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Measuring robustness of a processed cheese production system through Value Stream Mapping: a case study in the context of the COVID-19 crises

Messung von Robustheit eines Schmelzkäseproduktionssystems mittels Wertstromanalyse: eine Fallstudie im Kontext der COVID-19-Krise

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Summary

Market disturbances, such as the demand shock caused by the COVID-19 pandemic force food manufacturing companies to increase robustness of their production systems. The purpose of this study is to show how Value Stream Mapping and EPEI value calculation are applied to an Austrian processed cheese manufacturing company to measure the current state and the flexibility of the production system. Thereby, Customer Takt Time is used to link the customer demand and the production. The results indicate that high variability, caused by high setup times and loss times are major drives for being inflexible. However, the applied method is limited by its inability to measure dynamic behaviors.

Keywords: robustness, COVID-19, VSM, food processing industry, standardization

Zusammenfassung

Marktstörungen, wie der durch die COVID-19 Pandemie verursachte Nachfrageschock, drängen lebensmittelverarbeitende Unternehmen dazu, die Robustheit ihrer Produktionssysteme zu erhöhen. Die vorliegende Studie soll zeigen, wie die Wertstromanalyse und die EPEI-Wert-Kalkulation in einem österreichischen Schmelzkäseunternehmen angewendet werden, um den aktuellen Zustand und die Flexibilität der Produktion zu messen. Dabei wird der Konsumententakt dazu genutzt, um die Konsumentennachfrage mit der Produktion zu verknüpfen. Die Ergebnisse lassen erkennen, dass hohe Variabilität, die durch hohe Rüstzeiten und Verlustzeiten verursacht wird, maßgebend für unflexible Produktionsprozesse sind. Dennoch ist die angewendete Methode darin begrenzt, dynamische Verhalten zu messen.

Schlagworte: Robustheit, COVID-19, Wertstromanalyse, lebensmittelverarbeitende Industrie, Standardisierung

1 Introduction

Production systems are increasingly exposed to disturbances and disruptive changes (Stockmann and Winkler, 2022). Uncertainties, such as global conflicts, scarcity of resources, changing consumption patterns or pandemics (Nakat and Bou-Mitri, 2021; Sarmentoa et al., 2019; Zangiacomi et al., 2019; Melvin and Baglee, 2008), force companies to increase robustness of their production environments towards becoming adaptive to high volatile market situations (Stockmann and Winkler, 2022; Zangiacomi et al., 2019; Stricker and Lanza, 2014). One of the most recent disturbances is the COVID-19 pandemic, which has induced a rapid demand shock in many industries (Weersnik et al., 2020).

The food processing industry was one of the first industries to experience the pandemic, as it fulfills one of the most fundamental needs of humankind (Chowdhury et al., 2020). Many manufacturers and suppliers of perishable products have lost their core sales channels due to the closing of specific industry sectors, including the HoReCa (Hotel-Restaurant-Café) sector, food service, schools, etc. (Coluccia et al., 2021). Concurrently, customers reacted in a panic buying and stockpiling behaviour (Galanakis et al., 2021; Hobbs, 2020), which sharply increased the demand of non-perishable food products (Coluccia et al., 2021; Galanakis et al., 2021), such as processed cheese.

Demand shocks are often accompanied by the so-called bullwhip-effect (Coluccia et al., 2021), which makes it difficult to predict real demand. The phenomenon emerges when volatility in demand at a lower stage of the supply chain is amplified along upstream stages, due to misinterpretation and misinformation, but also synchronization of orders and batching of economic lot sizes (Cachon and Terwiesch, 2013). Improving communication and interaction between individual supply chain partners effectively diminishes such fluctuations (Sticker and Lanza, 2014). However, this paper focuses on the robustness of an individual food processing company, but not on the entire supply chain.

Stricker and Lanza (2014) defined robustness of a production system as the ability to deal with disturbances, while keeping the production performance on an acceptably high level. This can be either achieved by being impervious to disturbances (*resilience*, *agility*) or by a suitable reaction to varying conditions. The latter can be further divided into short- and medium-term (*flexibility*) and costly long-term disturbances (*changeability*). This paper aims to regard short- and medium-term disturbances within a specific flexibility corridor, which occurred due to the demand shock of the COVID-19 pandemic.

