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Operational performance of two-stage food production systems

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The food-processing industry is an important industrial sector. In terms of turnover and employment, it is the largest manufacturing sector in the European Union (CIAA, 2005). As an illustration of the sectors' size, some key indicators for the Dutch food-processing industry can be found in Table 1.1. With almost 25% of the total industrial turnover, it is a major part of the economy. In the last decade, we have seen several important developments in the food sector:

- In the European Union, food retailing has become more and more concentrated and is expected to further concentrate (Dobson *et al.*, 2001). For food producers, Dobson *et al.* argue, this can result in fiercer competition, where retail chains dictate terms of sale and food manufacturers see their margins get squeezed.
- An increasing focus on food safety (*e.g.*, Griffith, 2006), leading to more stringent legislation. Examples can be found in traceability requirements or HACCP implementation. From a food producers' viewpoint, this results in additional production complexity.
- The increasing importance of sustainable production (CIAA, 2002). Organizations are not only held responsible for the quality of their products, but also for the environmental performance (in terms of waste, but also ecological production) of their production system (see *e.g.*, Bansal and Roth, 2000).

Table 1.1. Characteristics of the Dutch food-processing industry (CBS, 2006).

Characteristic	Value (2003)	Share of total industry
Number of companies	4,785	10.43%
Number of employees	118,000	16.14%
Turnover	EUR 53,841 million	24.10%
Financial result	EUR 3,708 million	28.94%

In order to keep a competitive advantage in light of these developments, food manufacturers are increasingly interested in improving the efficiency of their operations. Subsequently, good operations management (OM)¹ has never been more important in the food-processing industry.

1.1 Operations management in the food industry

In contrast to discrete industries, process industries have had relatively less attention in the OM literature. Over the last 25 years, a few authors emphasized the differences between discrete and process industries (*e.g.*, [Taylor et al., 1981](#); [Fransoo and Rutten, 1994](#)), but only recently, the research efforts concerning process industries seem to be increasing (*e.g.*, [Berry and Cooper, 1999](#); [Dennis and Meredith, 2000](#); [Flapper et al., 2002](#)). This is also reflected in a recent special issue of the Journal of Operations Management on OM in the process industries ([Van Donk and Fransoo, 2006](#)). However, given the industry's size, research attention is still lacking behind.

As an important sector within the process industries, the food-processing industry has had relatively little attention within the literature on process industries. It was also noticed by several other authors, because in recent years, we have seen that a number of areas within the food-processing industry have been explored, leading to interesting contributions to the field. Below, some of these contributions will be outlined to give an impression of recent literature on OM in food processing, and to set the scene for the research questions addressed in this thesis.

- [Hill and Scudder \(2002\)](#) explore the use of electronic data interchange (EDI) in the food industry. Based on survey results, they state that firms see EDI mainly as a tool for improving efficiency rather than supply chain integration.
- As a result of the increasing competitiveness, food producers who traditionally followed make-to-stock (MTO) strategies, have partly moved to make-to-order (MTS) strategies. This issue is discussed by [Soman \(2005\)](#), who develops tools and models to gain insights in the planning and control of production environments in mixed MTO-MTS situations.

¹According to the APICS dictionary, operations management can be defined as “the field of study that focusses on the effective planning, scheduling, use, and control of a manufacturing or service organization through the study of concepts from design engineering, industrial engineering, management information systems, quality management, production management, inventory management, accounting, and other functions as they affect the organization” ([Cox and Blackstone, 2002](#))

