A simulative approach to optimize a cooking center

DANIELA RITA MONTELLA, GIUSEPPE NAVIGLIO, LIBERATINA CARMELA SANTILLO
Department of Materials Engineering and Operations Management
University of Naples “Federico II”
P.le Tecchio – 80125 Napoli
ITALY
danielamontella@hotmail.it giuseppe.naviglio@unina.it santillo@unina.it http://www.impianti.unina.it

Abstract: - The obtainment of standards such as effectiveness, efficiency and quality is pursued in an increasingly growing in any area, including the catering and therefore the field of school meals. This observation led to analyze the operation of a cooking center that provides meals to a lot of schools. For the plant analyzed was created a model using Arena 8.0, was then proceeded to validation, optimization and verification of results, whereas a significant increase in demand and varying appropriately the characteristic parameters of the system, such as number of employees and the number of machines. The model used represents a valid decision support for a company aiming to achieve a full customer satisfaction.

Key-Words: - Food manufacturing, Simulation, Optimization, Arena, Discrete event simulation.

1 Introduction

In recent years the tightening of the market and of the competition between companies has created a substrate on which a growing research of efficiency, effectiveness and quality both in products and services had development. No exception to the catering sector and especially to the field of school meals, that has evolved considerably on the wake of economic, cultural and social changes.

At the same time to the canteen, the meal time of schools has to be reorganized:

- medical advances diagnosed food allergies, intolerances, personalized diets that were unimaginable at the time, with the consequent increase in the variety of daily meals which were required to satisfy the increasingly specific desires of students;
- the increasing schooling rate and then the increasing number of students shows structural weaknesses of the refectories.

Then the meal activity becomes very hard and it requires skills not always present in schools, with a consequent and natural evolution towards outsourcing and with the birth of the first companies dedicated to catering.

The current view sees a clear approach in the field of catering more to industry itself:

- Machinery automation makes the preparing meals processes not dissimilar to a drilling or turning process, for example;
- Technology development and procedures standardization has succeeded, to some extent, to extrapolate knowledge; the skill required of an operator is no longer purely culinary, but it is required ability to use machines and knowledge in information technology sector.

This study arises from following this evolutionary social, scientific and technology context.

The aim of this work is to define a decision support system through optimization and simulation, on a testing capacity for a cooking center forecasting an increase in the number of schools to be satisfied and therefore an increase in demand.

2 Literature review

Many scientific studies are conducted on the food industry and many attempts have been made to represent these manufacturing realities with simulation.

In particular, regarding food manufacturing systems, simulation techniques and analysis have been studied to synchronize discrete and continuous processes and customize the supply chain; studies were conducted on the state of art of the production simulation; scheduling techniques, trends, Constraint-based approaches were analyzed to investigate the process flexibility; Process Control Strategy were implemented; 3-dimensional scanners for food process modeling have been used.

A review of these papers has been conducted; it is shown in table 1, where for each paper the key characteristics were indicated.
### Problem Formulation

The cooking center observed provides meals for a lot of schools. In this firm works 29 employees with different tasks, divided into three categories:

- Staff employees;
- Kitchen employees;
- Packer employees.

The main reason of this study is to the doubling number of the served schools and the increase in demand over the previous one, so it is necessary to verify the ability to ensure an acceptable service level (99%) by the company.

#### 3.1 Production process description

The kind of clients given, working 5 days per week on a shift, that starts at 06:00 and ends around 14:00. The production process is divided into the following phases:

- Forecasting meals number;
- Preparing side dishes;
- Transferring batch in the packaging center;
- Preparing second dish;
- Defining the final number of meals;
- Preparing first dish;
- Transferring batch in the packaging center;
- Sharing food in the packaging center;
- Delivery food to customers.

Instead, the demand forecasting is done by the management office.

The parameters used to decide the number of meals to be produced are:

- Number of schools that require the service of meals for the next day;
- Average number of students, teachers and administrative staff present;
- Day of the week;
- Any holiday present immediately before or after the date of examination;
- Period of the year;
- Historical data, stratified according to needs of staff;
- Festivity occurring before or after the day that may change the behavior of the application.

The period analyzed extends along five months. The meals are classified in SMALL (meal referred to nursery, primary, test meals, and extra meals) and BIG (meal referred to teachers, administrative staff and students of secondary schools). The setting of the meals number has to complete within 10:30 am: until that time the schools reported the number of students, teachers and administrative staff present, and then the total of meals is sent to the cooking center and to the packaging center for a possible calibration of the number if it differs significantly from the forecast. This work considers the real number of the meals.

