Received 4 November 2015
Revised 21 July 2016
9 November 2016
Accepted 9 November 2016

Design and control of food job-shop processing systems

A simulation analysis in the catering industry

Stefano Penazzi, Riccardo Accorsi, Emilio Ferrari and Riccardo Manzini
Department of Industrial Engineering, University of Bologna, Bologna, Italy, and
Simon Dunstall
Data61, Commonwealth Scientific and Industrial Research Organisation (CSIRO), Melbourne, Australia

Abstract

Purpose – The food processing industry is growing with retail and catering supply chains. With the rising complexity of food products and the need to address food customization expectations, food processing systems are progressively shifting from production line to job-shops that are characterized by high flexibility and high complexity. A food job-shop system processes multiple items (i.e. raw ingredients, toppings, dressings) according to their working cycles in a typical resource and capacity constrained environment. Given the complexity of such systems, there are divergent goals of process cost optimization and of food quality and safety preservation. These goals deserve integration at both an operational and a strategic decisional perspective. The twofold purpose of this paper is to design a simulation model for food job-shop processing and to build understanding of the extant relationships between food flows and processing equipment through a real case study from the catering industry.
Design/methodology/approach – The authors designed a simulation tool enabling the analysis of food job-shop processing systems. A methodology based on discrete event simulation is developed to study the dynamics and behaviour of the processing systems according to an event-driven approach. The proposed conceptual model builds upon a comprehensive set of variables and key performance indicators (KPIs) that describe and measure the dynamics of the food job-shop according to a multi-disciplinary perspective.
Findings – This simulation identifies the job-shop bottlenecks and investigates the utilization of the working centres and product queuing through the system. This approach helps to characterize how costs are allocated in a flow-driven approach and identifies the trade-off between investments in equipment and operative costs.
Originality/value – The primary purpose of the proposed model relies on the definition of standard resources and operating patterns that can meet the behaviour of a wide variety of food processing equipment and tasks, thereby addressing the complexity of a food job-shop. The proposed methodology enables the integration of strategic and operative decisions between several company departments. The KPIs enable identification of the benchmark system, tracking the system performance via multi-scenario what-if simulations, and suggesting improvements through short-term (e.g. tasks scheduling, dispatching rules), mid-term (e.g. recipes review), or long-term (e.g. re-layout, working centres number) levers.

Keywords Food processing, Simulation, Food industry, Catering industry, Job-shop system

Paper type Research paper

1. Introduction

The food and drink industry is the largest manufacturing sector in the EU (14.6 per cent of GDP in 2014) with a turnover of €1.048 billion and employs 4.2 million people in approximately 286,000 companies, mostly small and medium enterprises (Food Drink Europe Data and Trends, 2014).

The development of this sector follows the evolving trends of food habits and consumer expectations (Hollingsworth, 2003). The growth of potential new markets for safer, healthier, and higher quality food leads practitioners to re-think and re-design the traditional food processing systems and operations to cope with consumer needs (Zokaei and Simons, 2006; Khan *et al.*, 2013; Wu *et al.*, 2015). In lieu of standardized food products, a growing segment

The International Journal of Logistics Management
Vol. 28 No. 3, 2017
pp. 782-797

0957-4093
DOI 10.1108/IJLM-11-2015-0204

of consumers push for customized food items that provide nutrition and a better sensory experience and prevents illnesses and chronic pathologies (Regmi and Gehlhar, 2005).

In order to address this demand and create value-driven food supply chains, the food industry has to re-align its production systems and operations with advanced technologies and procedures enhancing both efficiency and flexibility (Bourlakis *et al.*, 2012). The variability of food items depends on many factors, including their nature (e.g. solid, liquid, paste), their processing (e.g. assembling, mixing, slicing, mincing, cooking, freezing), their properties (e.g. density, viscosity, texture, geometry), and their value (Matthews *et al.*, 2007). The complexity of food processing is further increased by the seasonality of both supply and customer demand (Taylor, 2006) and the ability to handle this variability with the increasing production mix.

To achieve higher flexibility in handling the increased production mix, the processing systems are progressively shifting from flow-line production systems to job-shop systems (Curt *et al.*, 2007). The design and management of food job-shops involves integrated and challenging issues dealing with long-term decisions (e.g. the plant layout, the processing equipment), mid- and short-term decisions (e.g. the definition of the production mix, the recipes and the related working cycle), and operational daily decisions. Operational decisions range from the scheduling of the processing tasks to comply with demand or technical priorities, labour and equipment availability, and safety limitations.

A food job-shop system processes multiple items (i.e. raw ingredients, toppings, dressings) according to their working cycles in a typical resource and capacity constrained environment. The generic working cycle results in multiple concurrent and non-concurrent tasks, performed in manual and/or automatic working stations. Given the increased complexity of such systems, the divergent goals of process cost optimization and of food quality and safety preserving require integration at both the operational and the strategic decision making perspective. These decisions may include determining the size and type of the processing equipment, planning the facility layout, scheduling the processing activities, allocating the labour capacity, establishing buffers, and implementing hazard analysis and critical control points protocols.

While such decisions are generally allocated to various departments (e.g. production planners, the quality department, plant engineering, sales), their insight interdependency critically affects the efficiency of the production process. Decision-support tools based on optimization or simulation techniques, as well as implementation of integrated management models, are therefore necessary to join divergent expertise, methodologies, and objectives underlining the food job-shop.

This paper explores the application of simulation modelling to understand the dynamic behaviour of a food job-shop processing system. The twofold aim of this paper is to design a simulation model for food job-shop processing and to build the understanding of the extant relationships between food flows and processing equipment through a real case study from the catering industry. The results highlight the role of the proposed methodology in supporting the assessment of bottlenecks, as well the re-design of the processing equipment and their layout given both the bounds of the process and the product features.

The application of simulation techniques to study the dynamics of food systems has a long tradition. Using computer-aided process engineering, Saravacos and Kostaropoulos (1996) and Gulati and Datta (2013) review the equations describing the physical, mechanical, thermal, drying, electrical phenomena, and related parameters to be implemented into simulation tools. Close to these contributions, Lemus-Mondaca *et al.* (2011) explore the role of simulation coupled with physical experiments and analytical solutions in enhancing the knowledge on heat transfer in food processing. Simulation is indeed very popular in aiding food engineering (Saguy *et al.*, 2013; Datta, 2016) since understanding the food physics phenomena in depth is not still possible solely via empirical methods.

Similarly, the motivation to apply simulation techniques for modelling food processing systems includes prototyping efficient processing equipment, studying the bottlenecks, and overall balancing the food flow with the processing tasks, the equipment, and the labour. Huda and Chung (2002) provide the background to this paper through a simulation model in a high-speed combined continuous and discrete food manufacturing system. These researchers focus on a single production line system for bagged coffee and couple continuous flow tasks with discrete tasks (e.g. packaging).