Standardization of production systems is vital for improving robustness, as operational complexity is steadily increasing (Roh et al., 2019). Thus, fluctuations are decreased and boundaries of the flexibility corridor are not reached as quickly. Higher variability is associated with high loss times causing unstable and long lead times, which make the production flow slow and inflexible (Erlach, 2020; Thonemann, 2015). Standardization ensures that working procedures are carried out equally; independent from workers and time. Moreover, standardized and small production lot sizes have the advantage of production reacting faster to customers' needs, as the production is capable of producing in the interval of customer demand (Thonemann, 2015) and peaks in order volumes are smoothed. Processed cheese production plants are especially characterized by complex production systems, including high variability, heterogeneous lot sizes, high variant variety, and hence high setup times.

Increasing robustness starts by understanding and measuring the current state of the production system. One of the most applied lean methods is Value Stream Mapping (VSM) (Dal Forno et al., 2014), which was originally developed during the Oil Crisis in the 1970's, induced by a drastic shift in demand (Ohno, 1988). It is a paper-and-pencil approach (Dal Forno et al., 2014), which maps the current state by separating value adding times from non-value adding times, whereas the latter is defined as *waste* and is to be eliminated. The VSM approach follows the fundamental principle of taking the perspective of the customer, whereby the Customer Takt Time is the most important reference point (Erlach, 2020). VSM was originally developed for discrete manufacturing, however, more recently it has become popular in the process industry (Abdulmalek and Rajgopal, 2007) and is constantly being further developed (Huan et al, 2019).

A novel lean approach for analyzing the flexibility of the production system is the EPEI value calculation (Every Part – Every Interval), which has been rarely mentioned by the literature so far. It is the time needed to produce every single variant once, within a given working period, including setup times and loss times. In principle, the lower the EPEI value, the more flexible the production is (Erlach, 2020).

The aim of this paper is to show how VSM and EPEI value calculation is applied to a processed cheese manufacturing company to identify improvement potentials, aiming to increase robustness to unpredictable disturbances, such as the demand shock caused by the COVID-19 pandemic. The analysis follows two major steps: an analysis of the current state and a detailed evaluation of the flexibility of the production system.

2 Data and Methodology

The present analysis was conducted at an Austrian processed cheese manufacturing company as it produces durable food products and thus was directly affected by the demand shock in the early phase of the COVID-19 pandemic. Moreover, it was closed due to a coronavirus outbreak among its workforce. The product group of Individually Wrapped Slices was investigated, which has an annual production volume of 14,000 tons, corresponding to 35 % of the total Austrian processed cheese production quantity and to 191 % of the national consumption (Statistik Austria, 2021).

The product group is produced 256 days a year, with 15 shifts per week, and some additional weekend shifts when demand exceeds the maximum production capacity and delivery dates are jeopardized. The product range is heterogeneous and consists of over 300 different variants, however, the production process is equal for every single product. Around 30 % of the product variants are *make-to-stock* and 70 % are *make-to-order* products. The product variant with the highest turnover and the most common packaging configuration has been chosen as representative for the analysis of the current state of the value stream. For the detailed calculation of the EPEI value the production plans of an entire year as well as the production efficiency recordings of all production lines are evaluated.

The production is divided into two stages – a batch processing stage (recipe mixing) and a continuous flow production stage (heating and packaging stage) – whereby each stage has multiple processes. The three batch processes consist of *weighing raw materials*, *weighing auxiliary materials*, and *shredding*, whereas *mixing and heating*, *filling and packaging*, and *final packaging* belong to the continuous flow production stage. The production system consists of two identical lines; however, the stage *filling and packaging* has two resources per line.

