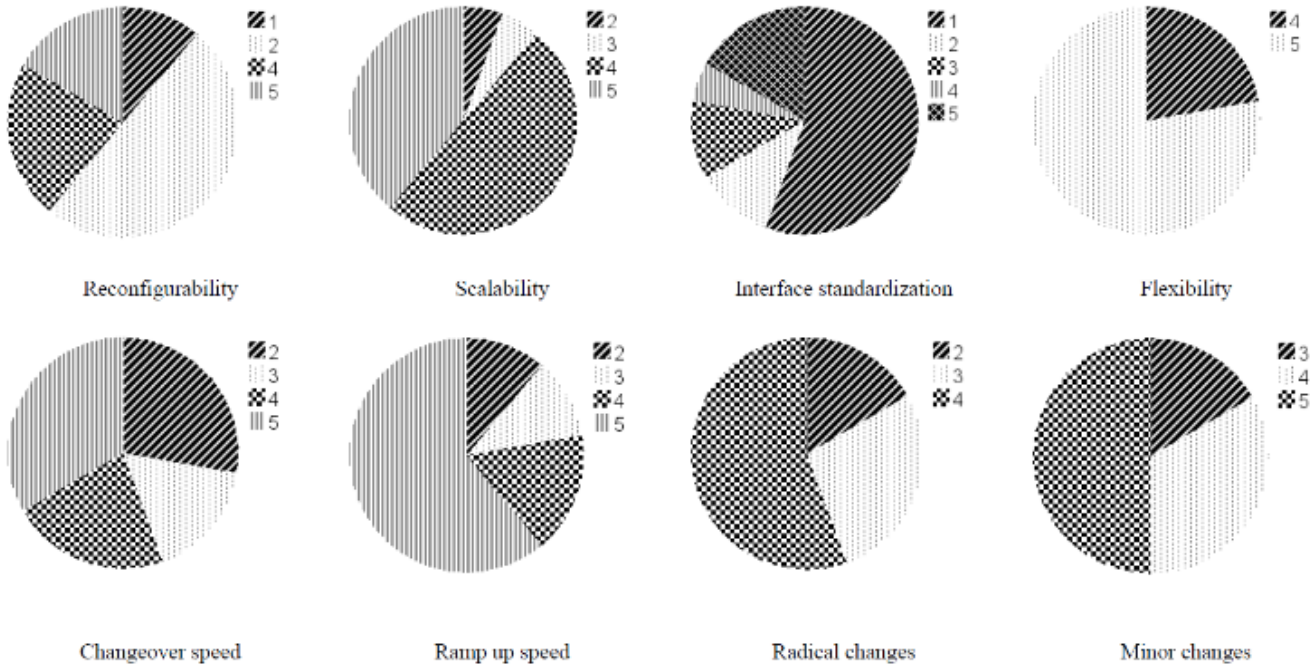

Fig. 3. Distribution of answers on the four changeability enablers and outcome measures

corresponds to large disagreement and 5 corresponds to large agreement of the statement. Even though the questions are scored one to five, the spacing between the values may not be identical. Data was collected using google forms, and the analysis was conducted using SPSS version 25 and RStudie Version 1.0.143.

The four changeability enablers and outcome measures are listed below. An extract of the questionnaire is include in fig 2.

Changeability enablers

- Reconfigurability: One production line can produce new product types. It is possible to remove parts of the production equipment from the line and introduce other equipment to change functions of the production line.
- Scalability: It is possible to scale up and scale down the number of units produced per hour.
- Interface standardization: A standard interface has been defined between the machines on the line, so it is possible to remove a machine and insert another machine on the production line.
- Flexibility: With the same production line, multiple variants of the same product type can be produced.

All changeability measurements are formulated in such a way that a high score indicate a changeable production line. The changeability measurements are as follows:

- Changeover speed: The time it takes from producing product A to starting to produce B, is a minor part of overall production time.
- Ramp up speed: The time it takes from starting production of a product to the time that the line is running with the required speed and quality, is a minor part of overall production time.
- Ease of new product introduction (radical changes): The current opportunities for introducing products with brand new recipes and / or shapes on a short time scale?
- Ease of product variant introduction (minor changes): The current opportunities for introducing products that are alike the current products on a short time scale?

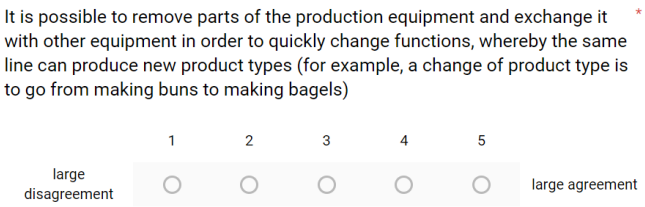

Fig. 2. An example of the questionnaire and variables based on only one question.

