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Operational performance of two-stage food production systems

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Document Version

Publisher's PDF, also known as Version of record

Publication date:

2007

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):

Akkerman, R. (2007). *Operational performance of two-stage food production systems: process interactions and capacitated storage*. [Thesis fully internal (DIV), University of Groningen]. s.n.

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CHAPTER 7

Summary and discussion

In this chapter, we outline the results from the individual papers. Also, we look at the the scope and limitations of these papers and what the implications are for future research.

7.1 Summary

The food sector has seen several important developments in recent years. First, competition has become fiercer because of the increased market power of food retailing. Secondly, quality legislation has become more stringent due to a growing concern for food safety throughout the society. Third, sustainable production has become more important, and organizations are held responsible for the environmental performance of their production system.

Concerned for their competitive advantage, food manufacturers increasingly focus on the efficiency of their operations. The developments mentioned are important reasons why good operations management (OM) and especially production planning and control (PPC) have become the key factors in keeping a competitive advantage. Despite a growing amount of research on OM and PPC in the food-processing industry, the field is still lacking behind in comparison with other industries. The overall aim of this thesis is therefore to extend the body of knowledge on OM and PPC in the food-processing industry.

The research presented in this thesis builds on the idea that industry-specific characteristics and configurations have implications for OM and PPC decisions. For example, time-constrained intermediate storage of food products can affect the performance of planning procedures. It is not straightforward that methods that work well in other production situations will also perform well under such perishability constraints. Another example is that increasing market pressure can cause extremely short required lead times, which in turn can force a food manufacturer towards a (partial) make-to-

order strategy and accompanying changes in scheduling and storage policies. These two examples illustrate the complex interactions between industry-specific characteristics and OM and PPC decisions.

To study these interactions, we choose to study two-stage food production systems with capacitated intermediate storage. The focus on two stages comes from the notion that food production typically takes place in two steps: processing and packaging. Between the two stages, intermediate products are normally stored in tanks or silos. Analyzing such an archetype system allows us to study a reasonably simple production system, which already contains complex interactions between industry-specific characteristics and OM and PPC decisions.

Chapter 2 starts this thesis with a detailed discussion of the product and production characteristics of the food-processing industry, based on previous research and several case studies. This industry-specific combination of characteristics should be the starting point of any study concerning OM and PPC problems. In the past, PPC has been widely studied in several research areas, resulting in a large number of methods, prescriptions, and approaches. However, the impact on practice seems relatively low, especially concerning production scheduling. Based on ideas about decomposition of scheduling tasks and decomposition of production processes, Chapter 2 develops a methodology for analyzing scheduling problems in the food-processing industry. It combines an analysis of structural (technological) elements of the production process with an analysis of the tasks of the scheduler. Combining these aspects helps to describe, structure, and ultimately solve scheduling problems in food processing. It also forms a basis for improving scheduling and helps in applying scheduling methods developed in the literature.

One of the most striking features of the food-processing industry is the presence of capacity- and time-constrained storage; limited shelf life of intermediate products results in time constraints, next to the —more obvious— capacity constraints. In Chapter 3, we show how various capacity and time constraints influence the performance of a two-stage system with a batch processor in the first stage and packaging lines in the second stage, linked by storage tanks. Using simulation, we demonstrate the impact of several well-known scheduling rules. The success of these rules depends on the performance measure used, and is significantly affected by the variation in packaging times. Due to blocking and starvation effects caused by the capacitated intermediate storage, the longest-processing-time-first (LPT) rule is able to maximize the total production volume per day —contrary to the common

sense in operations management. Furthermore, we show that relaxing the capacity constraint by adding one single intermediate storage tank already has considerable positive effects in terms of delivery performance—but also negatively affects the amount of product losses in the system. Finally, we conclude that the optimal setup frequency for batches (which corresponds to batch sizes) in the first stage is dictated by the storage time constraint. An important managerial insight based on these results is that both blocking and starvation negatively affect performance (in terms of production time), but only blocking causes product losses.

