



13th Global Conference on Sustainable Manufacturing - Decoupling Growth from Resource Use

"Waste Reduction by Product-Quality based Scheduling in Food Processing"

"Marcel Wagner^{a,*}, Stefan Kaluschke^a, Fabian Keller^a, Gunther Reinhart^a"^aFraunhofer Institute for Machine Tools and Forming Technology, Beim Glaspalast 5, 86153 Augsburg, Germany* Corresponding author. Tel.: +49-821-568-8389 ; fax: +49-821-568-8350. E-mail address: marcel.wagner@iwu.fraunhofer.de**Abstract**

Related to resource efficiency waste reduction is the crucial point in the processing of food. As shown in different Food Waste Studies the amount of waste in food processing is enormous. Up to 400.000 metric tons of edible food is disposed every year caused by wrong treatment, handling and processing. Processing is the major point to deal with. In the case of manual processing in a cantina kitchen waste can be classified into waste associated with overproduction, product damages or technical interruptions. To reduce the amount of loss by using technical solutions it is possible to reduce up to 60 % of loss during the processing. Related to the product itself the automation and especially the scheduling of the processes in a commercial kitchen is more complex than the scheduling of standard products e.g. in the automotive sector. This article shows a solution to extend the criteria of production planning within an automated food processing environment. The paper introduces a product model that prescribes the progress of product quality while processing.

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Nomenclature

KPI.....Key Performance Indicator
MRP.....Manufacturing Resource Planning
PPC.....Production Planning and Controlling

1. Introduction

The reduction of food waste should be one of the most important targets of highly developed industry nations. With certain countries, especially in Africa, Asia and Latin America [1], still suffering from mal-nutrition of their population, the brisance of this subject will not cease in the near future. The steadily increasing global population [2] plays a role in contributing to this situation. With up to 402.250 metric tons [3] system catering and factory catering can be identified as perpetrators of a high rate of food waste. It appears that two-thirds of the caused waste arise in the sectors of food manufacturing, food processing and at the customer (see Fehler! Verweisquelle konnte nicht gefunden werden.re 1).

The main reasons for this amount of waste emerge due to faults in planning and processing. An automated manufacturing of food can be a solution to these problems. The faults in planning and processing could be eliminated and

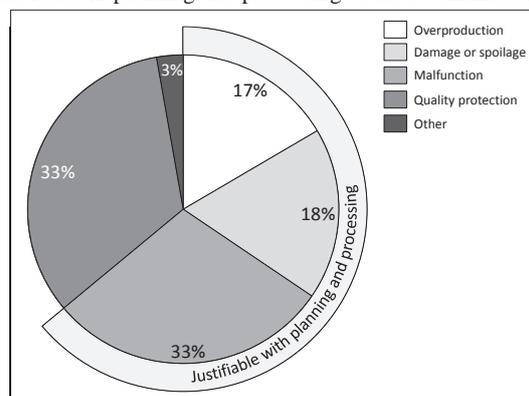


Figure 1:Responsible fields of food waste [3]

a decrease of food waste could be ensured.

Furthermore the lack of food sustenance of employees caused by variable working times could be abolished.

An automated processing of primary products typically requires a production planning and controlling (PPC). However production planning and controlling in food business is based on different challenges as for example in metal working.

This paper is dedicated to acquire the specific requirements of a PPC in an automated system catering kitchen. Therefore existing planning models shall be determined and adapted to the claimed case of application.

1. State of the Art in PPC concerning waste reduction

PPC has main importance in most industrial enterprises [4], involving the complete job handling from quotation processing to dispatch. The main purpose of PPC is the fulfillment of four basic aims: maximum adherence to schedules, short processing time, minimum stocks and maximum occupancy rate [5]. Because of the dependence of those four aims, none of them can be fulfilled completely, but only best possible. The compromise, which is formed, represents the profitability.

In times of rapidly changing markets and supplier conditions, PPC of manufacturing companies is often not able to cope with the quickness of the changing environment [6]. Usually it is too stiff to keep up with the food market's dynamic [7]. Therefore changeable PPC systems have to be established, containing a structuring design and building blocks to reach systematic software changeability [6].