Table 1: Kendall's tau Nonparametric Correlations Test

	Reconfigurability		Scalability		Interface standardization		Flexibility	
	τ	p	τ	p	τ	p	τ	p
Changeover speed	-.035	.864	-.589	.006*	.072	.727	-.135	.544
Ramp up speed	-.581	.006*	.243	.267	-.664	.002*	.333	.146
Radical changes	-.240	.260	.027	.487	-.569	.008*	.412	.072
Minor changes	-.107	.620	.626	.005*	-.376	.080	.443	.055

*Significant at the 0.05 level

2.2. Kendell's tau

The Kendall's tau correlation test is selected as method for studying the relation of different enablers and measurements of changeability. The correlation coefficient is a measure of the strength of the relationship between two variables. The Kendall's tau is a non-parametric correlation coefficient frequently denoted tau (τ) [15]. The correlation coefficient have a range between -1 and +1, if there is a correlation between the variables close to 1 it expresses a strong relationship. Contrary, if the value of τ is zero there is no relationship. Kendall's tau correlation test operates with a sample size of $14 \leq n \leq 24$ [16]. This sample size meets the collected sample size with $n = 18$ of this study. A statistically significance level of .05 is accepted [13].

3. Results and discussion

Fig. 3 shows the distribution of answers on the four changeability enablers and outcome measures, where table 1 shows the results of the Kendall's tau test, see Table 1

The results indicate a negative significant correlation (τ = -.581; p < .05) between a production line's reconfigurability and ramp-up speed, a production line's scalability and change-over speed (τ = -.589; p < .05), a production line's scalability and ability to introduce similar product (τ = -.626; p < .05), and the standardization of a production line's interfaces and ramp-up speed (τ = -.664; p < .02) and the standardization of a production lines interfaces and the how easy it is to introduce entirely new products (τ = -.569; p < .05). These negative correlations might indicate that the individual changeability enablers cannot support all outcomes simultaneously.

3.1. Ramp up and change-over

For instance, the correlation indicates that the production lines that more easily reconfigured and have standardized interface in order to accommodate the production of new products are also those with longer ramp-up time, that is, they require a longer time until the production line operates with desired speed and quality. This makes sense, as these reconfigurable systems would in all likelihood require more adjustments before being capable of producing at full capacity, whereas more dedicated and integrated equipment makes it easier to achieve quick ramp-up, observation which was also verified during subsequent interviews at the company. In other words, there might be a trade-off between the time needed to ramp-up individual products and the production systems overall ability to produce a greater variety of products. A similar logic can be used to explain the negative correlation between a production line's scalability and change-over speed. This finding indicates that for the production lines wherein it is easier to adjust volume, it takes more time to change-over from producing one product to another. So, in this case, there is a tradeoff between inherent scalability in the system and the resulting change-over flexibility. In all these instances, however, further investigation will be needed to indicate if there indeed is a relationship between these changeability enablers and changeability outcomes, and if so, explore why these relationship exists.

3.2. Introduction of entirely new product

The latter negative correlation is between the degree to which the production lines has standard interfaces, which enables the easy removal and replacement of machines, and the ease to which entirely new products can be introduced to the production line. There are multiple manners of introducing a new product, the recipe can be changed and/or the shape. When changes are made to the recipe, the differences only affect the mixing process, where all the other subsequent processes can be identical or similar to the production processes that other products go through – meaning no or little change to the overall production setup. On the other hand, in order to produce a new shape, different equipment might be needed and/or an entirely new production setup with a new sequence or positioning of the equipment. In such a case, one might expect that standard interfaces would make it easier to adjust to new product shapes. Therefore, the negative relationship between standard interfaces and new product introduction is surprising, and requires further analysis. This analysis would benefit between making a distinction between the type of product introduction at hand, whether, for instance, the new product is a result of a radical change to recipe, shape or both. Therefore, further studies are needed to determine this correlation.

3.3. Introduction of similar product

The only positive significant relationship is found between the product line's ability to change production volume and the ease to which to introduce products which only differ little from existing products (τ = 0.626; p < 0.05) . Further, even though not statistically significant, there also seems to be a correlation

between to which degree to production line can produce product variants (flexibility) and the introduction of similar products ($\tau = 0.443$; $p = 0.055$). The interpretation at the case company is that this correlation is true, and the fact that the score does not indicate a significant correlation may be attributed to the sample size or bias in answers. Production lines which are able to handle changes in volume (scalability) and variety (flexibility) would in all likelihood also be able to more quickly accommodate for minor changes in the products to be produced on said line. However, further studies are needed to determine this correlation.

