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Balancing environmental and economic performance in the food-processing industry

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Abstract: Changing customer requirements, unpredictable disturbances combined with expensive production facilities, are major problems for food processing companies to achieve synergy between the economic and environmental performance. There notably is a lack of tools to support decisions to explore effects on performance related to new product introductions, changes in production equipment, changes in planning concepts and their cross sections. We argue that interdisciplinary research that uses operations research techniques, operations management insights, food process technology and product design helps in exploring the effect of uncertainty in demand and production. As a result, process design can be more robust: both economic and environmental. This position paper explores the problem and the main elements of the proposed scenario-based simulation approach.

Keywords: food industry; sustainability; product design; process design, simulation, scenario analysis

1. Introduction

Over the last years, sustainability and sustainable operations have been put on the agenda of industry, research, and government. Kleindorfer et al. (2005) consider sustainable operations as one of the key topics in Operations Management and Operations Research (OM/OR) research. Most of this research so far has been done in the context of discrete manufacturing and deals among others with remanufacturing, closed loop supply chains, and improving supply, but has ignored sustainability in process and food-processing industries (e.g., Flapper et al., 2002, French and LaForge, 2006). Within industry, many initiatives have been taken to reduce energy consumption, reduce waste, increase health and safety, etc. This often includes use of the ISO 14001 standard, a widely implemented environmental management standard (ISO, 2004, Kitazawa and Sarkis, 2000).

The development towards sustainability is also known as triple-bottom-line thinking, explained by Kleindorfer et al. (2005) as: 'integrating profit, people, and planet in the company's culture, strategy, and operations'. The main point being that profitability is only one aspect in performance measurement for firms. Theoretically, this seems to result in a trade-off between economic results and environmental results, as environmentally friendly production could be expected to increase production cost. But, as Porter and Van der Linde (1995) argue, in practice this situation can lead to innovative solutions that enhance resource productivity. An important aspect of their argument is that reducing pollution is also reducing valuable waste. Although these arguments are already a decade old, this synergy between economic and environmental performance has not yet been achieved (Kleindorfer et al., 2005), and is still debated in the literature (e.g., Ambec and Barla, 2006). On top of the debate on the possibility of synergies, the causality of the relationship can also be debated. Is improved environmental performance the result of efforts on improving economic performance ('lean is green', cf. King and Lenox, 2001)? Or does economic performance benefit from increased environmental efforts ('it pays to be green', cf. King and Lenox, 2002; Corbett and Klassen, 2006)?

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Realizing synergies between economic and environmental performance likely depends on industry-specific characteristics (Karagozoglu and Lindell, 2000). So far, research in sustainable operations has mainly focused on discrete industries, and has scarcely been paying attention to other types of industries and their typical characteristics. Here, we focus on the food industry as using often expensive, natural resources, and as being the largest manufacturing sector in the European Union (CIAA, 2005). The use of natural resources especially makes waste reduction an important aspect of sustainable production. Even more interesting is that this industry can be characterised as having a high level of expensive equipment and a high level of introduction of new products accompanied by a large uncertainty in volume and mix of demand. Due to these factors, the sustainable operation of food production systems is under heavy pressure. The main purpose of this paper is therefore to explore how the economic and environmental performance of the food industry can be improved. We present an approach that enables food companies to explore the effect of different scenarios for their production system performance, with a specific focus on uncertainty with regard to demand. Although we focus on food processing, the general approach might applicable in other types of industry as well.

The remainder of this paper is structured as follows. Section 2 first presents the background for this research. Then, we present the developed approach in Section 3, followed by a discussion about the development of scenarios in Section 4. Next, an illustrative example is presented in Section 5. Finally, Section 6 presents our conclusions.

2. Background: sustainability and food industry

Sustainability has been approached from different, often isolated, angles: e.g. being a technological, psychological or quality problem. In order to reach both economic and environmental improvements, more innovative and fundamental improvements are required. An interdisciplinary approach, combining operations management insights with technological expertise is necessary, as was recently argued in both the operations management community (Corbett and Klassen, 2006), as well as the engineering community (Azapagic et al. 2006, Edwards, 2006). Such an interdisciplinary approach can support the development of models and tools for use in the industry. This innovative knowledge creation would be a significant contribution to the sustainability of future production systems.