In the field of food preparation PPC has not been established entirely. A study, commissioned by the packaging company Ishida, reaches the result that automation and, as a consequence thereof, PPC is mostly used by companies producing foodstuffs with extended shelf life, e.g. frozen foods [8]. On the contrary in system catering or factory catering meals are mostly prepared manually. Thus preplanning is usually made on basis of the head chef's experience. To transfer automation to sector of system catering, PPC has to enable an adaptive planning of the production of individual products. Such systems are already partly applied in high developed production companies, such as automotive companies.

2. Challenges and Requirements

As already shown above, automation and PPC in food processing is not used in the extent as it is used in automotive industries or metal processing. Thus most of the usually applied PPC systems have been developed for those highly automated sectors. To transfer those systems, adaptations have to be done to reach a compatibility with the food sector. Subjects like the reduction of waste or the dealing with inhomogeneity of raw materials are not explicitly contemplated in most of these systems. Based on a morphological analysis, target values for a PPC system have

been determined. This analysis shows that the four aims of production planning and controlling, i.e. maximum adherence to schedules, short processing times, minimum stocks and maximum occupancy rate are equally valid in a food processing environment. Nevertheless production planning and controlling has to be adapted to fulfill the requirements in the preparation of food. Therefore these four aims have been completed by five food-specific aims:

Table 1: Nine aims to evaluate the PPC system

No.	Aim	Attribution
1	Short processing time	Basic aims of conventional PPC
2	Maximum adherence to schedules	
3	Minimum stocks	
4	Maximum occupancy rate	
5	Securing of quality	Food specific aims
6	Reduction of food waste	
7	Dealing with inhomogeneity of raw materials	
8	Control of process parameters	
9	Dealing with customer feedback	

As an evaluation method, an influence and relevance matrix can be used to compare the nine aims in terms of their significance. Hereby the elements, which have been determined in advance, can be compared by pairs with each other to detect their importance [9]. An analysis with an influence matrix yields two kinds of results: the active and passive sum. The active sum of an aim indicates its influence on each of the other aims. The passive sum indicates the influenceability of the determined aim from the other aims.

An analysis using a relevance matrix investigates the relevance of one aim compared with another. In the end there can also be formed a sum, which shows the relevance of the different aims in a ranking.

Those three sums deliver a three dimensional evaluation, which can be illustrated in a system grid. On the abscissa the passive sum rank is plotted. On the ordinate the active sum rank can be seen. Both of them are plotted descending. The size of the bubbles reflects the rank in the relevance matrix. Rank one to three are displayed with big bubbles, rank four to six with medium and rank seven to nine with small bubbles.

It shows up that the aims 'securing of quality' and 'maximum adherence to schedules' are influenceable and influential, as well as relevant. The aim 'reduction of food waste' is as influenceable and relevant but slightly less influential than those two aims. The aims like 'short processing time', 'dealing with inhomogeneity' and 'control of process parameters' are ranked medium in the influence and relevance matrix. Only the 'control of process parameters' has a better rank in the relevance matrix and is displayed with a big bubble. The three aims 'minimum stocks', 'maximum occupancy rate' and 'dealing with customer feedback' are barely influential, influenceable and relevant. Figure 2 shows the evaluation illustrated in a system grid based on the elements given in Table 1.

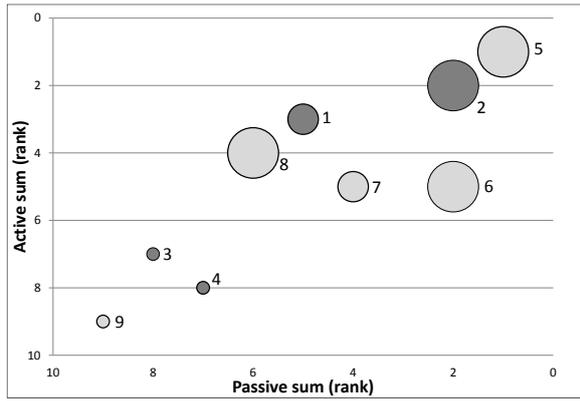


Figure 2: System grid for prioritization of PPC goal criteria

The securing of food quality is the most important planning aim. Influencing factors, as well as hygienic guidelines have to be observed by PPC to obtain optimal quality. Also short processing times contribute to optimal quality and flavor of the nutrition.