We build upon this experience, by designing a simulation tool enabling the analysis of food job-shop processing systems. A methodology based on discrete event simulation (DES) is developed to study the dynamics and behaviour of the processing system according to an event-driven approach. The events represent instantaneous changes in the state of the system. While the use of simulation techniques to study production line systems in job-shops are analysed in the non-food industry (Mahdavi *et al.*, 2010; Pérez-Rodríguez *et al.*, 2014; Pawlewski, 2014), the originality of this paper is in addressing highly complex food job-shop processing systems. The catering industry is the focused environment of the proposed methodology. This sector is growing in developed countries, where the increased awareness and expectations of consumers about nutrition drives the development of new challenges and opportunities for the out-of-home eating business (Zhang *et al.*, 2014). The job-shop processing system responds to catering needs by meeting a wide demand mix that varies daily, fulfilling diverse customers (e.g. canteens of companies and public offices, schools, banquets, hospitals, restaurants), and complying with food safety management system (ISO 22000, 2005) rules through an integrated production-delivery service (Gou *et al.*, 2013).

Other examples of simulation techniques linked to the food industry are provided to study supply chains flows and transport activities (Jansen *et al.*, 2001; Reiner and Trcka, 2004; Thron *et al.*, 2007).

Section 2 of this paper illustrates the methodology and the key patterns implemented via DES to model the food job-shop system. Instead of focusing on the illustration of the graphic user interfaces and the operating principles of the developed computerized tool, Section 3 showcases the adoption of the methodology to a job-shop processing system of a renowned Italian catering company. The results from the simulation analysis are illustrated in Section 4, which also discusses the main findings and the potential further applications of the modelling techniques. Section 5 summarizes the conclusions and provides priorities for further research.

2. Methodology

In order to explore the behaviour, assess the performance, and support continuous improvements of a food job-shop processing system, this paper proposes a methodology based on a simulation model able to address the extant complexity of such systems. Sargent (2005) provides the theoretical background of the methodology by illustrating a paradigm that aids verifying and validating the development process of the simulation model. He identifies the so-called problem entity, the conceptual model, and the computerized model.

According to Sargent's notation, we consider the problem entity (i.e. the insight goal of the proposed methodology) as supporting the re-design and management of a food job-shop system. The main job-shop entities and their operating principles constitute the conceptual model of the environment to be simulated. To study the dynamics of the conceptual environment, a computerized DES model is designed and implemented.

As stated in the literature for both food engineering and food distribution operations management, simulation techniques are valuable methods to understand the multiple criteria involved in the assessment (e.g. efficiency, quality, safety) and limitations of analytical and empirical solutions. The architecture of the input data set is built according to the problem entity. It relies on the main entities of the job-shop system whose behaviour and dynamics are to be simulated. These entities include the plant, the product, the processing equipment or resource, and the order. Regarding each system entity, Figure 1 summarizes the main setting variables or model variables, which are defined to configure the job-shop system.

The product entities are depicted by the production mix, the ingredients per recipe and the working cycle (e.g. the processing task, the task duration, and the cooking temperature). The resource entities include the characteristics and type of the resources, their capacity, the buffers, the dispatching rules (e.g. how to manage the queues), and the sorting rules (e.g. how to assign items to parallel resources). The demand entities include the number of meals demanded, the order priority and the due date. The entity plant includes the plant layout, the identification of the processing and storage areas and the set of working centres for each area. To populate the model and properly explore the entities' interdependencies, data collection is necessary because of the wide set of required setting variables. This is one of the main strengths and limitations of the proposed methodology.

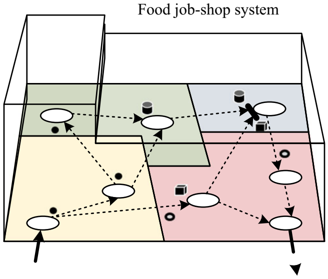
Figure 1 schematizes the job-shops streams and lists the main entities and setting variables involved in the DES model.

The system state is a result of a specific configuration of the setting variables. The variables illustrated in Figure 1 might also be considered as potential levers for both the strategic design and the daily operational management of the food job-shop.

The conceptual model is then built upon the model variables to facilitate the analysis. The model is designed to aid both the design of a new job-shop system and the assessment of an existing system. The former includes designing a job-shop system from a green field to address strategic long-term decisions regarding the layout and the establishment of processing equipment. In this case, the conceptual model of the job-shop system involves a provisional layout of processing equipment to be analysed and assessed via simulation. The related model uses a number of variables, such as those related to long-term levers, the plant layout, the resource type and capacity, the production mix, and the standard recipes.

Conversely, the latter scenario is built upon the shape of an existing job-shop system, and the long-term setting variables are not levers of the analysis. We assume that the plant layout and the processing equipment are fixed, so the focus is on the management of daily operations to observe their impact on the system performance. This scenario addresses the operational short-term decisions which may include how to schedule the processing tasks, which products are priority, and how to allocate labour and equipment to each task.

In both scenarios, the conceptual model standardizes the behaviours and the operating principles of the processing equipment (i.e. resources) into six classes as illustrated in Figure 2. This allows the model to address the complexity of real job-shop systems and cope



Plant
- Plant layout
- Processing/storage areas
- I/O and access point
- Inside climate (per area)
- Outside climate (per season)
- Working shifts

Product
- Offer mix (menu)
- Product characteristics
- Ingredients/BOM
- Recipe/working cycle
- Kinetic models

Resource
- Resource type/characteristics
- Resource capacity
- Min/max saturation
- Input/Output buffer capacity
- Assembling/disass. hierarchy
- Dispatching rules
- Sorting rules
- Nominal power (el./th.)
- Ergonomics and safety constraints

Demand
- Meals number
- Volume per meal
- Order priority
- Due date

Figure 1.
System entities and setting variables

simultaneously with different working centres which include related settings (e.g. set-up time, capacities), products, working cycles, and order lists. In this lies the main originality of the proposed methodology.

As a result, the processing flow of different products is simulated simultaneously to understand how products share the working centres, how they contribute to create queues and bottlenecks, and how they wait throughout the processing system. Queues in food systems generate delays, costs, and inefficiencies and also result in exposing products to environmental stresses and risky conservation conditions that may affect both safety and quality (Boxman *et al.*, 2011).

This developed conceptual model then analyses the queuing process and the associated costs and risks through input and output buffers before and after each working centre.

The input buffer holds the product flow before processing, while the output buffer contains the products until they are handed to the following task and associated working centre. Both buffers are characterized by a capacity level in terms of volume and number of portions, the dispatching rules undertaking the queuing process, and the conservation temperature experienced by products in queue.

The working tasks and the related working centres are standardized in classes devoted to preparation, assembling, and portioning activities and differs for the number of resources used (i.e. single or multiple/parallel). According to the single resource preparation phase pattern, the product is prepared or transformed by a single machine. The baking and the blast chilling tasks are examples of this operating pattern.