In practice, there are normally more intermediate products than intermediate storage tanks. This means some products have to share storage space. But, in order to meet the short lead times required by the current competitive market, storage tanks are sometimes dedicated to a single product to be able to package this product on demand, ensuring the required lead time. Dedication of storage is a widely used practice, and not only because of the lead-time reduction. It can also be the consequence of limited connectivity of equipment, or the result of planning and scheduling habits. In Chapter 4, dedicated and flexible intermediate storage is studied, combined with the prioritization of products in the packaging stage. Both these issues are ways to cope with the required lead times in the food-processing industry. The chapter aims at investigating the fundamental effect of prioritization and dedicated storage in a two-stage production system, for various product mixes. Simulation results show the improvements in performance for a prioritized product, as well as the negative effects for the remaining products (that have to share intermediate storage). The results also show that these effects decrease with more storage tanks, and increase with more products. Finally, by analyzing several product-mix scenarios, we illustrate that the dedication decision causes irregularity in the production schedules, leading to increased blocking and starvation effects. The results also indicate that the share of the prioritized product in the product mix determines the amount of blocking and starvation caused by the prioritization (and related dedication). For both relatively low and relatively high shares for the prioritized product, blocking and starvation effects increase, which leads to lower efficiency of equipment. In an industry where utilization already is high, this is obviously an undesirable situation.

Due to the increasingly fierce competition in the food industry, we see regular introductions of new products and/or special offers. Often, such an introduction or promotional effort affects the demand for other products or

packaging types. This means individual product demands are correlated. In Chapter 5, we study the effect of such correlated demand. More specifically, the aim of this chapter is to study the effect of product mix variability and correlated demand in a two-stage food production system. Correlation of demand can be found on two levels: the product level and the package level, and can be both positive (affecting other product or package types in the same direction) and negative (affecting other product or package types in the opposite direction). Results from a simulation study show that increasing correlation on the product level results in an increase in average lead times. For correlation on the package level, the increase is also found, albeit slightly smaller. Also, there do not appear to be interactions between the two levels of correlation. Similar results are found for the average amount of product losses. Increased demand variability strengthens the effects found. Overall, the analysis shows that demand correlations are an important consideration in decisions involving the product mix (e.g., new product introductions, order acceptance), and the consideration should include both levels of correlation as they have about the same impact on lead times and product losses.

Finally, Chapter 6 focuses on reduction of product losses in the production process. In food processing, losses are an inherent part of production; raw materials are normally lost in setups, cleaning procedures, and other process interruptions. Considering the fierce competition in the food sector, the reduction of such losses is of great importance for improving profitability. Furthermore, it is also a major step towards sustainable operations. In Chapter 6, we contribute to this topic by developing a research framework and a decision support tool for analyzing the effect of planning decisions on the amount of product losses in the food-processing industry. The research framework aims to collect and analyze data, supporting the development of a decision support tool that helps to investigate different scenarios for the planning decisions and production parameters. The first steps in the framework are the analysis of (i) process characteristics, (ii) demand characteristics, and (iii) production disturbances. The results from these analyses can subsequently be used in the development of a decision support tool. In Chapter 6, the analysis and tool development are applied in a case study in the dairy industry, where the Excel-based tool was able to reduce the planning-related losses with nearly 20%. Next to the reduction of product losses, maybe an equally important result is the insight gained on the interactions between processing, packaging, and intermediate storage (e.g., when equipment has to stop due to full or empty intermediate storage). The framework and tool

can easily be adapted to other situations.

7.2 Discussion

The main aim of this thesis was to improve the knowledge on the interactions between industry-specific characteristics and OM issues within typical two-stage food production systems with capacitated intermediate storage. This aim was translated into three research questions. The first question concerned the effects of capacity and time constraints on the intermediate storage. This issue was addressed in Chapter 3 and 4 (and was also illustrated in the case study in Chapter 6). The second research question, the effects of high product mix variability and lead-time reductions were addressed in Chapter 4 and 5. Finally, the third research question specifically concerned the influence of planning decisions and process configurations on the realization of product losses in the production process, and was dealt with in the case study in Chapter 6. The results presented in this thesis provide insights in the operational performance of two-stage food production systems with intermediate storage. This performance not only entails competitiveness (through the insights on lead time performance), but also sustainability (through the insights on product losses).