In system catering environment adherence to schedules plays an important role. PPC has to assure the production flow so that customers do not have to wait for their ordered meals. The prioritisation at the bottleneck (mostly an oven in the scenario given) ensures optimal resource utilization.

The reduction of food waste also is one of the major important aims. PPC has to ensure optimal process parameters, which support a minimization of food waste due to wrong preparation.

Another task of PPC is the dealing with inhomogeneity of raw materials. Foodstuffs are natural goods and therefore their texture and quality can vary. Nevertheless every meal should be delivered in optimal and consistent quality. Therefore PPC has to be able to vary the quantity of every raw material to reach these aims.

3. Quality-based Approach for Waste-reducing PPC

To face these challenges it is necessary to extend the capabilities of a PPC and especially the scheduling of the food processing. Therefore standard procedures were analyzed. In conclusion it can be said, that there is no efficient algorithm to handle the requirements of food products. As described above, quality and the reduction of waste are most important in these processes. In the following the waste reduction is subsumed as a secondary aim of achieving customer's individual wishes. Nevertheless special objectives have to be addressed.

Objectives in Food Processing will be introduced in this section. The sophisticated and subjective process of preparation of meals brings up huge technological challenges for an automated solution, especially in relation to constraints the result from the processing of food. During the preparation of food, one can assume that the storage after a certain processing step leads to major loss of quality and an increased waste amount.

But in a given environment it is necessary to go beyond these definitions and create a mathematical description for quality as a subjective parameter [10].

The minimization of the waiting time in the production flow is assigned a high priority, due to the mentioned reason of quality loss based on waiting time.

A process scheduling with respect to waiting times and product quality and timely fulfillment of customized orders is only possible in conjunction with a real-time creation of a schedule [10]. In addition, the reduction of the order deadline to a few minutes in a canteen environment before the desired completion time of the product requires an alternative to the well-known scheduling algorithms that can typically have an overnight run for optimization and scheduling (methods like MRP2 [11]).

Due to modelling and developing an adapted approach for scheduling in food processing environments there have to be k products $p_i, i = 1..k$ which are to be respectively assigned to one of the $n \leq k$ customer orders. Then there is a functional description $z: [1, k] \rightarrow [1, n]$, which assigns a job to each product. A scheduled starting time $t_{start, i}$, i.e. the time to start the preparation of this product, and an end time $t_{end, i}$ at which the product has to meet to be ready to serve can be defined.

The most important aim of the scheduling process is linked to the minimization of the waiting time $t_{wait, j}$ with $j = 1..n$. $T_{wait, j}$ here is defined as the difference between the smallest and the largest end time of all the products p_i belonging to one order (also compare [10, 12]). Waiting time typically leads to a loss of quality. To summarize these objectives a function is defined as:

$$\min [\sum_{j=1}^n t_{wait, j}] = \min [\sum_{j=1}^n (\sum_{\{k|z(k)=j\}} \sum_{\{l|z(l)=j\}, k < l} |t_{end, k} - t_{end, l}|)] \quad (1)$$

The desired end time of each job j will be defined to be $T_{end, j}^*$. This target time is to deviate as little as possible from the scheduled end time of the job j . Therefore, an additional objective function can be set as:

$$\min [\sum_{j=1}^n T_{wait, j}] = \min [\sum_{j=1}^n |T_{end, j} - T_{end, j}^*|] \quad (2)$$

Start and end time of a single job j can be calculated by:

$$T_{start, j} = \min_{z(i)=j} t_{start, i} \quad (3)$$

$$T_{end, j} = \max_{z(i)=j} t_{end, i} \quad (4)$$

To meet the expectations of the customers and to avoid waste based on customer's food disposal due to insufficient quality levels it is necessary to plan quality as a KPI.

Since quality of food is the sum of all assessable characteristics from a food product [3, 13]. The enjoyment value $q_{sensory}$ that gives information on the sensory quality and also the health value that equals the nutritional quality q_{nutri} . Due to the diversity of different aspects of food quality it addresses various interest groups like grower, producer, retailer and consumer. [14] gives an overview on the focus area in the field of quality of food products. In conclusion the sensory and nutritional qualities are most relevant to the customer.