The single resource assembling phase assembles and mixes multiple products into a single product, such as the production of the *ragù Bolognese* sauce created by adding tomato sauce to smashed meat. The single resource portioning phase operates with a single machine that portions a product, such as *Lasagne Bolognese* portioning. These phases can be operated also by parallel working stations as illustrated in Figure 2. Alternative dispatching rules (i.e. FIFO, LIFO, FEFO, random) and sorting rules (e.g. less empty queue) are also implemented to manage the product flow within the queues and to allocate the products to the alternative parallel resource.

Inspired by the literature (Huda and Chung, 2002), the conceptual model also combines working centres that operate with continuous or discrete product flows for all of the

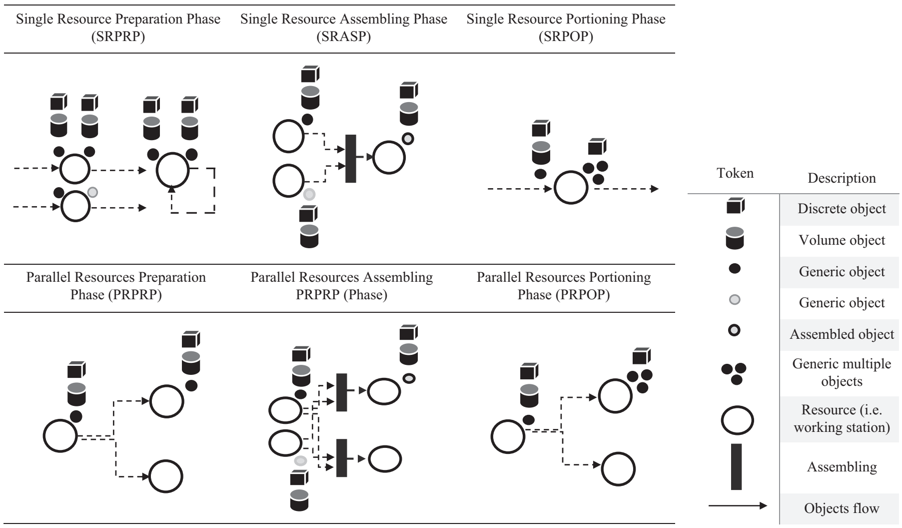


Figure 2.
Resources operating patterns

assembling, processing, and portioning activities. The dispatching and sorting rules are the primary levers to change the ways in which the daily production mix utilizes the processing equipment.

The management of the daily processing tasks (e.g. tasks scheduling) reflects the complexity of the working cycles (i.e. recipes), which rely on chefs who typically do not have competences in production management. Among every model variable, the product recipe (i.e. working cycle), such as the *Lasagne Bolognese* in Figure 3, portrays the complexity of the job-shop system and highlights how a few changes in the task sequencing, pre-empting, or allocation may significantly affect the performance of the processing system.

Finally, the computerized model has been developed to cope with the conceptual model and face the problem entity. An in-depth description of how the resource operating patterns are developed in the computerized model is not included since it would be beyond the scope of this paper.

The design of an accurate simulation model requires verification and validation (Sargent, 2005). Model verification assesses its correct implementation in accordance with the conceptual model and the expected output, while validation indicates how the model accurately represents a real system. An accurate model validation is extremely difficult in food job-shop systems. It would require comparing the responses from the model and the real system to the same setting of input variables for each control point. Given the broad number of control points in the job-shop, manual monitoring is not feasible, and integrated data monitoring systems involving every control point would be necessary. The lack of accurate data acquisition architecture in a processing system relies on the model validation via the assessment of macro input-output production data (e.g. daily processing throughput, number of items delivered).

Section 3 describes the application of the developed simulation model to a real food job-shop system of a renowned Italian catering company. The analysis is conducted through a computerized tool built upon the proposed model. This case study highlights the potential of the model in assessing the behaviour of an existing system by identifying process bottlenecks, inefficiencies, and ranking priorities for system improvements.

3. Application and case study

The proposed simulation model is applied in a real food job-shop processing system of a renowned Italian catering company. The purpose of the analysis is to explore the

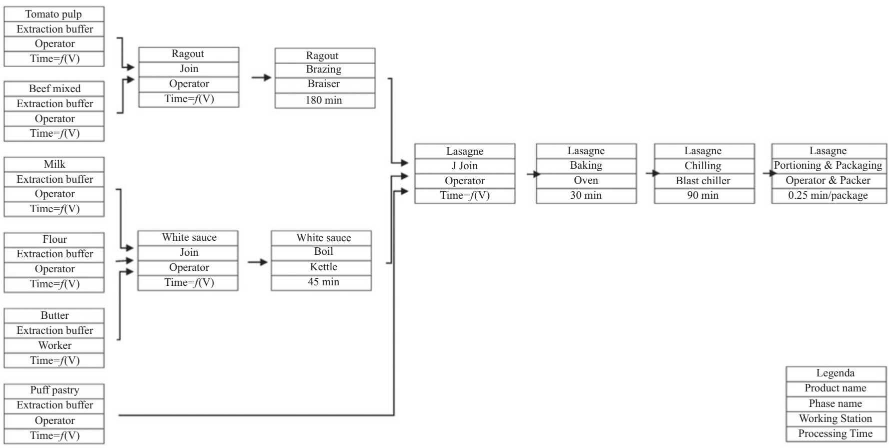


Figure 3.
Example of working cycle: *Lasagne Bolognese* recipe

application of simulation in studying the behaviour of an existing job-shop system (i.e. as-is system configuration), and quantifying a panel of key performance indicator (KPIs) to lead evidence-based system improvements. The characteristics of the job-shop system under analysis, including the layout, are summarized in Table I. The processing system is organized in nine departments which include the raw material and finished product warehouses, the manual working stations, the braziers, the ovens, the blast chillers, the mixers, and the packaging lines.

The job-shop has 61 working centres and 14 stations devoted to manual tasks (e.g. cleaning, unpacking, cutting) and operates over three shifts. To benchmark the production system, we consider a typical working day which represents the average demand of 75 recipes and 715 different tasks.

Figure 4 illustrates the distribution of the ordered kilos per product and the distribution of the time slot for the beginning of the processing tasks. Roughly half of the recipes processed during the characteristic day begin within the first hour, and approximately 40 per cent of the products are requested in less than 50 kilos per day. This poorly balanced production pattern is necessary to meet the requirements of the services for canteens, schools, and hospitals which demand a broad product mix delivered at lunch time. As a consequence, the processing system is expected to face frequent setups, lower equipment utilization, and related WIP flow queuing.

The distribution of the departments over the layout affects the travelling and handling activities between the working centres. The travelling path between every pair of control points is setting variables of the given plant entity and are referred to as the as-is configuration of the system state. This lever allows understanding of the impact of in-site logistics and handling tasks performed by operators, hand-pallet trucks, or via part-to-man conveyors.