- Based on the current importance of food safety, there is an increasing possibility of product recalls. This requires food producers to be able to trace products efficiently. In this setting, [Dupuy et al. \(2005\)](#) discuss traceability and batch dispersion to be able to minimize the quantity of recalls.
- In a study on the implementation of Advanced Planning and Scheduling systems in the fresh food industries, [Lütke Entrup \(2005\)](#) concludes that several issues are important for all the case studies he presents. Among characteristics like intensive supply chain collaboration and the importance of quality management, he identifies product shelf life as the most distinguishing characteristic of the fresh food industry. In a related publication, [Lütke Entrup et al. \(2005\)](#) present a number of mathematical models for planning and scheduling in yoghurt production.
- After describing the increasing need for flexibility in the food-processing industry, [Van Wezel \(2001\)](#) notices an inconsistency between the flexibility of food production systems and the flexibility that is required by the market. He discusses several production planning issues, such as hierarchical planning and computer support, in the light of flexibility. In [Van Wezel et al. \(2006\)](#), the discussion on flexibility is continued, and the study shows that existing production planning approaches are often not able to make the most of the available flexibility in the production process.
- A growing concern for the environment is leading the industrial sector to adopt waste minimization programmes. For the food sector, [Bates and Phillips, 1999](#) demonstrate the financial and environmental benefits of such programmes. Following this development, [Kleindorfer et al. \(2005\)](#) see numerous possibilities and challenges for sustainable OM in general. Specifically for process industries, [Flapper et al. \(2002\)](#) reviewed planning and control of rework, an important aspect of sustainable operations.

It is interesting to note that also from the field of food engineering — which is normally more oriented towards food properties and chemical engineering— there seems to be a growing interest in OM-related topics, illustrated by a recent special issue of the *Journal of Food Engineering* ([Tarantilis and Kiranoudis, 2005](#)).

Obviously, this is by no means an exhaustive review of OM research in the food-processing industry. It does, however, show some interesting recent

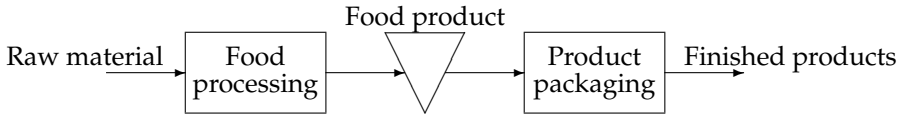


Figure 1.1. Two-stage food production system with intermediate storage.

developments, and illustrate several important characteristics of the current food-processing industry —*i.e.*, the focus on production efficiency, lead time reductions, a rising concern for food quality, the importance of shelf life, the need for flexibility, and an increasing concern for sustainable production.

Next to the described developments, the food-processing industry has a specific set of product and process characteristics (*e.g.*, perishable goods, divergent product structure). These characteristics have a significant impact on the management of operations. Concerning the process characteristics, food production typically concerns two production stages: processing and packaging. Between these stages, the unpackaged food product can normally be stored in intermediate storage tanks or silos (see Figure 1.1 for an illustration). For developments in OM in the food industry, this two-stage setting with capacitated intermediate storage is an important underlying process configuration. Processing and packaging are often two distinct production types (the latter concerns discrete units, while the former concerns a continuous product flow), which results in separate —though dependent— OM decisions. This especially concerns the intermediate storage, as the interaction between the two stages reveals itself there.

Concluding, we can say that —despite the described recent developments— there is still little research on OM in the food-processing industry, given its importance. Also, numerous industry-specific characteristics are involved in a focus on efficiency and sustainability. This increases the importance of OM in the food-processing industry.

1.2 Research objectives

From the recent attention in the literature, we learn that there are numerous research topics concerning OM in the food-processing industry. Production managers in this industry still have numerous questions concerning the management of their operations. Most of these questions have to do with industry-specific characteristics (such as limited shelf life and volatile demand patterns) and their interaction with OM decisions. This thesis aims to

contribute to the knowledge on OM in food processing. The main aspect of OM discussed in this thesis is production planning and control (PPC), but the included papers also relate to other OM aspects such as quality management, inventory management, and sustainability.

More specifically, this thesis focusses on two-stage food production systems with capacitated intermediate storage (see Figure 1.1). Within these systems, we study the interactions between industry-specific characteristics and OM issues. In Chapter 2 to 6 of this thesis, several aspects of this overall theme are addressed. Every chapter depends on industry-specific characteristics, and addresses one or more OM issues in light of these characteristics. In the following section, the research questions addressed in this thesis are discussed in more detail.

1.2.1 Research questions

As could be seen in Figure 1.1, typical two-stage food production systems have intermediate storage possibilities between the processing and packaging stage. This storage is normally constrained in capacity and time. Capacity constraints are found in the form of a limited number of tanks or silos that have to be shared by various products. Time constraints follow from the (aforementioned) limited shelf life of food products.

In practice, the implications of these different storage constraints are not always straightforward. It is often hard to decide on the number of tanks needed for intermediate storage, or whether or not storage should be dedicated, and how such decisions influence production performance. This brings us to the first research question:

RQ1 What are the implications of capacity- and time-constrained intermediate storage on production performance?