The VSM approach, proposed by Erlach (2020), was applied for the analysis, as it is one of the most recent further developments of the well-known approach introduced by Rother and Shook (1999). The analysis starts by calculating the Customer Takt Time (*TT*), which is the quotient of the available yearly working time in seconds (WT_y) and the yearly output in kilograms (Q_y) (1).

$$TT = \frac{WT_y}{Q_y} \tag{1}$$

TT...	*customer takt time (sec/kg)*
WT_y...	*working time per year (sec)*
Q_y...	*output per year (kg)*

The next step aims to map the current state of the value stream. Information is gathered contrary to the production flow, as the purpose of production originates from the customer (Erlach, 2020). Only customer order related production processes have been considered, which means that process steps, including the receiving department are excluded.

The value of each process is measured by directly stopping the time of each task. Value adding times are represented by process times, whereas non-value adding times occur due to setups, quality losses, malfunctions, slow running, and other downtimes, including planned maintenance during working time. Malfunctions, slow running, and downtimes reduce technical availability. Setups and quality losses are recorded separately. Moreover, inventory between the production processes is also counted, as it hides wastages and extends lead time (Erlach, 2020).

The quotient of the process time (*PT*) and the number of available resources per process with equal capacities (*#Res*) results in the Cycle Time (*CT*), which is the minimum time needed to produce one kilogram of cheese (2).

$$CT = \frac{PT}{\#Res} \tag{2}$$

CT...	*cycle time (sec/kg)*
PT...	*processing time (sec/kg)*
$\#Res$...	*number of resources*

Thereby, the process with the highest Cycle Time is the pacemaker for the entire production. The resulting capacity utilization is presented by the Operator Balance Chart, which is shown in the subsequent section.

Flexibility of the production is measured by the EPEI value. The equation used in this study is derived from the calculation proposed by Erlach (2020), which differs from the subject of the capacities. We used the summed machine operating times as well as the summed working times of all lines as the line capacities are not equal for every line. The EPEI value is calculated by the aggregated machine operating time, which is the summed product of the average lot sizes per variant (LS_i) and the variant specific process times (PT_i), multiplied by the share of quality losses (Q) and added by the summed average setup times (ST_i). The result is the total production time for the product range on all lines. By dividing the total production time by the summed available working time per day and line (WT), which is reduced by the technical availability (A), the EPEI value in days is received (3).

$$EPEI_{actual} = \frac{\sum_{i=1}^{\#Var}((LS_i \times PT_i \times (1+Q) + ST_i)}{\sum_{j=1}^{\#L}(WT_j \times A)} \tag{3}$$

$\#Var$...	*number of variants*
LS...	*average lot size per variant (kg)*
PT...	*process time per variant (h)*
Q...	*quality loss (%)*
ST...	*average setup time per variant (h)*
$\#L$...	*number of lines*
WT...	*total available working time of all lines per day (h)*
A...	*technical availability (%)*

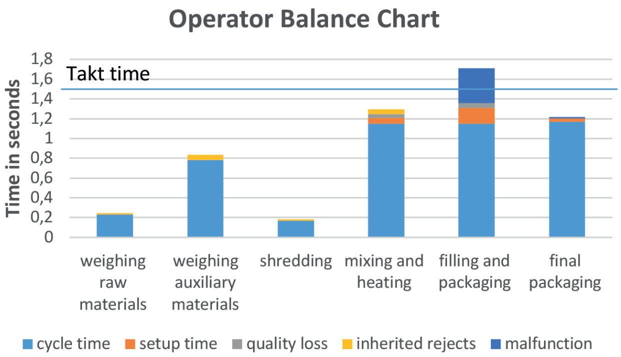
The technical availability is generated by weighting the line specific speed and downtime losses with the line specific available working time. Quality loss is the weighting of line specific time loss due to rework and rejects and the line specific available working time, whereby times of quality losses are aggregated by the variant specific process times.

3 Results

The summed inventory of the representative results in a lead time of 119 minutes, which is opposed to a summed process time of 12.22 seconds. The latter indicates the maximum theoretical pace of the production. The relatively high lead time results from the inventories between the batch processes. Considering only the flow production stage, a lead time of

4 minutes and 13 seconds faces a process time of approximately 10 seconds.

Figure 1: Operator Balance Chart of the main production processes



Source: Own representation based on Erlach (2020).