Since each product is to be delivered in the best possible quality to the customer, a function which represents subjective components of enjoyment and health value have to be defined [10].

A tuple of three parameters can be controlled in the examined application for automated processing of meals related to influence products quality. These parameters are temperature Θ , processing time t and humidity LF . Since humidity represents the cooking process itself it is more or less a fixed parameter.

The integration of the sensory quality in the planning process was realized with a particular kind of calculation. The so called degree of food consistency [15] is a method of calculation based on sensory evaluations of taste and consistence of food in relation to the temperature Θ and the time of heat treatment. The result of this evaluation is approximated with an exponential characteristic [10, 16]:

$$t_G = e^{a+b \cdot \Theta} \tag{5}$$

The parameters a and b are characteristic for the progress of consistency and can be mathematically evaluated out of empirical data [17]. With this correlation, it is possible to calculate the degree of food consistency G . This is defined as the relation between current time of heat treatment t_{kept} and the time to the best sensory quality in the process t_G .

$$G = \frac{t_{kept}}{t_G} \tag{6}$$

Due to the dynamics of processing parameters in a cooking process the equation given above needs to be extended to a time-dependent more precise way of calculation:

$$G(t) = f(\Theta, t) = \int \{e^{-a-b \cdot \Theta(t)} dt\} \tag{7}$$

Therefore the knowledge of the temperature profile inside of the food is necessary. For this reason, a mathematical model of the processed food item and the processing equipment is picked up. The two models mentioned previously enable to simulate the food's core temperature and calculate the degree of food consistency G (see formula 8). By using this function it is possible to find an optimal enjoyment value $q_{sensory}$ for each temperature in a steamer. The knowledge on degradation processes available in the field of food preservation is used to derive a function for the health value (see formula 9):

$$q_{sensory} = f_1(G) = f_1(\Theta(t), t, LF) \tag{8}$$

$$q_{nutri} = f_2(G) = f_2(\Theta(t), t, LF) \tag{9}$$

The combination of the nutritional quality and the sensory quality has an impact on the range of the calculated quality q .

Therefore, a tuple of the optimal values $\Theta^*_i, t^*_{kept,i}, LF^*_i$ with $q: R^+ \times R^+ \times [0,100] \rightarrow [0,1]$ for each product p_i is given.

A function like this opens the possibility to predict the processing parameters for meeting a certain quality level q for each product related to the timely scheduling. Thus, the

quality of a job Q_j can be calculated as the mean of all products belonging to this job [12]:

$$Q_j = \frac{1}{|Z(t)=j|} \cdot \sum_{i|z(t)=j}^{\infty} q_i \tag{10}$$

The scheduling algorithm uses such a function; so that this is another objective function maximizing the qualities (11) of all orders can be considered.

$$\max [\sum_{j=1}^n Q_j] \tag{11}$$

There are several ways to influence the schedule of the processing. On the one hand, it is possible to determine a product in one job by changing its processing time. On the other hand, this is more or less an implicit result, while pre-control the relevant process parameters, the same quality goal can be reached although multi product processing in one process chamber can be performed. The Figure 3 introduces two fundamental methods of these approaches.

Limitations in a test scenario arise apart from the above objective functions concerning several technical constraints

In general, one can define a function b , for D machines with F compartments, which outputs, the number of occupied compartments subjects in the steamer d at any given time.

$$b_d(t) \leq F \forall t \text{ in } \mathbb{R}^+ \tag{12a}$$

To prepare the food, two steamers are available with adjustable process parameters. Each of the steamers used has five compartments in which the products can be processed. The relevant constraint can be achieved as:

$$b_d(t) \leq 5 \text{ with } d \in \{1,2\} \tag{12b}$$

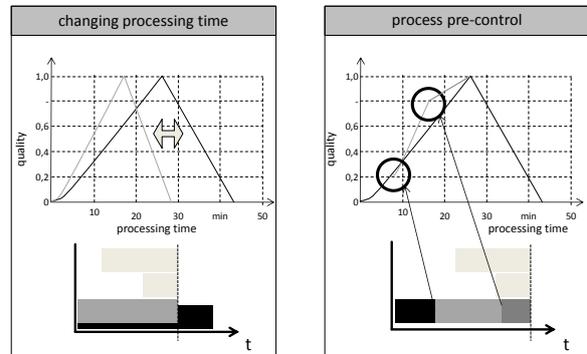


Figure 3: Possibilities to influence processing time by to meet the same quality requirement

Besides this, since a machine is fully occupied with five products no additional product can be processed.