The product working cycle is distributed by duration in Figure 5. This distribution refers to the minimum processing time required by an un-capacitated production system. Most of the recipes last between two and ten hours. Typically, the longer the cycle, the higher the number of man-uncontrolled tasks (e.g. defrosting, cleaning, soaking).

The distribution of the ordered kilos per recipe does not meet the distribution of the working cycle duration. This finding indicates the lack of scalability of the production process. As a result, small production batches may occupy the processing equipment for a longer duration, depending on their working cycle. The high number of tasks per recipe, including the number of assembling tasks (i.e. 158 out of 715 in the observed system), enhance the complexity of the processing operations. The illustrated setting variables showcase how such production systems differ from line-processing systems and how their management is challenging. This highlights the need for computer-aided tools to support both strategic and operational decisions with a quantitative approach.

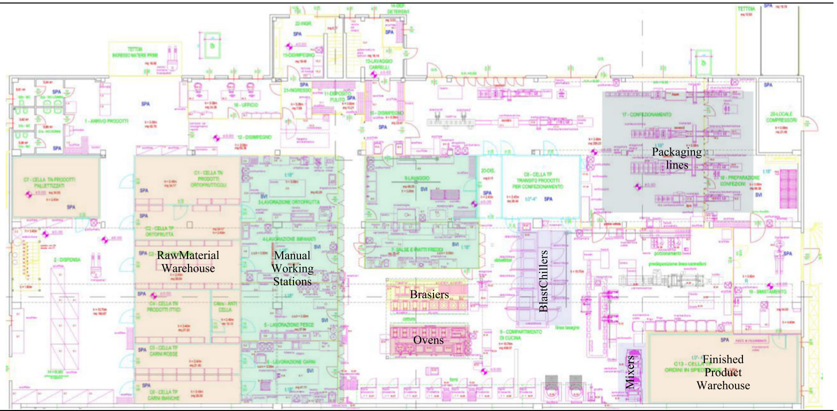
To analyse the presence of process bottlenecks, every working centre is configured with un-capacitated input and output buffers. Consequently, the streaming products are processed as soon as the machine is empty and are shipped to the next station as soon as the processing task is completed. Therefore, the input buffers represent the control points where we track wait time and delays. The analysis assumes the complete availability of the raw materials at the starting time t_0 which corresponds to the beginning of the working day. The simulation ends when the daily demand mix is completely fulfilled and all working cycles are complete.

Among the implemented dispatching rule (i.e. LIFO, FIFO, FEFO, priority driven), FIFO rule is used to cope with the buffers behaviour. The sorting rule, such as how to allocate the products to parallel machines, follows the "less utilized machine" rule.

Given the set of illustrated setting variables and the undertaken assumptions, the simulation model is applied to benchmark the as-is system configuration of the food job-shop system and to provide evident-based suggestions for the system improvement.

Table I.
Input job-shop characteristics and layout

Job-Shop Characteristics		
Working stations	61	
Manual working stations	14	
Labor	51	Operators
Warehousing areas	9	
Working shifts	3	
Recipes/Products	75	
Daily processed flow	29,077	kg
Weight of finished product	8,739	kg
Phases	715	
Assembling phases	158	
Portioning phases	75	
Overall working time	1,020	min/day
Minimum processing time	75	min/Recipe
Minimum processing time	867	min/Recipe
Maximum number of recipes per station	30	Recipes



4. Results and discussion

The application of the simulation model to the case study results in assessing the performance of the as-is system configuration. Via simulation, the daily menu is completely fulfilled within 961 minutes in accordance with the tracked working time in the real job-shop system. As explained in Section 2, the model validation on the overall throughput is not feasible for this sort of processing system.

The performance of the job-shop is tracked and stored for the analysis by the developed computerized tool for both working centre and input buffer utilization. The analysis of the time-dependent utilization of the generic working centre and related buffer is necessary to identify the process bottlenecks. We assume $v_i^b(t)$ and $v_i^w(t)$, respectively, as the product volume in queue at time t within the buffer b of the working station i, and the volume in processing by the working station i at time t. The volume in queue and in processing at time t per working station i are defined, respectively, by the following equation:

$$V_i^b(t) = \int_0^t v_i^b(\tau)d\tau \tag{1}$$

$$V_i^w(t) = \int_0^t v_i^w(\tau)d\tau \tag{2}$$

The graphs in the left column of Figure 6 report the trends of $v_i^b(t)$ (i.e. grey line) and $v_i^w(t)$ (i.e. dark line) for the generic oven i, while the graph in the right column represents the trend of the cumulate $V_i^b(t)$ and $V_i^w(t)$. We assume $t^b_{\text{last } i}$ as the instant until the buffer of the working station i is definitely emptied, as shown in Figure 7, and vtp_i^w as the total processed