7.2.1 Reflections on results

In a large part of this thesis, results are based on studies of fairly basic production situations. This choice was made to keep models simple, yet still large enough to contain fundamental interactions. This way, the results provide a basic understanding of the complex interactions found in two-stage food production systems with intermediate storage. In the various studies, specific assumptions were made to minimize the number of influencing factors and focus the analysis on the subject of study. Adding more factors to the models (for instance sequence-dependent setup times) would increase the interactions between factors, and make it difficult to draw conclusions on the most important factors chosen in this research.

The results presented in this thesis focus on operational performance (in lead times and product losses). This does not necessarily mean that the insights gained are limited to operational performance. For instance, the results can also be used in the (re)design of food production systems; numerous important decisions have to be made in this stage, including the connectivity of equipment, or the choice between a few large storage tanks or multiple small

ones. These choices are often related to investment decisions based on trade-offs between additional process capacity and flexibility on the one hand and operational costs on the other hand.

Although the issues studied in this thesis were inspired by and are typically found in the food-processing industry, other industries might also face similar issues. To what extent the results are usable in other environments depends on the characteristics of the production process. This research has focused on two-stage processes with intermediate storage. Furthermore, the products get their discrete form in the second stage of the production process. This means that for the most part, the product does not have a shape or form and is to be stored in tanks or silos. If these characteristics are present in other production situations, the insights from this thesis can be used. Obviously, this holds for most food manufacturers, but likely also for numerous other process industries.

7.2.2 Future research possibilities

This thesis has specifically focused on a number of characteristics (*e.g.*, shelf-life constraints, management of intermediate storage tanks) found in the food-processing industry. In the previous chapters, specific suggestions for future research have already been made. Here, several more general guidelines are presented.

Next to the food-specific characteristics discussed in this thesis, several other characteristics (as outlined in Chapter 2) make interesting topics for further research. Especially, a good understanding of the various sources of uncertainty found in food production (concerning processing yields, raw material quantity or arrival times, etc.) would be an interesting and valuable extension to this research. In the design of production systems—including intermediate storage facilities—one should be able to take these factors into account. Two different directions can be identified for this proposed further research. First, similar small production situations could be utilized to study the effects of other important characteristics of the food-processing industry, like variable processing yields. Secondly, another research direction would be to study such characteristics in more complex production situations, although this would likely result in very system-specific results, which was to some extent already the case in the basic systems used in Chapter 3 to 5 of this thesis. Studying more complex (or even real-life) situations would make it possible to show in which specific contexts the results from this research are the most dominant.

The production situations studied in this thesis all have full connectivity, *i.e.*, all equipment is connected. In practice, this is often not the case; production systems often consist of a collection of (weakly connected) groups of fully connected resources. This could mean that real-life situations are just a collection of smaller systems (close to our archetype production system), but it could also mean a distinction between certain strongly connected resources and a number of weakly connected groups of resources. This would also lead to different kinds of system interactions, which are an interesting topic for further study.

Due to the increasing competition in the food sector, market characteristics are becoming a very important factor. New product introductions are common, and product ranges have grown over the last decade. Production processes have not changed as much in this period, which often led to increasing unbalances between the product mix and the production system that is supposed to support it, resulting in production inefficiencies. The possible interactions and relationships between product design and process design have hardly been considered in the literature, but seem to be an important factor in performance realization. The correlated demands discussed in Chapter 5, and the product losses issue discussed in Chapter 6 are related to this theme, but there are many more aspects that warrant further investigation.

Future research could also be conducted to develop decision tools to help production managers understand the interactions (and their magnitudes) in their specific production system. From the experiences with the simulation tool presented in Chapter 6, it was clear that interactive models in an easy-to-use environment could provide production managers and planning staff with a lot of additional insights in the dynamics of their production system. In Chapter 6, modelling was done in Microsoft Excel, which is already familiar to most potential users and therefore reduces barriers for usage. More specifically for the tool presented in Chapter 6, future work could also include a different approach to the breakdown behaviour in the packaging stage. This was based on a deterministic model, but could also be approached stochastically to be able to gain a deeper understanding in the interactions between processing, packaging and intermediate storage. Furthermore, the results in Chapter 6 are partially case-specific. Although the tool is built to facilitate reuse in other situations, further research could lead to more general modelling tools for the analysis of product losses (or other performance measures) in the food-processing industry. Part of this research could possibly apply to the process industry in general.