Due to a mechanism that moves the products to the ovens, an additional time span arises. The start and end times of all products, handled by one mechanism have to add the time constant t_{oven} . This constant represents the time required for the delivery mechanism to move an ingredient in the oven. This results in the following constraints:

$$|t_{start,i} - t_{start,j}| \geq t_{oven} \tag{13}$$

$$|t_{end,i} - t_{end,j}| \geq t_{oven} \tag{14}$$

Another quality-oriented constraint arises from the fact that the customer wants to get his dish warm and without additional waiting time. For this reason, the minimization of this time has been chosen as an objective function [10]. In addition, the food may not be finished before the customer due date $T_{end,j}^*$, that have to be less than or equal to the actual scheduled end time $T_{end,j}$.

$$T_{end,j}^* \leq T_{end,j} \quad \forall j = 1 \dots n \tag{15}$$

The scheduling algorithm consists of several phases (see Figure 4).

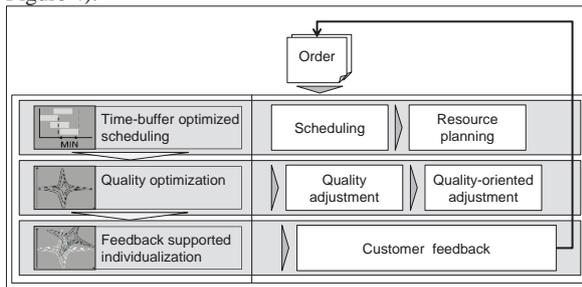


Figure 4: Scheduling algorithm for quality scheduling

The first “*Time-buffer optimized scheduling*”, results in a first plan, which violates the constraints. Then the times are changed so that the constraints (13) and (14) are met. Only after this step, the condition (12a) is checked and satisfied by shifting the start times of the products of one order so that a resource allocation is made. After this shift, the second phase “*quality optimization*” follows with determination of the job related process parameters. This step will lead to an effect on the time schedule of the products, and additionally provide a profile of the temperature and humidity in the oven to ensure optimal quality of the orders. The last step shown in Figure 4 represents the possibility of individualizes orders of the same ingredients in the future. “*Feedback supported individualization*” allows to precisely adjusting the processing for all products ordered by a customer to its own sensory recognition.

The presented scheduling algorithm schedules the processing of food by means of prioritizing and shifting the orders available. In order to achieve the objective functions (1), (4) and (11) are minimized until the pareto optimality while satisfying the constraints (12a), (13), (14) and (15).

The optimum is not found by several iterations, but rather formed within a heuristically way by ordering the products to satisfy all constraints. This sequence is considered to be the optimal solution.

From this point of view scheduling is regarded as setting the start time $t_{start,j}$ and determining an optimal set of process parameters used in the steamers (the temperature and the humidity). Every other information relevant for the objective functions and constraints result implicitly.

As shown in Figure 4 n jobs (synonym to orders) with a desired end time $T_{end,j}^*$ will be the input expected. The start and end times will then be rescheduled so that the constraints (13) and (14) are met. Thus, the start times of all products p_j , for which the conditions (13) or (14) are violated were recalculated as following:

$$t_{start,j} = t_{start,j} + t_{oven} \tag{16}$$

Thereafter, each of k products has a unique start and end time. Furthermore, it is guaranteed that the waiting time is kept as small as possible. This is equal to the number of products of the order time’s t_{oven} while no specific time shifts are necessary. In addition, by shifting forward in time the condition (15) satisfied. Following this step, the order buffer is passed through the check against constraint (12b).