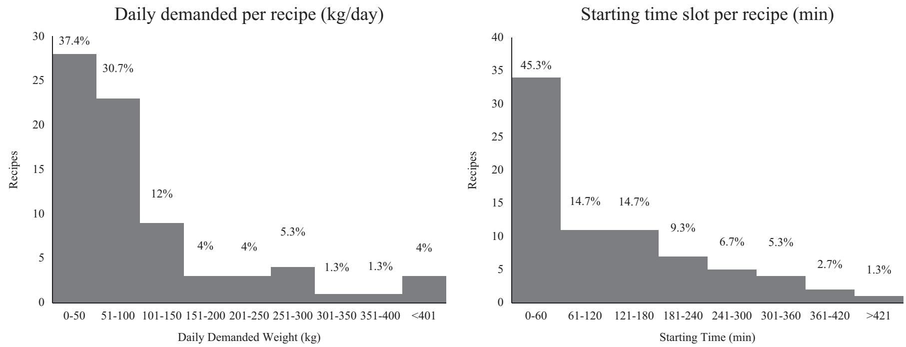


Figure 4.
Production mix (i.e. recipes) distribution: demand and time slot

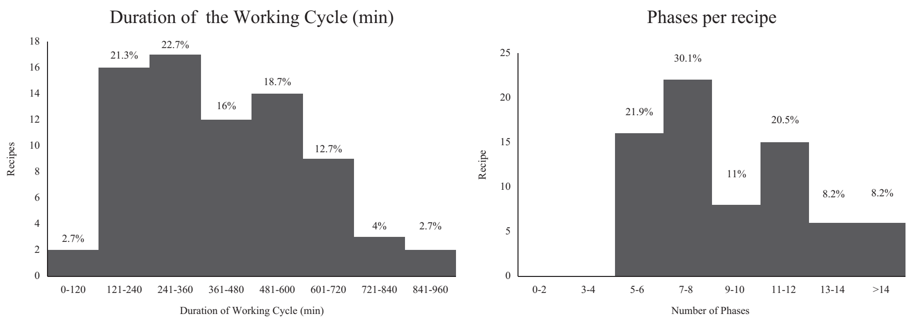


Figure 5.
Production mix (i.e. recipes) distribution: duration and tasks

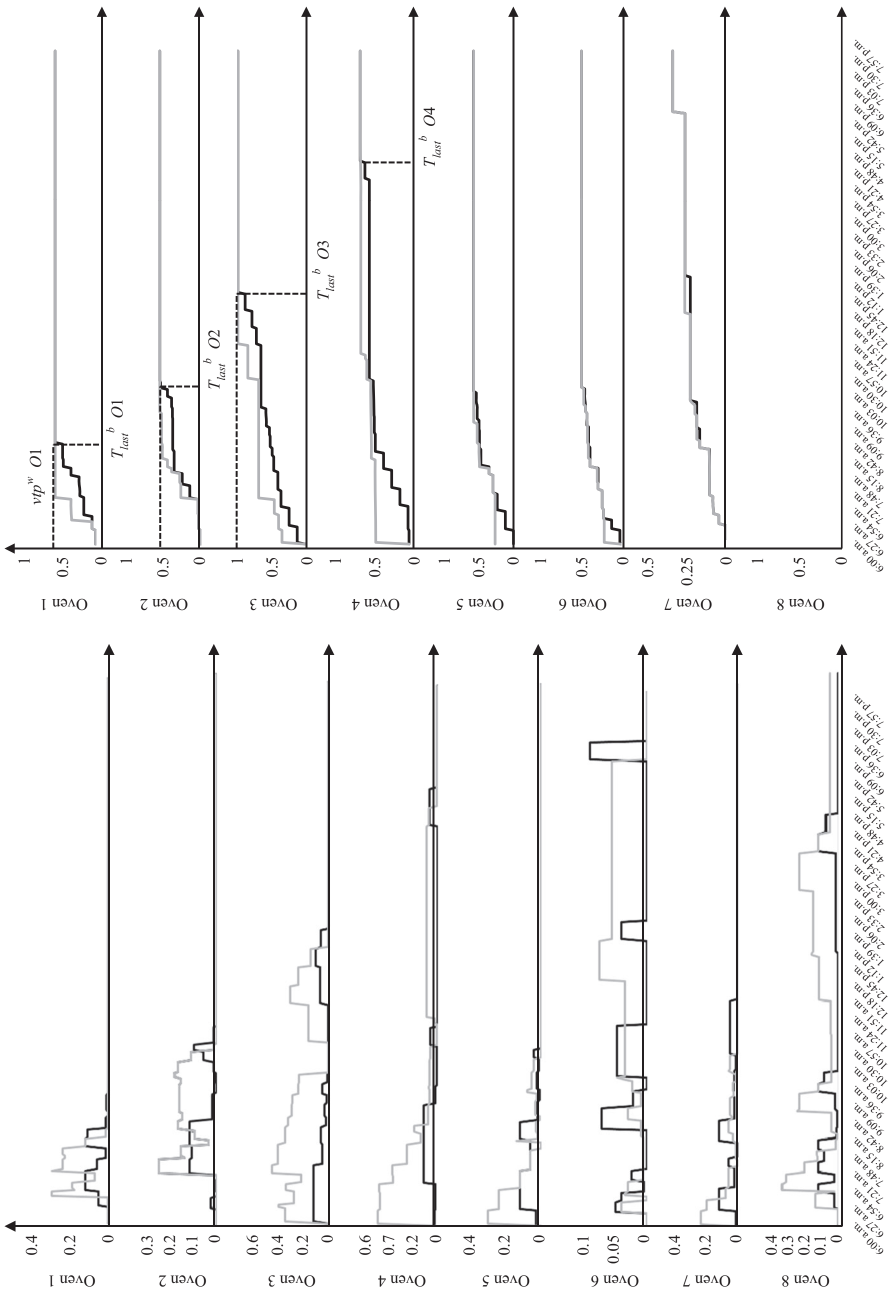


Figure 6.
Time-dependent utilization of ovens and buffers

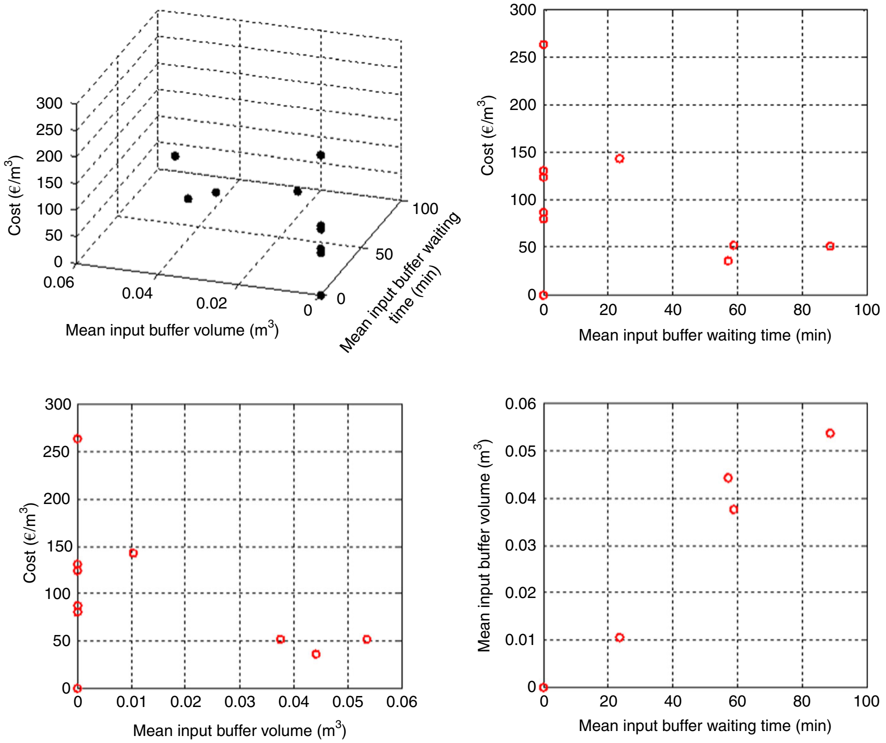


Figure 7.
A 3D key performance analysis of the braisers department

volume by the working station i at period $t^b_{last\ i}$. The vertical distance between $V^b_i(t)$ and $V^w_i(t)$ in each instant t identifies the products volume within the input buffer, while the horizontal distance represents the time spent by a generic unit of volume (e.g. 1 cubic metre) inside the input buffer.

Another assumption is the constraint for the working station to process one mission/flow at a time. Such a constraint compels that the working centre might begin processing a task even if its capacity is not completely utilized.

The main performance indicators for buffer and working centre utilization are defined by Equations (3) and (4), as the mean volume in the buffer queue i (i.e. Mean V^b_i), and the mean time spent in the buffer i (i.e. Mean T^b_i).