3.4. Fresh and frozen relationship

Studying fresh and frozen production lines respond to degree of implementation of enablers, a distinction was discovered, see Fig. 4. The production lines producing frozen products have higher reconfigurability and a higher degree of interface standardization, which indicates that these production lines should be more capable of changing their production setup in order to accommodate new product types and equipment compared to production lines producing fresh products.

On the contrary, the fresh production lines are more scalable in volume and have a high flexibility. These two changeability types are very important for the production of fresh produce. Due to the short shelf-life of these fresh products, the company needs to produce in smaller batches and cannot rely on stock-keeping as a buffer. As a result, these production lines are capable of production a variety of similar products at different volumes, according to changes in demand. On the other hand, the production lines of frozen products produce products that are more different, and thus rely on reconfigurability and interface standardization instead.

4. Conclusion

Increasing demands for higher product variety and innovativeness while still keeping manufacturing costs low is pushing the food industry to increasing their flexibility. This paper argues that this challenge cannot be met by only improving planning and control, but also requires the food manufacturers to adopt more changeable production equipment. To examine how changeability can be implemented in the food industry, this paper used evidence from 18 production lines; data collected via questionnaires addressed at plant managers from six different plants part of the same industrial bakery. Based on preliminary interviews at this case company this paper identifies four changeability enablers pertinent to the food industry; reconfigurability, scalability, flexibility and interface standardization of production lines. It then explores how these enablers impact the respective production line's change-over speed, ramp-up speed, and ability to introduce incrementally and radically new products.

The findings indicate that there are significant correlations between the changeability enablers and outcome measures. Negative correlations are found between the studied production

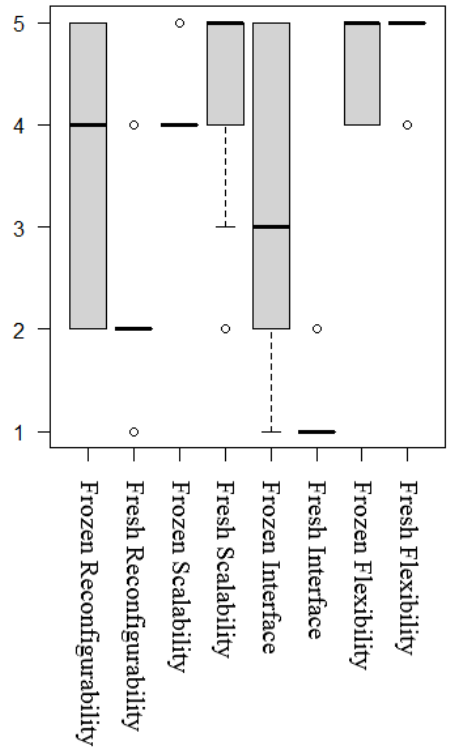

Fig. 4. Boxplot of the enabler divide by fresh and frozen.

lines' 1) reconfigurability and ramp-up speed, 2) scalability and change-over speed, 3) interface standardization and ramp-up speed and 4) interface standardization and ease to which radical production innovation is implemented. These negative correlation indicate that changeability enablers cannot support all outcomes simultaneously, and that trade-offs between certain enablers and outcomes may exist. For instance, increasing the reconfigurability of a system and introducing standardized interfaces might mean that it takes longer time to ramp-up production, compared to ramp-up production on a more dedicated and integrated set of equipment. Not all results, however, could be explained. Contrary to the results, the authors expected that the used of standard interfaces would make it easier to introduce radically different products. Similarly, one might expect a significant positive relationship between reconfigurability and introduction of radically different products.

The findings indicate that there are significant correlations between the changeability enablers and outcome measures. Negative correlations are found between the studied production lines' 1) reconfigurability and ramp-up speed, 2) scalability and change-over speed, 3) interface standardization and ramp-up speed and 4) interface standardization and ease to which radical production innovation is implemented. These negative correlation indicate that changeability enablers cannot support all outcomes simultaneously, and that trade-offs between certain enablers and outcomes may exist. For instance, increasing the reconfigurability of a system and introducing

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Half of the production lines at the case company produced frozen products, the other half fresh products. Whereas the manufacturing setup producing frozen products had implemented a reconfigurability enabler and interface standardization to a relatively high degree. The other production lines were mostly focused on accommodating the ability to produce multiple variants of the same products. This indicates there might be a hindrance towards creating a production setup capable of accommodating a larger variety of different fresh products

Since this paper only presents findings based on a singular case study, further research will be needed to verify the relationships between changeability enablers and changeability outcomes, and if so, explore why these relationship exists. Not only studies on a larger scale, but also addressing different types of food manufacturers, as the perishability of the product at hand might impact which degree and type of changeability enablers might be feasible or appropriate for the specific manufacturer.

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