#### 3.2 The demand

Observing the trend of the actual demand, there has been a cyclic behavior.
A stratification of data has been required by day of week trying to find a correlation, if it exists, which may help to minimize the forecast error. By stratifying the data by day of week it has been found some days when the variability is reduced and some days with high variability of students present.

### 3.3 Meals production

The preparation of meals is the most delicate phase. It is bound by the delivery and holding of specific quality standards. The meal packaging can be divided into two macrophases:

- Preparing meals;
- Preparation meal fittings.

These two macrophases are made into two rooms: the first in the cooking center, the second into the packaging center. The process is showed in Figure 2.

**Fig.2 – The production process flow**

### 4 Problem Solution

This process has been studied and analyzed through simulation. The software used is Arena 8.0; it is a software that, although oriented to the development of problems in manufacturing, is very flexible in adapting to any type of system. Moreover, the optimizer OptQuest has been integrated with Arena, which is able to perform the optimization of systems modeled with Arena by metaheuristic algorithms through variables, constraints and objectives provided by the user.

**4.1 The methodology steps**

The methodology phases of this work are the following:

- Seeing the process;
- Breakdowning the process in its early stages;
- Creating logical diagrams of the process;
- Selecting the product mix;
- Data collection (operations time, inputs, demand);
- Building the model;
- Model validation through simulation of the "Current State" on historical data;
- Determination of decision variables and objective function;
- Optimization of the model validated on forecasting demand;
- Testing the simulation results with the configuration obtained by the optimization.

**4.5 Building the Arena model**

Each optimization of the process requires a set of experiments: checking and testing the decision variables choice. In this case, due to the complexity of the process, the lack of the data in the database and the impossibility to conduct field tests, the modeling was necessary to perform the experiments required.

**4.5.1 Data Collection**

For the data collection necessary for modeling, the interviews were conducted to the employees and the operations times were recorded using a proximate timing, while the quality rules were considered for the cooking time of food.

**4.5.2 The Arena model**

These data were used to create the simulation and optimization model, which was then transferred to Arena. Specifically the most critical process was modeled, that is: the production of the side dish, of the second dish and the cooking of the first dish.

**Fig.3 – The Arena model**
4.6 Model Validation

After building the model, it must be validated. In practice the model behavior was tested on historical data and the output was compared with those obtained by simulation. The input of the model is the demand, which from historical series is distributed as a normal with mean of 3800 and standard deviation of 250 meals.

Five hundred simulations run and Makespan was recorded. To ensure timely delivery of the product, the firm defines as "Due Date" a maximum makespan of 5.5 hours, to assure the packaging within the 11:30 am and then the delivery of the meals within the 12:30 am (that is the time fixed by the contract).

To validate the model it is used the real input of the firm, so it can verify the shift between the output of the simulation and the actual output. So a frequency histogram of the makespan was created as shown in Fig. 4.

The number of intervals has been obtained by the following formula:

\[ N_i = 1 + 3.3 \times \log_{10} N_d \]  

(1)

Where:

- \( N_i \) is the number of intervals;
- \( N_d \) is the number of available data.

![Fig.4 - Frequency Histogram of the makespan](image)

This histogram shows that the distribution of the makespan is all within the range [0; 5.5], and it shows that the company can assure a unit service level with the actual number of the resources.

So for this value of demand the resources are oversized, because it is calibrated on a greater demand value. For this reason the result obtained is guaranteed by a sufficient production capacity of the plant.

4.7 Future scenario

The aim of this study arises because in the future the number of schools to satisfy will grow with an increase of the demand over the previous one, so it’s necessary to verify the ability to ensure a good service level (99%) of the company.

According to the forecast demand for the two production batches, a set of simulations run to study the behavior of the system in terms of makespan, with the same increase of human resource levels previously used by the company. After setting the decision variables, simulations were performed with these values:

- No. kitchen employees: 2 to 3;
- No. packer employees: 2 to 4;
- No. Thermo sealing: 1 to 2 (the second thermo sealing is already present in the company but underused).

The demand value is a normal random variable of average 8000 and standard deviation of 300.

The results have been reported in a histogram built as previous (Fig. 5).