The definition of these metrics enables the study of a generic working station or a generic shop. The collected panel of key performance metrics are summarized in Tables II and III. These samples describe the dynamic behaviour of the oven and the braiser departments, which are used with the majority of the recipes:

$$\text{Mean } T^b_i = \frac{1}{vtp^w_i}\left(V^b_i\left(t^b_{last\ i}\right) - V^w_i\left(t^b_{last\ i}\right)\right) \tag{3}$$

$$\text{Mean } V^b_i = \frac{1}{t^b_{last\ i}}\left(V^b_i\left(t^b_{last\ i}\right) - V^w_i\left(t^b_{last\ i}\right)\right) \tag{4}$$

The metrics quantified by Equations (3) and (4) are important in the food processing process to manage the on-site operations and to address food safety issues (Boxman *et al.*, 2011).

	Input buffer					Working centre				
	Mean volume (m^3)	Mean time (min/m^3)	Recipe entry time	Recipe exit time	Total time in buffer (min)	Pick power (kW)	Total processed volume (m^3)	Max volume (m^3)	Energy (kWh/dd)	Cost (€/m^3)
Oven 1	0.204	51.82	6:18 a.m.	8:57 a.m.	159	20	0.591	0.12	53	30.4
Oven 2	0.098	42.84	6:18 a.m.	10:45 a.m.	267	20	0.597	0.12	89	50.5
Oven 3	0.178	78.75	6:03 a.m.	1:35 p.m.	438	20	0.993	0.12	146	49.8
Oven 4	0.153	140.27	6:00 a.m.	5:09 p.m.	669	20	0.737	0.12	223	102.5
Oven 5	0.068	29.58	6:00 a.m.	10:27 p.m.	267	20	0.618	0.12	89	48.8
Oven 6	0.035	16.36	6:03 a.m.	10:33 a.m.	270	20	0.574	0.12	90	53.1
Oven 7	0.005	9.75	6:18 a.m.	6:39 p.m.	741	20	0.389	0.12	247	215.3
Oven 8	0.107	66.91	6:18 a.m.	4:12 p.m.	594	20	0.932	0.12	198	72.0

Table II.
Summary of the oven centres performances

	Input buffer					Working centre				
	Mean volume (m^3)	Mean time (min/m^3)	Recipe entry time	Recipe exit time	Total time in buffer (min)	Pick power (kW)	Total processed volume (m^3)	Volume capacity (m^3)	Energy (kWh/dd)	Cost (€/m^3)
Braiser 1	0.044	57.24	6:00 a.m.	8:20 a.m.	140	14	0.324	0.065	34.5	36.1
Braiser 2	0.037	58.84	6:18 a.m.	8:03 a.m.	105	14	0.201	0.065	30.8	51.8
Braiser 3	0.053	88.59	6:00 a.m.	8:19 a.m.	139	14	0.270	0.065	41	51.4
Braiser 4	0	0	–	–	–	14	0.103	0.065	37.5	123.6
Braiser 5	0	0	–	–	–	14	0	0.065	0	0
Braiser 6	0	0	–	–	–	14	0.649	0.065	16.5	86.4
Braiser 7	0	0	–	–	–	14	0.546	0.065	42.4	263.6
Braiser 8	0	0	–	–	–	14	0.109	0.065	25.6	79.8
Braiser 9	0	0	–	–	–	14	0.1058	0.065	40.8	130.8
Braiser 10	0.010	23.58	6:56 a.m.	7:57 a.m.	61	14	0.081	0.065	34	142.7

Table III.
Summary of the braiser centres performances

The buffer wait time erodes the product shelf-life at a rate dependent on the conservation temperature (Sahin *et al.*, 2007; Gwanpua *et al.*, 2015). To limit the risk of pathogen growth, a strategy to reduce the site temperature is usually pursued which results in an increased cost of air conditioning. The optimal trade-off between safety and costs is therefore hard to identify. Table II also reports the energy costs allocated to a unit of product flow (i.e. 1 cubic metre) processed by a given working centre. This cost depends on the equipment pick power and is also influenced by the utilization of the working centre. Because of the long duration of the equipment's run-up and set-up tasks, the working centres remain operative until the daily processing is over. This results in poorly utilized working centres that enhance the indirect energy cost allocated to the processed products, as reported in the last column of Tables II and III.

By analysing these metrics, a multi-disciplinary team of production managers, facility engineers, food technologists, chefs, and processing operators might investigate the utilization of processing equipment, as well as the product queuing through the system, to understand how costs are allocated in a flow-driven approach. They can also identify the trade-off between the investments in equipment and the operative costs. The proposed simulation model helps with these decisions by using a multi-scenario what-if analysis with alternative system configurations (states). These system configurations differ in the adopted dispatching and sorting rules, in the characteristics of the processing equipment and in the number of working centres in the department layout, and in the recipes pre-emption.

The three-dimensions plots of Figures 7 and 8 show the behaviour of each working station according to the aforementioned KPIs. Figure 7 is focused on the braiser department and highlights how six out of ten working centres do not utilize the input buffer (i.e. mean volume and mean time in buffer equal to 0), which results in low capacity saturation and high energy costs allocated to the processed products. Evidently, the braiser department results show overuse of the number of working centres. This result is one of the primary findings of the analysis.

In Figure 8, the dispersion of the points (i.e. each representing a working centre) highlights that the ovens department is not well balanced, and the working centres experience high variability in the mean time and mean volume in buffer. This outcome can be addressed by re-scheduling the daily processing tasks and working cycles. It can be further investigated by assessing the response of the system to varying time-slot allocations, dispatching and sorting rules, and what-if simulations.

The proposed simulation model aids the re-design and management of a food job-shop to achieve multi-dimensional goals. These goals include the minimization of process queues, the reduction of in-site handling/logistics costs, the improvement of the working centres' utilization, the minimization of the energy costs, and compliance with food safety and quality standards.