In the food industry, next to economic performance, environmental performance has been a main issue for several decades (CIAA, 2002; Mattson and Sonesson, 2003). Recent studies in the European Union (Dobson *et al.*, 2001) report that environmental performance is increasingly important in gaining competitive advantages. The European Union's Lisbon Strategy even labels it a prerequisite for lasting success of improved competitiveness (Commission of the European Communities, 2005). Significant improvements have been made in this area, but often specific for a certain production site, product, or process. An important methodology in this respect is life cycle assessment (LCA), which aims to assess the environmental impact of products over their entire life cycle (see also Mattson and Sonesson, 2003).

Most food-processing industries have a product-based layout: the sequence and type of operations on a product determines the position of equipment opposite to each other as well as the specific characteristics of each of the machines. Even small changes in recipe of packaging might need changes in the equipment. Mostly, production lines are dedicated to a family of related products, which are produced in individual batches. Overall equipment efficiency (economic and sustainable) is influenced by such factors as introduction of new products and their 'fit' to the machinery, number of products on the line (inducing the number of set ups), the mix of products, the volatility in demand (both in mix and volume). In general, the number of products has increased in the food-processing industry, and one of the major challenges is to produce that increased number of products on existing production lines with only minor adaptations in it (Van Donk *et al.*, 2008). Operations management (e.g. planning, quality management) aims to bridge the gap between the capabilities of a process design (as originally

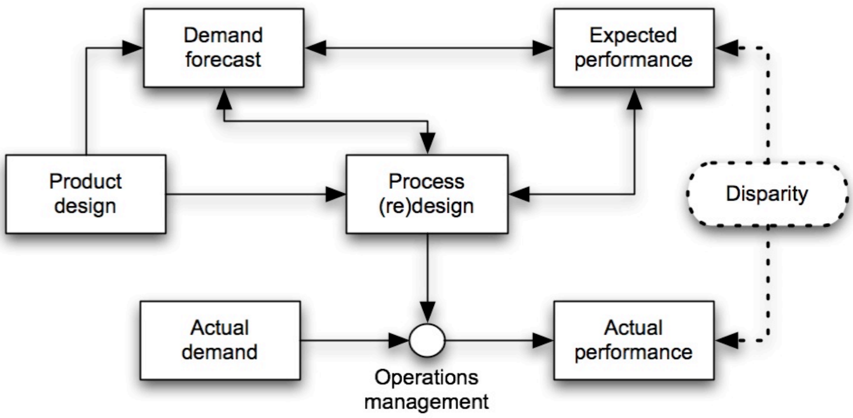

Figure 1. Performance implications of product and process design.

fitted to some expected situation) and the actual requirements induced by demand and products.

Overall, this situation results in an increasing unbalance between products and processes, leading to production inefficiencies (on several levels: product wastes, capacity utilization, manpower utilization, etc.) and decreased supply chain performance (Shah, 2005). Product design and process design have a central role in the actual performance of production systems, which is illustrated in Figure 1. The unbalance between the product mix for which the production process was initially designed and the (highly volatile) product mix that is actually produced leads to a situation in which expected performance and actual performance differ significantly. According to Vachon and Klassen (2007), the current unbalance between products and processes can be partly attributed to the fact that different parties within a supply chain are involved in product design and process design. These effects are extremely important in case of, for instance, new product introductions, but have hardly been considered in the literature (Lu and Wood, 2006).

3. Scenario-based simulation approach

In order to deal with the problems described in the previous sections, we propose a research direction that can lead to innovative and sustainable improvement of food production systems (in terms of economic and environmental performance). Starting with the situation illustrated in Figure 1, we believe tools can be developed to gain more insight into the relationship between process design and operations management on the one hand and demand characteristics and resulting performance on the other hand. Figure 2 shows our proposed framework. The grey-outlined part covers the concepts that are relevant in the development of simulation tools. Development of tools can range from custom-made software to simple spreadsheet models. What is important is that these tools can then be used to analyse various scenarios for e.g. process designs, operations management strategies, and future product demand (mix, volume).

