DEVELOPMENT OF A SAFETY MONITORING AND ASSURANCE SYSTEM (SMAS) FOR THE MANAGEMENT OF THE FOOD CHILL CHAIN

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ABSTRACT

The weakest link that affects directly safety and quality of chilled products is the actual chill chain. Meat products, unless processed, packaged, distributed and stored appropriately can spoil in relatively short time and when temperature abused pause a potential hazard for the consumer. Application of an optimised quality and safety assurance system for chilled distribution of fresh meat and meat products requires continuous monitoring and control of storage conditions from production to consumption. The principles of a novel chill chain management policy, coded “Safety Monitoring and Assurance System” (SMAS) are based on product’s time-temperature history, with the use of Time-Temperature Integrators (TTI), variation in product’s characteristics, and the use of predictive models for the growth of food pathogens, allowing to give priority to products in such a way that risk at consumption time is minimized and quality optimized. SMAS compared to the First In First Out (FIFO) current approach, can lead to significant reduction of the risk for unsafe products and improve quality at the consumption time.

SMAS is being developed and evaluated in the European Commission RTD project QLK1-CT-2002-02545 (http://smas.chemeng.ntua.gr)

Keywords: SMAS, Distribution management system, Time-Temperature Integrators, Food safety, Shelf life

INTRODUCTION

In the last decade, the incidence of foodborne disease has increased in Europe, despite the introduction of HACCP, and the proliferation of food safety regulations. The increasing international competition in food manufacture and trade, the stricter consumer demands and the social changes, combined to the recent foodborne outbreaks stress the need for more effective food quality and assurance systems. The current philosophy for food quality assurance is steadily decreasing the focus on end product testing and verification, traditionally the cornerstones of quality and regulatory control (Taoukis et al. 1999). Food industry and authorities focus on the development and application of structured quality assurance systems, based on prevention through monitoring, controlling and recording of critical factors throughout the entire life cycle of a product. Despite the improved quality assurance policy, the chill chain of perishable foods, such as meat, suffer from substantial
quality losses, mainly due to significant deviations from the recommended temperature conditions. Temperature determines the rate of deterioration and the spoilage of meat and meat products; thus, monitoring and controlling temperature during chill distribution is of central importance for an effective and reliable quality and safety assurance system. The detection and the possible improvement of the weak links of the problematic distribution chain, the quantitative evaluation of their impact on the final food quality, as well as the continuous control of the actual quality level can be realized with the use of Time Temperature Integrators or Indicators (TTI).

**Time Temperature Integrators (TTI)**

TTI are simple, inexpensive devices that indicate with an easily measurable, time-temperature dependent change, the temperature history and quality status of the food they are attached to (Taoukis 2001, Taoukis and Labuza 2003). The irreversible change expressed by TTI response is usually a mechanical deformation or color development, based on mechanical, chemical or enzymatic systems (Taoukis et al. 1991). TTI effective application and reliability as quality index of food depends on the kinetic characteristics of its response. Most TTI systems can be appropriately designed either to imitate or to be correlated to food spoilage behavior at a target constant temperature (Taoukis and Labuza 1989a,b). However, the activation energy of TTI systems, expressing their temperature dependence, is limited to specific ranges, depending on their principle of function.

On the other hand, a substantial requirement for TTI application is that the $E_A$ of TTI response is as close as possible to the activation energy of food deterioration mode. Any difference in temperature sensitivity between TTI response and food spoilage may lead to a significant error when using TTI as tools of shelf life estimation, at any point of the distribution chain of products (Taoukis and Labuza 1992).

For accurately implementing TTI correlation scheme, a systematic study of TTI response and food degradation kinetics is necessary.

**Development of SMAS system**

SMAS is an integrated chill chain management system that aims at optimizing chill distribution, from a safety and quality point of view. The main principle is to develop reliable and practical Time Temperature Integrator (TTI) systems, that will continuously monitor the temperature conditions of each product, and establish their applicability as safety monitors of meat products from manufacture to consumption. TTI response can be correlated with the safety and the quality status of meat products at any point of the chill distribution chain, allowing for a reliable shelf life evaluation.

SMAS acronym is a short title for the “Safety Monitoring and Assurance System” that is developed and applied under a RTD project, funded by the European Commission (QLK-CT-2002-02545), coordinated from the National Technical University of Athens. The main cornerstones of the system include the development of validated predictive models for (a) the growth of meat pathogens and spoilage microorganisms, and (b) TTI response, all included in a generalized TTI application scheme that translates TTI response to the actual meat microbiological identity. 7 European Institutes/Research Centers are currently working on the main interrelating workpackages in order to finally obtain an effective tool for the optimized management of the actual, problematic chill chain.