In order to satisfy this constraint the orders which have not passed this condition test are moved so that the maximum number of compartments is not exceeded. If at time t , the constraint (12b) is violated, the start time of the products that are in the oven at that time, were moved again. To satisfy the objective function (1) the start time of all products belonging to one order have be moved. Because of the fact that the start times of all items of one job j are moved as an undividable block. At this point, the products are now scheduled, in a way that the start and end times are fixed and satisfy the constraints. So it is known which products are going to be processed together in one steamer. In the next step of the algorithm “*quality optimization*” a given quality function, introduced in [10, 12, 16], is used, an optimal profile of the temperature and the humidity in the ovens can be determined, so that the quality of the food is maximized.

The presented algorithm derives a valid set of process parameters for each time at which the allocation in the steamers change to meet a desired quality level for each customer. This adjustment in parameter settings can occur, if a product is put into or taken out of one oven. By building a discrete grid along a continuous quality function, the way that all temperature values $T = \{50, 55, 6, \dots, 250\}$ are combined with all humidity levels $LF = \{0, 2, 4, \dots, 100\}$ helps to find the best process conditions. For all these pairs of values, the average of the quality is calculated using (11).

4. Results and economic impact

Due to the reduction of food waste during the processing of meals and an optimized portion size of individual meals, a great amount of food waste can be avoided.

Exemplary the support of canteen kitchens in hospitals can be mentioned as fields of use. Moreover employees could be provided during night shift or weekend work in public institutions or the army. In conclusion any facility, in which kitchen operation outside the usual kitchen times does not seem economically worthwhile, can be seen as a field of application. The approach to integrate a quality function in the machine scheduling to achieve an intelligent planning and controlling of conditionally cacheable goods can be transferred to other industries (e.g. foundry or chemistry).

The efficiency is evaluated on the basis of the described use case, which is mapped by the presented approach. The comparison between maintaining the supply of a cafeteria over the weekend (48h) by personnel and by automation provides the basis for a calculation. The Figure 5 below shows the comparison between four different scenarios:

- complete manual solution (1)
- automated processing with provision of dishes, including costs for rinsing (2)
- with reduced rinse costs due to dish provision (3)
- a loose realization with take-away packaging (4)

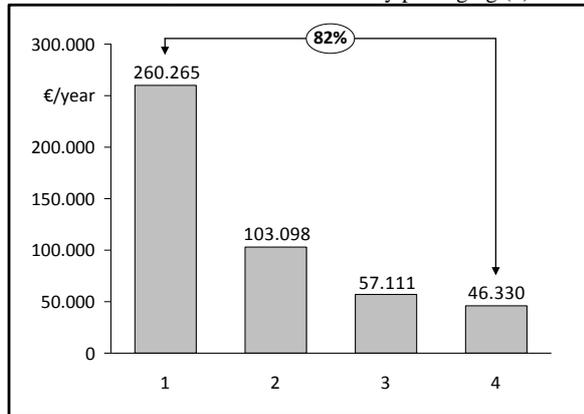


Figure 5: Economic impact in an autonomous kitchen environment

Scenario 1 consists of staff costs of €240.000 plus service costs of €20.000. The purchase and operation of an automated solution has a payback period of less than one year. The acquisition (around €40.000) and operation costs of the system (additional €30.000) are the base for scenario 2. In addition costs of an employer supervising the operation of the facility arises (€12.000 to €70.000). In total, savings up to 82 percent are possible (Figure 5).

5. Conclusion and Future Work

This approach shows an algorithm to optimize the processing order in a totally automated kitchen environment to create a job plan in order to save resources and taking into account various constraints. Concerning the topic of waste reduction the prevention of waste from overproduction by producing individual ordered meals and the consequent waste of energy plays an essential role. For demonstration purposes two steamers, a prototypically implemented portioning machine as well as a transport system based on autonomous robots were implemented. The plant allows the support of a commercial kitchen with full automation capabilities in the food preparation process as well as a planning platform for individual quality issues of any customer.

An important task for the future will be to precisely define the models of different products. Then the algorithm that is based on different thermodynamic product models can be used on a wider range of processing. Also the transfer to different applications with requirements concerning products with an ageing process can be seen in the future.

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