The design and management of food processing systems is typically driven by the prediction and control of product quality and safety, the minimization of costs, or the enhancement of energy efficiency (Jacxsens *et al.*, 2011; Valero *et al.*, 2012; Newborough and Probert, 1988). Built upon these experiences, this proposed methodology uses simulation to potentially integrate multiple dimensions of analysis. The set of output metrics and KPIs can be used to assess the behaviour of the food job-shop. The set of KPIs should also belong

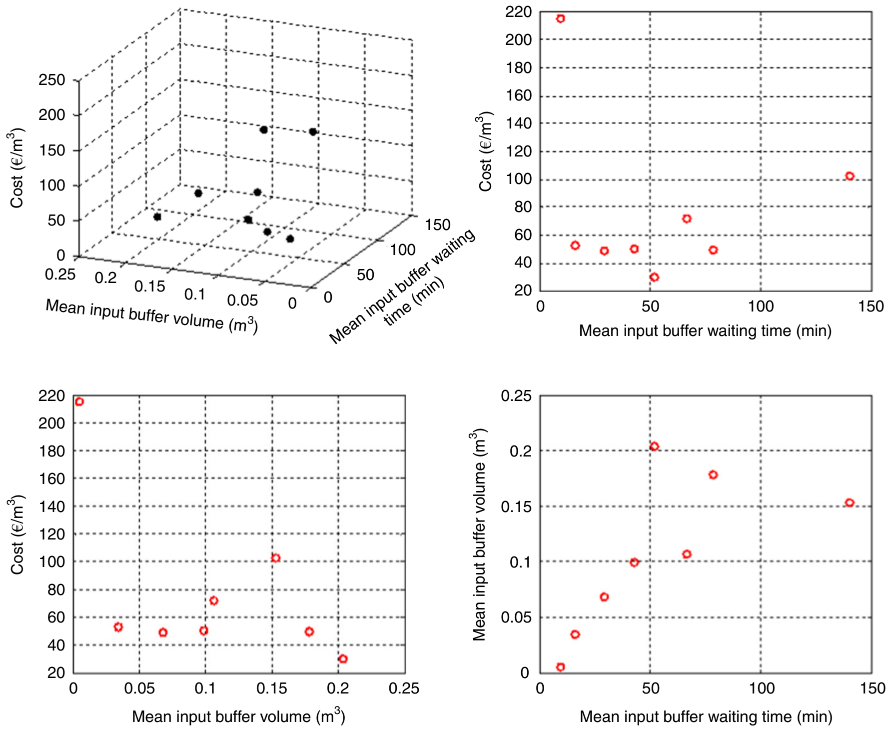


Figure 8.
A 3D key performance analysis of the oven department

to multiple areas of interest, such as the conservation temperature experienced by products throughout processing (Sahin *et al.*, 2007), the energy consumption accounted for by each processing and packaging task (Batty *et al.*, 1988; Accorsi *et al.*, 2015), the distance travelled by operators, and the food and packaging WIPs within the facility. As result, the proposed methodology could also be applied to flow-driven cost accounting, as well for understanding inefficiencies with the tasks, equipment, operators, recipes, and layouts.

5. Conclusion

This paper proposes a simulation model to facilitate the re-design and management of food job-shop processing systems. In such highly complex systems, lean and balanced production is necessary to maximize the system throughput, increase the equipment utilization, and minimize queues and process bottlenecks. These parameters affect both the system efficiency and product safety. A balanced and cost-effective production system is a result of integrated decisions between different company functions and departments (e.g. food technologists, processing operators, system engineers, quality staff, civil engineers, chefs) which commonly operate independently.

To address this issue, we illustrate a multi-disciplinary methodology built upon a simulation model to assess the as-is job-shop configuration, define the benchmarks, and identify evidence-based improvements toward a cost-effective and better-balanced production system. The model can be applied both to green-field systems and to existing systems. It aids simulating short-term (e.g. task scheduling, dispatching, and sorting rules), mid-term (e.g. recipes), and strategic long-term (e.g. layout and working centres) levers. The main purpose of the proposed model relies on the definition of standard resources and operating patterns that can meet the behaviour of a wide set of food processing equipment and tasks, thereby addressing the complexity of a food job-shop.

The illustrated case study applies simulation to explore the as-is configuration of a real job-shop from the catering industry. The showcased analyses is focused on the trade-off between the process bottlenecks and the energy costs allocated to the working centres, highlighting a redundant number of brasier centres in the department. The insight from the analyses demonstrates the impact of integrated, multi-dimensional, and evidence-based decisions in addressing the cost effectiveness and safety standards in food processing systems.

Future developments are expected to extend the boundaries of simulation outside the plant (Accorsi *et al.*, 2014; Valli *et al.*, 2013; Manzini *et al.*, 2014) by including the catering delivery services. This will study the impact of integrated production-distribution decisions on the cost, quality, safety and environmental sustainability of food products at the place of consumption. Further studies will also investigate how outside and inside climate conditions (e.g. temperature, humidity) couple with the presence of processing bottlenecks to increase the risk of pathogen growth.

References

Accorsi, R., Manzini, R. and Ferrari, E. (2014), "A comparison of shipping containers from technical, economic and environmental perspectives", *Transportation Research Part D: Transport and Environment*, Vol. 26, pp. 52-59.

Accorsi, R., Manzini, R. and Versari, L. (2015), "Glass vs. plastic: life cycle assessment of extra-virgin olive oil bottles across global supply chains", *Sustainability*, Vol. 7 No. 3, pp. 2818-2840.

Batty, W.J., Conway, M.A., Newborough, M. and Probert, S.D. (1988), "Effects of operative behaviours and management planning on energy consumptions in kitchens", *Applied Energy*, Vol. 31 No. 3, pp. 205-220.

Bourlakis, M., Maglaras, G. and Fotopoulos, C. (2012), "Creating a 'best value supply chain?' Empirical evidence from the Greek food chain", *The International Journal of Logistics Management*, Vol. 23 No. 3, pp. 360-382.

Boxman, I.L.A., Verhoef, L., Dijkman, R., Hägele, G., te Loeke, N.A.J.M. and Koopmans, M. (2011), "Year-round prevalence of norovirus in the environment of catering companies without a recently reported outbreak of gastroenteritis", *Applied and Environmental Microbiology*, Vol. 77 No. 9, pp. 2968-2974.

Curt, C., Hossenlopp, J. and Trystram, G. (2007), "Control of food batch processes based on human knowledge", *Journal of Food Engineering*, Vol. 79 No. 4, pp. 1221-1232.

Datta, A.K. (2016), "Toward computer-aided food engineering: mechanistic frameworks for evolution of product, quality and safety during processing", *Journal of Food Engineering*, Vol. 176, pp. 9-27.

Food Drink Europe Data and Trends (2014), "European food and drink industry 2013-2014", May, available at: www.fooddrinkeurope.eu/uploads/publications_documents/Data__Trends_of_the_European_Food_and_Drink_Industry_2013-2014.pdf (accessed May 2015).

Gou, J., Guguan Shen, G. and Chai, R. (2013), "Model of service-oriented catering supply chain performance evaluation", *Journal of Industrial Engineering and Management*, Vol. 6 No. 1, pp. 215-226.

Gulati, T. and Datta, A.K. (2013), "Enabling computer-aided food process engineering: property estimation equations for transport phenomena-based models", *Journal of Food Engineering*, Vol. 113, pp. 483-504.