The Operator Balance Chart in Figure 1 shows how the processes fit within the Customer Takt Time. The chart reveals that the batch processing stages (*weighing raw materials*, *weighing auxiliary materials* and *shredding* are faster than the continuous flow production stages (*mixing and heating*, *filling and packaging* and *final packaging*). Thereby, the batch processing stages have excess capacity that is more than twice the capacity used, whereby workers have high idle times. Capacity utilization accounts for 49 %, however, if considering only the continuous flow production stages, it is 72 %.

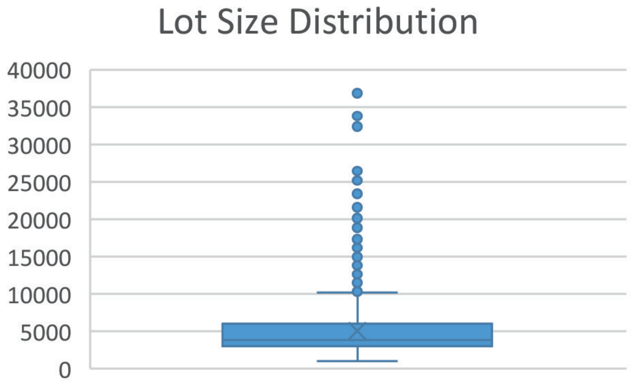
The real pacemaker process is not illustrated in the chart, as the stages *mixing and heating*, *filling and packaging* and *final packaging* are continuously connected to each other. However, an analysis of the production plans showed that the pacemaker and thus the bottleneck are moving between the continuous flow production stages, depending on the configurations of the product variant. For the representative, the bottleneck occurred at stages *mixing and heating*, meaning that the stage is running at full capacity.

As no Cycle Time of any process exceeds the Customer Takt Time, there is no absolute bottleneck in the system. However, at stage *weighing auxiliary materials*, the sum of Cycle Time, setup time, quality loss, and malfunction exceeds the available time limit by 7 %; thereby, technical availability results in merely 78 %.

The EPEI value calculation required a detailed analysis of the production data and showed that technical availability amounts to 81 %, quality loss to 3 %, machine operating time to 1,700 hours, summed setup times to 118 hours, and summed working time of all lines to 74 hours. Accordingly, actual EPEI value accounts for 30.9 days.

The main influencing factors in reducing EPEI value are setup times, production quality and technical availability. Decreasing setup times by 3 % results in an EPEI value of 30.8 days through decreasing quality loss by 3 %, an EPEI value of 30.1 days is obtained. The greatest positive impact is achieved by increasing the technical availability by 3 %, which leads to a reduction of 1.1 days to 29.8 days.

Figure 2: Lot size distribution



Source: Own representation based on the production plans.

Moreover, lot sizes are heterogeneous and vary between 1,000 and 37,000 kilograms per production order with a median of 3,800 kilograms.

On the administrative side, there is an order backlog of several weeks, which is amplified by high fluctuating lot sizes. However, the minimum order quantity is equal for every product variant, regardless of its specific process time.

4 Discussion and Conclusion

The present study gives valuable insights on how VSM and EPEI value calculation are applied to a processed cheese manufacturing company to measure production robustness to demand shifts, which occurred in the early stage of the COVID-19 pandemic. The purpose is to uncover *wastages* by identifying non-value adding times and evaluating flexibility of the system. Accordingly, the production system is made more adaptive to unpredictable disturbances through standardization, whereas boundaries of the flexibility corridor are not reached as easily. However, as the impacts of specific disturbances depend strongly on the occurring influencing factors, the boundaries of the flexibility corridors are not limited (Stricker and Lanza, 2014).

For decades, VSM has been successfully used in various industries for improving standards of production systems. However, due to the static nature of VSM, dynamic behaviors like moving bottlenecks or fluctuating demand cannot be captured appropriately by only taking a snapshot of the production (Erlach, 2020). Nevertheless, when repeated at regular intervals, it reveals valuable insights to the system performance. Recent developments may overcome these limitations by applying simulations that are capable of displaying dynamic behaviors (Abdulmalek and Rajgopal, 2007). Additionally, digitalization tools (Weersink et al., 2020) are being increasingly utilized for real time monitoring of the value streams (Huang et al., 2019).