The interdisciplinary setting is of the utmost importance: both technological and managerial aspects should be considered in the development of models and tools and the design of scenarios. For the development of models, this means the need for in-depth knowledge on e.g. detailed process characteristics from process technologists, planning and scheduling procedures from production managers, and demand behaviour from the sales department. Combined with a thorough analysis of available production data sources, this leads to models that are usable for detailed scenario analysis. In the design of scenarios, the detailed analysis of existing process and demand characteristics provides a starting point from which it is possible to

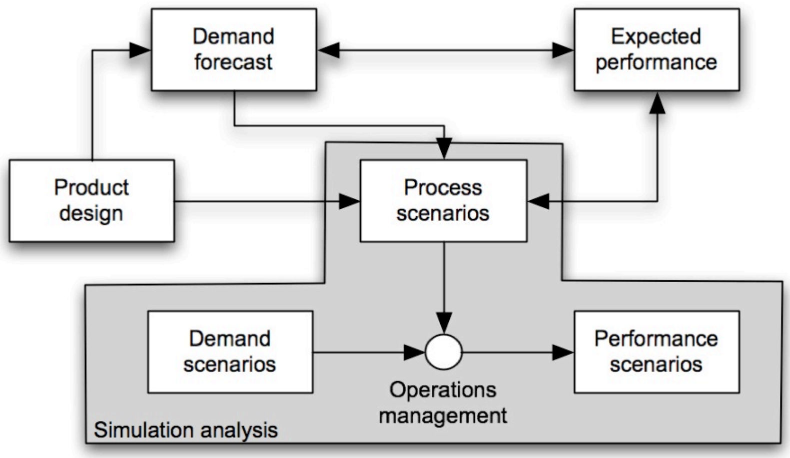

Figure 2. Proposed framework for simulation analysis.

develop new scenarios. The performance measures used in these tools can and should cover both economic and environmental aspects.

This approach provides the possibilities to design robust production processes, and robust operations management methods. Overall, it should lead to the development of new theoretical and practical models and insights into (i) the relationship between product and process design and (ii) the synergies (or trade-offs) between economic and environmental performance of production systems in the food industry. It is important to note that the proposed research methodology includes the use of case research. By itself, these cases can already be very valuable in applied research (Lyons, 2005), but over time, these cases can contribute to a sound theory-building process. Therefore, they should cover a wide range of process types (theoretical sampling), which provides the means for generalisation to build valid theory and models suitable for the whole industry (Eisenhardt, 1989).

This approach is inspired by a research project by Akkerman and Van Donk (2008), in which a case study was performed and a decision support tool was developed. Their study can be seen as an illustration of the approach presented in this paper. Their decision support tool aimed to support process design and production planning decision making in light of the reduction of product losses (economically and environmentally interesting!). Various scenarios were studied, using a spreadsheet simulation model. The study demonstrates (i) that the approach is able to reduce the product losses significantly, and (ii) that simulation tools can be very helpful in understanding the complex dynamics found in real-life production systems.

4. Modelling and scenario analysis

The analysis of different scenarios for the various elements in the framework is at the core of the approach presented in this paper. To be able to perform these analyses, a working simulation model of the production process should be developed. To aid this process, Table 1 provides an overview of important model parameters. Obviously, this is by no means supposed to be an exhaustive list, but we feel to have included the most relevant issues for the food industry. It should be mentioned that this stage normally requires a large effort in data collection, as not all the necessary data will be readily available. Initially, the simulation model and its parameters are modelled after the current reality. This is very important in the validation and verification of the model, as it provides the means to recreate historical scenarios, and get the users to appreciate and grow confidence in the simulation model.

Table 1. Overview of model parameters and their classification in the example.