Typical for the food-processing industry are introductions of new products, promotions and special (export) orders following from tenders. This can result in a high product mix variability. In addition, the current competitive market often requires extremely short lead times. The influence of these demand characteristics on production performance is not clear, and this results in the following research question:

RQ2 What are the performance implications of demand characteristics like high product mix variability and lead time reductions?

The final research question addresses the issue of product losses. Due to economical and environmental requirements, the reduction of product losses

is important in improving profitability and sustainability of food production systems. In most cases, product losses are seen as a direct result of technological characteristics of the production system, but the interactions between the process configuration and PPC issues also plays an important role. However, the effects of planning decisions and production parameters are not straightforward, and this leads us to the following research question:

RQ3 How do planning decisions and process configurations influence the realization of product losses?

Next, we will describe how these research questions are discussed in the remainder of this thesis.

1.2.2 Thesis outline

As industry-specific characteristics have a central place in this research, the thesis starts with a detailed discussion of the characteristics of the food-processing industry in Chapter 2. Based on previous research and several case studies, a specific combination of product and production characteristics for the food-processing industry is presented. To be able to relate these characteristics to OM and PPC issues, Chapter 2 also develops a framework to analyze planning and scheduling in the food-processing industry. The so-called context-based analysis methodology presented is based on decomposition of the production process and decomposition of the planning and scheduling task. It is intended to understand, describe, and structure planning and scheduling problems and the related organisational structures and information flows.

Chapter 3 starts discussing research question 1, by analysing the performance of several basic scheduling and sequencing rules under the mentioned capacity and time constraints on intermediate storage. The chapter aims to improve the understanding of the implications of such storage constraints in two-stage food production systems.

The current competitive market often requires extremely short lead times, which makes prioritization of products in planning and scheduling unavoidable. This often includes the dedication of intermediate storage capacity. In Chapter 4, this question is addressed and because the prioritization involves dedication of intermediate storage, the resulting paper contains insights on research question 1 and 2.

Next, Chapter 5 addresses the performance implications of product mix variability with correlated demand (relating to research question 2). An im-

portant aspect of the analysis in this chapter is that the correlations are defined on two dimensions: product types and package types. This resembles the two-stage production, where each of these two stages determines one of the defining characteristics of the end product.

Subsequently, research question 3 is discussed in Chapter 6, where the importance of planning in the realisation of product losses is emphasized and a research framework and a decision tool for reduction of product losses are developed. The research framework presented in this chapter is also applied in a case study in the dairy industry, where an Excel-based tool is able to significantly reduce the planning-related product losses. Furthermore, it clarifies the interactions between processing, packaging, and intermediate storage.

Finally, the thesis concludes with an overview of the results in Chapter 7. The conclusions from the individual papers are summarized, and possible directions for further research are outlined.

1.3 Included publications

The chapters in this thesis are all papers that are either published, accepted for publication, or under review for journal publication. This means that all of these chapters are readable as individual contributions, but it does not mean they are not related to each other. The chapters contain the following papers (with corresponding chapter numbers):

- 2 – RENZO AKKERMAN AND DIRK PIETER VAN DONK (2006), *Analysing scheduling in the food-processing industry: Structure and tasks*, Cognition, Technology & Work, accepted for publication.
- 3 – RENZO AKKERMAN, DIRK PIETER VAN DONK, AND GERARD GAALMAN (2006), *The influence of capacity- and time-constrained intermediate storage in two-stage food production systems*, International Journal of Production Research, accepted for publication.
- 4 – RENZO AKKERMAN AND DIRK PIETER VAN DONK (2006), *Product prioritization in a two-stage food production system with intermediate storage*, International Journal of Production Economics, accepted for publication.
- 5 – RENZO AKKERMAN AND DIRK PIETER VAN DONK (2006), *Product mix variability with correlated demand in two-stage food manufacturing with intermediate storage*, International Journal of Production Economics, accepted for publication.

- 6 – RENZO AKKERMAN AND DIRK PIETER VAN DONK (2006), *Development and application of a decision support tool for reduction of product losses in the food-processing industry*, Journal of Cleaner Production, accepted for publication.