The Operator Balance Chart further shows the capacity utilization of the system. Workers at the batch processing stage have high idle times, which makes them predestined for cross-training, allowing them to take on various tasks in case of illness or quarantine of colleagues. Additionally, in phases of high incidence of infection, social distancing is an acute measure that is often not avoidable on the shop floor. However, smart devices can support contact tracing of employees in case of infection (Nakat and Bou-Mitri, 2021).

The Customer Takt Time shows how customer needs have been considered in production thus far. Through the Operator Balance Chart, it becomes apparent that the bottleneck process has a buffer capacity of 21 % between Cycle Time and Customer Takt Time. However, the high variability of loss times as well as high setup times exceeds Customer Takt Time, thus production cannot keep up with the demand. According to the workers, the main drivers for high loss times are imprecise and unstandardized setup operations. The study of Melvin and Baglee (2008) confirmed that technical malfunctions are a common problem in the dairy industry.

Due to the ever-increasing number of variants, standardization of setup operations is becoming even more vital to decrease variability (Erlach, 2020), and concurrently problems are more easily traceable and correctable (Thonemann, 2015). Tools such as *Single Minute Exchange of Die* have been successfully used to improve setup operations (Erlach, 2020; Thonemann, 2015), however, employment and cross-training are further crucial factors.

The results further highlight that increasing technical availability has the greatest positive impact on reducing the EPEI value, as technical loss times decrease total available working time. Quality losses have the second most powerful impact on the EPEI value, as parts have to be produced repeatedly, thus increasing machine operating time of the variant. Although, reducing setup times has the least impact of the three mentioned, it is mainly responsible for loss times. However, a low EPEI value also requires small and equalized lot sizes (Erlach, 2020), which are often not achievable in the food industry due to the heterogeneity of lot sizes, which is depicted by the boxplot in the results section. Moreover, *make-to-order* products cannot be produced in stock without an order. A suggested approach is to group the product range according to the ABC-classification by the variants' yearly demand and to calculate group specific lot sizes (Erlach, 2020). Thereby, *make-to-order* products are to be split into smaller lot sizes, which requires a reduction of setup times and loss times. Linking Customer Takt Time and production should be the aim (Erlach, 2020). However, it has to be considered that administrative overhead costs may double, if lot sizes are decreased by 50 %.

Diversification and fast changing customer trends (Hobbs, 2020; Weersink et al., 2020; Roh et al., 2019; Melvin and Baglee, 2008) put increasing demand pressure on the production side (Hobbs, 2021) and require more sophisticated manufacturing processes (Roh et al., 2019). Increasing complexity requires constant improvements of production standards, making it more robust against unexpected events, such as demand shocks during crises (Erlach, 2020; Thonemann, 2015).

The findings highlight that improving standardization on the shop floor is vital for food processing companies to cope with disturbances, such as the demand shocks arising from the COVID-19 pandemic. Thereby, standardizing setup operations is identified as a major driver. The present study provides a valuable basis for further developing the VSM approach to make the food processing industry more robust. Further research can focus on lot size simulation referring to the dynamic behaviors of the food processing industry in order to reduce the EPEI value.

References

Abdulmalek, F.-A. and Rajgopal, J. (2007) Analyzing the benefits of lean manufacturing and value stream mapping via simulation: A process sector case study. International Journal of Production Economics, 107, 223-236. DOI10.1016/j.ijpe.2006.09.009.

Cachon, G. and Terwiesch, C. (2013) Matching Supply with Demand. An Introduction to Operations Management. New York: McGraw-Hill.

Chowdhury, M.-T., Sarkar, A., Paul, S.-K. and Moktadir, M.-A. (2020) A case study on strategies to deal with the impacts of COVID-19 pandemic in the food and beverage industry. Operations Management Research. DOI10.1007/s12063-020-00166-9.