Model parameters	Parameter classification in the example in section 5 Scenario 1	Scenario 2
Process		
Processing equipment (number/type/speed)	C	C
Packaging lines (number/type/speed)	C	C
Storage tanks (number/size)	**P**	C
Connectivity of equipment (degree of flexibility)	C	C
Setups (changeover matrix in time/labour/waste/…)	C	**P**
…		
Demand		
Product mix (number/recipes/packages)	C	C
Order sizes (small/large)	**U**	**U**
Order regularity (daily/weekly/…)	**U**	**U**
Level of uncertainty (high/low)	C	C
Seasonality	C	C
Lead times		
…		
Operations Management		
Batching decisions (size/splitting/…)	**P**	C
Sequencing decisions (and setups)	C	**P**
Capacity allocation (equipment/tanks)	C	**P**
Make-to-order/make-to-stock (or mixed)	**P**	C
Planning & scheduling organisation (when/how/…)	C	C
…		
Performance		
Economic (cost, utilization, lead times, …)		
Environmental (waste, energy use, …)		
Social (education, safety, …)		
…		

Legend: C: constant parameter, P: predetermined parameter, U: uncertain parameter

The actual development of the simulation tool can be performed with specialized packages or standard development languages, but as is also stressed by Thiriez (2004), development as a spreadsheet simulation model is often preferable due to improved user acceptance and software availability. This also allows for experimentation with the model by the problem owner, which adds to their knowledge of the behaviour of their production system –and the interactions between product mix and process design.

After having established a working simulation model of the production process, it can be used to perform scenario analysis. Table 2 presents several examples of scenario themes that can be studied, using an approach like this. Please note that scenarios often combine several of the examples mentioned –for instance: when studying shortened lead times for certain products, one might also look at batching and sequencing or technological adjustments.

After determining one or more scenario themes, a more detailed definition of the scenarios has to be made. Here, we can start by dividing the parameters in three categories: constant parameters, predetermined parameters, and uncertain parameters (cf. Schwartz, 1991). The first category concerns parameters that remain unchanged, the second category those that are changed in the scenarios, and the third category those that are out of the control of the researcher. Typically, the scenario design we propose here focuses on the formulation of a number of settings for the predetermined parameters (e.g., various sequencing rules, different

Table 2. Examples of scenario themes.

Category	**Level of influence**		
	Operational	**Tactical**	**Strategic**
Process	Minor technological adjustments	Major technological adjustments	Significant capacity investments
Demand	Order sizes, required lead times, rush orders, level of uncertainty	Regularity of orders, demand fluctuations	New product introductions, seasonality of products
Operations Management	Sequencing, batching, capacity allocation	Make-to-order or make-to-stock, planning horizon, order acceptance	planning hierarchy, plant allocation, supply chain integration
Performance	Cost, waste, realized lead times	Equipment utilizations, energy usage	Shareholder value, corporate image

storage tank sizes, etc.), and on analysing the uncertain parameters to estimate their possible future settings (which could lead to a number of settings or futures). For the purpose of this paper, the latter would likely concern most of the demand parameters.

In the case of shortening lead times, we could for example develop scenarios with different technological adjustments to the process, or a number of possible changes to the scheduling procedures (settings for the predetermined parameters). Combined with several possible demand patterns consisting of different order sizes, lead times, and arrival patterns (likely values for uncertain parameters), this should provide the necessary insights, and result in the best way to cope with the shortening lead times.

An important aspect of our approach is that scenario analysis is not bound to the operational, tactical, or strategic level. Scenarios on the strategic level could very well be compared with operational scenarios. This cross-level comparison is one of the key elements of the approach and results from the fact that the simulation models are created on the operational level –which is also necessary for analysis on the tactical or strategic level!

The main objective of a simulation tool like this is to answer what-if questions, but using more elaborate experimental designs for the scenarios, the tool can also be used to determine optimal solutions for issues like sequencing rules, the number of storage tanks, or tank sizes. For a more detailed exposure on the use of simulation, we refer to Law and Kelton (2000), and Robinson (2003), and for scenario analysis to Schwartz (1991) and Bood and Postma (1997).

5. Illustrative example

To illustrate the scenario-based simulation approach, this section contains a small illustrative example (derived from a real-life situation). In this example, we look at a typical two-stage food production system, consisting of a processing and packaging stage separated by intermediate storage tanks (Akkerman *et al.*, 2007). More specifically, we focus on the processing stage, which prepares recipes to be packaged in the second stage (see Figure 3). Between the raw material tanks and the intermediate storage tanks, several process routings exist to produce the recipes.