![Fig.5 - Frequency histogram of the makespan](image)

In this graph it notes as the makespan, whit an increase of resources, is beyond the period of 5.5 h with a decreasing of the service level about 40%.

For this reason an optimization of the resources number is necessary; this procedure was done with OptQuest Arena.

4.8 The optimization

The first step to optimize the model is the definition of the objective function, that is the analytical translation of the aim of the firm. The function to minimize should consider the service level, the number of resources and the makespan:

\[
\min \left\{ \mathbb{E}[T_{i,k,2,3}] - \mathbb{E}[T_{i,k,2,3}] \right\}
\]

(2)

It is subject to the following constraints:

\[ x_1, x_2, x_3 \in \mathbb{N} \]  

(The number of resources must be integer)
\( x_1 \leq 6 \); (There can be no more than six people at once for
the packaging phase)

\( x_3 \leq 3 \); (A fourth thermo sealing would require a layout
redesign)

\( Pr\{T_{fp} \geq \text{Due Date}\} \leq 0.01 \); (The company must
assure a good service level)

\( 4 \leq T_{fp} \leq 5.5 \); (More than a half an hour of delay is not
allowed and it wants to keep a low waiting time in the meal
bowl)

Where:

\( x_i \) is the resources number (\( x_1 \) and \( x_2 \) respectively represent
the employees and \( x_3 \) represents machinery); 

\( T_{fp} \) is the makespan.

The target is to minimize the expected value of the sum of
the penalty cost for the delay and resources cost. The
expected value is necessary because the makespan \( T_{fp} \) depends to the resources number and to the exogenous
demand that is a random variable.

The penalty cost is quadratic to avoid peak delay (a larger
number of small delays is better to a small number of large
delays).

Depending on the weight it gives to the delay (value \( \alpha \)), a
priority to the tasks can be given and, in this case, it is
preferable to minimize the delay by the resources increase
(they are linked with a linearity constraint to \( \beta_1, \beta_2, \beta_3 \)).

The steps are:

- Assigning the weights values;
- Assigning the constraints and “translating” these into
  OptQuest;
- Running optimization and recording the control
  variables value;
- Testing the solution reliability through simulation run
  and output analysis.

4.8.1 Determination of the weights

The choice of weights is very important, because they
"drive" the search of the solution.

Therefore the determination of this set of weights was done
in several stages.

At first it was defined the importance of weight according to
qualitative approach: so a priority of the tasks was defined
interviewing the management team.

The tasks considered are:

- Delivery time (minimizing delay);
- Minimizing the human resources;
- Minimizing the investment of the thermo sealing
  (process bottleneck).

The hourly cost of staff is about 10 €/h and the other costs
were calculated in proportion to this.

The thermo sealing cost was chosen larger, because of the
space constraint.

The delay cost (primary objective to minimize) is twice that
of the thermo sealing cost.

Comparing these costs to those of the staff, costs have been
made dimensionless and so they became weights.

An analytical formulation of the objective to minimize is
given below:

\[
\min_{x_1, x_2, x_3} \left[ 200 + \alpha_1 \left( T_{fp} - \text{Due Date} \right)^2 + 10 \alpha_2 x_1 + x_2 + 100 x_3 \right]
\]

This function was included in OptQuest and was selected
"Minimize Objective".

The optimization started after setting the number of
replications for each simulation.

The optimizer returned the following values:

- Kitchen employees \( (x_1) = 5; \)
- Packer employees \( (x_2) = 4; \)
- Thermo sealing \( (x_3) = 2. \)

Then these values were tested using statistical inference to
verify if the service level was the desired. Specifically, a
test of Chi-Square was made, according to the observations
sample of makespan, setting a significance level of 99%.

The normalized threshold value that was found is 5.01 and
the cumulated at this value is nearly unity, confirming the
goodness of the solution proposed by the optimizer.

5 Conclusion

The aim of this work is to provide a decision making
support for business; it’s to check if the production capacity
of cooking center is able to react to an increase in demand,
acting preferably on human resources, and if it is able to do
a different analysis through an academic view.

With these results it can summarize that the system
responds quickly to an increase in the resources level
regarding the process mix considered.

Furthermore a buffer of 20 minutes is created; it can be used
as a safety stock for any downtime that may occur during
the workday.

References:

modeling and analysis issues for high-speed combined
continuous and discrete food industry manufacturing

compliance within the production chain of food contact
materials by good manufacturing practice and