Gwanpua, S.G., Verboven, P., Leducq, D., Brown, T., Verlinden, B.E., Bekele, E., Aregawi, W., Evans, J., Foster, A., Duret, H.M., Hoang, S., van der Sluis, E., Wissink, L.J.A.M., Hendriksen, P., Taoukis, P., Gogou, E., Stahl, V., El Jabri, M., Le Page, J.F., Claussen, I., Indergård, E., Nicolai, B.M., Alvarez, G. and Geeraerd, A.H. (2015), "The FRISBEE tool, a software for optimising the trade-off between food quality, energy use, and global warming impact of cold chains", *Journal of Food Engineering*, Vol. 148, pp. 2-12.

Hollingsworth, P. (2003), "The 'self-care shopper' emerges", *Food Technology*, Vol. 57 No. 7, pp. 20-27.

Huda, A.M. and Chung, C.A. (2002), "Simulation modelling and analysis issue for high-speed combined continuous and discrete food industry manufacturing processes", *Computers & Industrial Engineering*, Vol. 43, pp. 473-483.

ISO 22000 (2005), "Food safety management systems – requirements for any organization in the food chain", International Organization for Standardization, ISO/TC 34/SC 17 Management systems for food safety.

Jacxsens, L., Luning, P.A., Marcelis, W.J., van Boekel, T., Rovira, J., Oses, S., Kousta, M., Drosinos, E., Jasson, V. and Uyttendaele, M. (2011), "Tools for the performance assessment and improvement of food safety management systems", *Trends in Food Science and Technology*, Vol. 22 No. 1, pp. S80-S89.

Jansen, D.R., van Weert, A., Beulens, A.J.M. and Huirne, R.B.M. (2001), "Simulation model of multi-compartment distribution in the catering supply chain", *European Journal of Operations Research*, Vol. 133 No. 1, pp. 210-224.

Khan, R.S., Grigora, J., Winger, R. and Win, A. (2013), "Functional food product development: opportunities and challenges for food manufacturers", *Trends in Food Science and Technology*, Vol. 30 No. 1, pp. 27-37.

Lemus-Mondaca, R.A., Vega-Galvez, A. and Moraga, N.O. (2011), "Computational simulation and development applied to food thermal processing", *Food Engineering Review*, Vol. 3 Nos 3-4, pp. 121-135.

Mahdavi, I., Shirazi, B. and Solimanpur, M. (2010), "Development of a simulation based decision support system for controlling stochastic flexible job shop manufacturing systems", *Simulation Modelling Practice and Theory*, Vol. 18 No. 6, pp. 768-786.

Manzini, R., Accorsi, R., Ayyad, Z., Bendini, A., Bortolini, M., Gamberi, M. and Valli, E. (2014), "Sustainability and quality in the food supply chain. A case study of shipment of edible oils", *British Food Journal*, Vol. 116 No. 12, pp. 2069-2090.

Matthews, J., Singh, B., Mullineux, G., Ding, L. and Medland, A.J. (2007), "An approach to develop design rules for food processing equipment", *Proceedings of the International Conference on Engineering Design (ICED), No. 247*, pp. 1-11.

Newborough, M. and Probert, S.D. (1988), "Evolution of energy-efficient food-preparation facilities", *Applied Energy*, Vol. 29 No. 2, pp. 83-178.

Pawlewski, P. (2014), "Multimodal approach to modeling of manufacturing processes", *Proceedings of the 47th CIRP Conference on Manufacturing Systems, Procedia CIRP, Vol. 17*, pp. 716-720.

Pérez-Rodríguez, R., Jöns, S., Hernández-Aguirre, A. and Alberto-Ochoa, C. (2014), "Simulation optimization for a flexible job-shop scheduling problem using an estimation of distribution algorithm", *International Journal of Advanced Manufacturing and Technology*, Vol. 73 Nos 1-4, pp. 3-21.

Regmi, A. and Gehlhar, M.J. (2005), "New directions in global food market", paper provided by United States Department of Agriculture, Economic Research Service in its series Agricultural Information Bulletins with number 33751, Washington, DC.

Reiner, G. and Trcka, M. (2004), "Customized supply chain design: problems and alternatives for a production company in the food industry. A simulation based analysis", *International Journal of Production Economics*, Vol. 89 No. 2, pp. 217-229.

Saguy, S., Singh, R.P., Johnson, T., Fryer, P.J. and Sastry, S.K. (2013), "Challenges facing food engineering", *Journal of Food Engineering*, Vol. 119, pp. 332-342.

Sahin, E., Zied Babai, M., Dallery, Y. and Vaillant, R. (2007), "Ensuring supply chain safety through time temperature integrators", *International Journal of Logistics Management*, Vol. 18 No. 1, pp. 102-124.

Saravacos, G.D. and Kostaropoulos, A.E. (1996), "Engineering properties in food processing simulation", *Computers & Chemical Engineering*, Vol. 20 No. S1, pp. S461-S466.

Sargent, R.G. (2005), "Verification and validation of simulation models", *Journal of Simulation*, Vol. 7 No. 1, pp. 12-24.

Taylor, D.H. (2006), "Demand management in agri-food supply chains: an analysis of the characteristics and problems and a framework for improvement", *The International Journal of Logistics Management*, Vol. 17 No. 2, pp. 163-186.

Thron, T., Nagy, G. and Wassan, N. (2007), "Evaluating alternative supply chain structures for perishable products", *The International Journal of Logistics Management*, Vol. 18 No. 3, pp. 364-384.

Valero, A., Carrasco, E. and García-Gimeno, R.M. (2012), "Principles and methodologies for the determination of shelf-life in foods", in Eissa, A.A. (Ed.), *Trends in Vital Food and Control Engineering*, ISBN: 978-953-51-0449-0, InTech, available at: www.intechopen.com/books/trends-in-vital-food-and-control-engineering/principles-and-methodologies-for-the-determination-of-shelf-life-in-food

Valli, E., Manzini, R., Accorsi, R., Bortolini, M., Gamberi, M., Bendini, A., Lercker, G. and Toschi, T.G. (2013), "Quality at destination: simulating shipment of three bottled edible oils from Italy to Taiwan", *Rivista Italiana Delle Sostanze Grasse*, Vol. 90 No. 3, pp. 163-170.

Wu, T.-J., Zhao, R.-H. and Tzeng, S.-H. (2015), "An empirical research of consumer adoption behavior on catering transformation to mobile O2O", *Journal of Interdisciplinary Mathematics*, Vol. 18 No. 6, pp. 769-788, doi: 10.1080/09720502.2015.1108088.

Zhang, H.-Q., Wu, W.-W. and Wang, X.-F. (2014), "Influencing factors of the development of China's catering industry", *International Conference on Management Science and Engineering – Annual Conference Proceedings*, pp. 767-773.

Zokaei, A.K. and Simons, D.W. (2006), "Value chain analysis in consumer focus improvement: a case study of the UK red meat industry", *The International Journal of Logistics Management*, Vol. 17 No. 2, pp. 141-162.

Corresponding author
Riccardo Accorsi can be contacted at: riccardo.accorsi2@unibo.it