The company in this example is a typical small make-to-order food producer, facing decreasing order sizes, combined with increasing order frequencies. The total production volume stays the

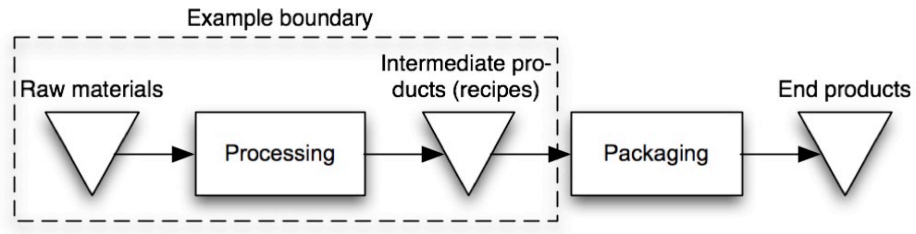

Figure 3. Production system considered in the example.

same, but this development has serious consequences for the production performance, as the number of setups increases, which in turn decreases utilization, and increases labour costs, energy usage, wastewater, and product losses. We choose to analyse the following scenarios:

1. Increase of the number of intermediate storage tanks, allowing for dedicated intermediate storage tanks for most of the recipes. This makes it possible to change the processing stage from make-to-order to make-to-stock, creating the possibility to increase batch sizes in the processing stage. We use two different parameter settings:
   a. Minor investment in tanks, and MTS for a few products
   b. Major investment in tanks, and MTS for most products
2. Optimization of production sequencing and routing decisions, aiming for less and shorter setups, based on sequence-dependent setup times. Again we use two different variants, allowing for different levels of flexibility in the production schedule (e.g., to cope with rush orders):
   a. Improved sequencing/routing, still allowing some flexibility
   b. Optimal sequencing/routing, removing almost all flexibility

For both scenarios, the division of parameters into constant, predetermined, and uncertain parameters is shown in Table 1. As can be seen, order sizes and regularity were assumed to be uncertain parameters, while other demand parameters were set as constants in the experimental setup. This resembles the market characteristics, and in the simulation experiments, several likely settings for these uncertain parameters are evaluated.

Due to space limitations, we will not present full numerical results of these scenarios, but will suffice with a summary of the effects of the scenarios on the main performance parameters (see Table 3). As we can see, the first scenario has the biggest impact on the chosen performance parameters, but this also has the largest investment cost. As the second scenario only results in shorter setups and not less setups, it does not affect all performance parameters (e.g., wastewater from rinsing piping still occurs).

It should be noted that the results in this example are to a large extent dependent on the constant parameters of the production system. This emphasizes the need for careful collection,

Table 3. Summary of resulting performance effects in the scenarios.

Performance parameter	Scenario			
	1a	1b	2a	2b
Number of setups	– –	– – –	0	0
Utilization	+ +	+ + +	+	+ +
Labour costs	– –	– – –	–	– –
Energy usage	– –	– – –	–	– –
Wastewater	– –	– – –	0	0
Product losses	– –	– – –	0	0

Legend: – : decrease, 0 : no change, + : increase analysis, and validation of data throughout the process of developing simulation models.

6. Conclusions and discussion

Due to continuously changing product mixes being produced on quite rigid production systems, performance of production systems in the food industry is often far from efficient. In this paper, we therefore present a scenario-based simulation approach to study the relationship between product design and process design in the food industry.

The benefits of the approach presented in this paper are threefold. First, it presents managers in practice with opportunities to gain additional insights in the behaviour of their production system. Secondly, it provides the means to find synergies (and possibly trade-offs) between different aspects of sustainability (especially economic and environmental performance). Finally, the approach can be used to facilitate interdisciplinary research approaches for robust process design, including operations management as well as engineering aspects.

For future research, we feel that multiple applications of the approach –in various situations– could lead to the development of a suite of models that cover a variety of process types found in the food industry. This also leads to an improved generalizability of the synergies and trade-offs found between economic and environmental performance in the food industry.

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