Coluccia, B., Agnusdei, G.P., Miglietta, P.P. and De Leo, F. (2021) Effects of COVID-19 on the Italian agri-food supply and value chains. Food Control, 123, 1-12. DOI10.1016/j.foodcont.2020.107839.

Dal Forno, A.-J., Pereira, F.-A., Forcellini, F.-A. and Kipper, L.-M. (2014) Value Stream Mapping: a study about the problems and challenges found in the literature from the past 15 years about application of Lean tools. The International Journal of Advanced Manufacturing Technology, 71, 5-8. DOI10.1007/s00170-014-5712-z.

Erlach, K. (2020) Wertstromdesign. Der Weg zur schlanken Fabrik. Berlin: Springer-Verlags GmbH.

Galanakis, C.-M., Rizou, M., Aldawoud, T.-M.-S., Ucak, I. and Rowan, N.-J. (2021) Innovations and technology disruptions in the food sector within the COVID-19 pandemic and post-lockdown era. Trends in Food Science & Technology, 110, 193-200. DOI10.1016/j.tifs.2021.02.002.

Hobbs, J.-E. (2020) Food supply chains during the COVID-19 pandemic. Canadian Agricultural Economics Society, 1-6. DOI10.1111/cjag.12237.

Huang, Z., Kim, J., Sadri, A., Dowey, S. and Dargusch, M.-S. (2019) Industry 4.0: Development of a multi-agent system for dynamic value stream mapping in SMEs. Journal of Manufacturing Systems, 52, 1-12. DOI10.1016/j.jmsy.2019.05.001.

Melvin, A. and Baglee, D. (2008) Value Stream Mapping: A Dairy Industry Prospective. IEEE International, 1-5. DOI10.1109/IEMCE.2008.4618003.

Nakat, Z. and Bou-Mitri, C. (2021) COVID-19 and the food industry: Readiness assessment. Food Control, 121, 1-10. DOI10.1016/j.foodcont.2020.107661.

Ohno, T. (1988) Toyota Production System. Beyond Large-Scale Production. Boca Raton, London, New York: CRC Press.

Roh, P., Kunz, A. and Wegener, K. (2019) Information stream mapping: Mapping, analysing and improving the efficiency of information streams in manufacturing value streams. CIRP Journal of Manufacturing Science and Technology, 25, 1-13. DOI10.1016/j.cirpj.2019.04.004.

Rother, M. and Shook, J. (1999) Learning to See. Value Stream Mapping to Create Value and Eliminate Muda. Cambridge: Lean Enterprise Institute.

Sarmentoa, M., Marques, S. and Galan-Ladero, M. (2019). Consumption dynamics during recession and recovery: A learning journey. Journal of Retailing and Consumer Services, 50, 226-234. DOI10.1016/j.jretconser.2019.04.021.

Statistik Austria (2021) Versorgungsbilanzen. URL: https://www.statistik.at/web_de/statistiken/wirtschaft/land_und_forstwirtschaft/preise_bilanzen/versorgungsbilanzen/index.html (21.05.2022).

Stockmann, C. and Winkler, H. (2022) Robustness of production systems: Evidence from the German manufacturing industry. Journal of Engineering and Technology Management, 63, 101672. DOI10.1016/j.jengtecman.2022.101672.

Sticker, N. and Lanza, G. (2014) The concept of robustness in production systems and its correlation to disturbances. Procedia CIRP, 19, 87-92. DOI10.1016/j.procir.2014.04.078.

Thonemann, U. (2015) Operations Management. Konzepte, Methoden und Anwendungen. Hallbergmoos: Pearson.

Weersink, A., von Massow, M. and McDougall, B. (2020) Economic thoughts on the potential implications of COVID-19 on the Canadian dairy and poultry sector. Canadian Journal of Agricultural Economics, 68, 195-200. DOI10.1111/cjag.12240.

Zangiacomi, A., Pessot, E., Fornasiero, R., Bertetti, M. and Sacco, M. (2019) Moving towards digitalization: a multiple case study in manufacturing. Production Planning & Control, 1-15. DOI10.1080/09537287.2019.1631468.