SMAS basic structure includes: (a) validated models of microbial growth of pathogens and Specific Spoilage Organisms (SSO) for each different meat product, (b) information on the initial prevalence and distribution of the spoilage
microorganisms, $N_0$, (c) continuous temperature monitoring of the chill chain with TTI and, finally, (d) the appropriate correlation of sensory acceptability to a specific level of microbial load, $N_S$, that signals the end of the product shelf life. These elements are introduced and integrated in the SMAS algorithm, allowing for the estimation of the actual remaining shelf life and the risk assessment of each product unit, at selected, critical points of the chill chain. At the selected points of the distribution, a decision can be made for further handling of products, based on the actual distribution of the remaining shelf life of products. The ultimate goal is to obtain a narrow quality distribution and a significantly reduced probability of illness at the final stage of consumption. The basic algorithm of decision making, which is the base for SMAS design, is illustrated in Fig. 1 at selected critical points of the actual distribution chain. At a selected decision making point, i.e. the distribution center, products are split in half and forwarded to two different marketing destinations, namely at the local and export market. This split can be done randomly, based on the common First In First Out (FIFO) policy, or, alternatively, taking into account the real quality level of each product (Giannakourou et al 2001). Following the proposed method of SMAS, products with the highest microbial load $N_0$, being the most spoilt ones, albeit still accepted from a safety and quality viewpoint, are given priority towards the closest destination (B), in order to be consumed as soon as possible. Products suffering less from microbial contamination are forwarded to the more distant market (A).

![Figure 1](image_url)

**Figure 1**: Logical diagram of the decision making routine at critical control points of the chill distribution chain. The spoilage level $N_t$ is calculated separately for each product unit and the decision for its further handling is based on its relative position in the respective distribution.

At important decision making points of the chill chain, SMAS application requires as input the response of the TTI and the kinetic characteristics of the attached food. This information will be fed in a portable unit with SMAS software, in order to obtain an automatic translation of this data to quality (expressed by $N_t$) and safety features. The structure of SMAS software includes kinetic models for the prediction of microbial growth, such as the 4-parameter logistic model, taking also into account the exponential phase of growth $\mu_{\text{max}}$ (h$^{-1}$) and the lag phase (h). The temperature
dependence is mathematically expressed with the Arrhenius or the Belehradek equations.

The final results of SMAS application on cooked ham distribution chain are illustrated in Figure 2, where the probability of illness is minimized (Figure 2a), and the remaining shelf life of the product, based on quality criteria, is significantly increased (Figure 2b).

![Figure 2](image)

**Figure 2**: (a) minimization of the probability of illness and (b) improvement of the remaining shelf life, based on quality criteria with the use of SMAS policy, instead of the First In First Out stock rotation method (red bars correspond to SMAS results and violet ones to FIFO results).

**Main goals of SMAS**

The aim of this research project is to study reliable and practical Time Temperature Integrator (TTI) systems and establish their applicability as safety monitors of meat products from manufacture to consumption. The project will capitalize and expand on the scientific state of the art approach of mathematical modelling of dominating meat pathogens and translate this knowledge to TTI.

**The major expected achievements of the project will be:**

- Accurate, validated mathematical models for safety and quality related microorganisms of ready to cook meat products. They will provide the meat industry with a tool for product development and safety assurance and the European authorities with a quantitative means for meat product risk evaluation.
- The development and study of an assortment of Time Temperature Integrators (TTI) suitable for meat safety monitoring. These TTI will provide the meat industry and retail business with effective tools to monitor the chill chain.
- Improved distribution logistics and management of the meat chill chain from the application the Safety Monitoring and Assurance System (SMAS). SMAS could replace the current “First In First Out” (FIFO) practice and lead to risk minimization and quality optimization.
- Increased ability of the meat sector to control its weak link, the chill chain
- Fulfilment of consumer expectations that extra efforts and state of the art technology, represented by the use of TTI active labels and SMAS, have been employed to guarantee him low risk-high quality meat products.
- Wide availability of state of the art information, from the project and other reliable sources (i.e validated mathematical models for pathogen growth, data for
pathogen prevalence and concentration, distribution temperature profiles, dose
response data, inactivation models, TTI and SMAS application) for Risk
Assessment of specific meat products, through the establishment of an effective
Internet site (http://smas.chemeng.ntua.gr)

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