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Shelf-life variations in pallet unit loads during perishable food supply chain distribution

M. Göransson [a, *], Å. Jevinger [b], J. Nilsson [c]

[a] Packaging Logistics, Department of Design Sciences, Lund University, Box 118, 221 00 Lund, Sweden
[b] Department of Computer Science and Media Technology, Malmö University, Box 50500, 202 50 Malmö, Sweden
[c] Department of Biomedical Engineering, Lund University, Box 118, 221 00 Lund, Sweden

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ABSTRACT

This paper presents an experimental study of the thermal inertia of a pallet loaded with returnable plastic crates containing primary packages of smoked ham. Based on this, food quality variations within the pallet were also investigated. Thermal time constants from 83 sensor locations were identified by studying the temperature changes when the pallet was exposed to instant temperature drops (16 °C −2 °C) and temperature elevations (2 °C–16 °C). The thermal time constants were used in microbiological prediction models to calculate the maximum difference in shelf life between packages at the two most extreme spots in the pallet unit load, when temperature elevated from 4 °C to a higher temperature (ranging from 4.5 °C to 12 °C), during different periods of time (ranging from 0.5 h to 200 h). The results showed a maximum difference in shelf life of approximately 1.8 days. The identified thermal time constants were also used to calculate the maximum difference in shelf life between packages at the two most extreme spots of a pallet unit load, in a real chilled food supply chain lasting for about 2.5 days. This resulted in a maximum difference of 0.1 days. The results imply that the location of a product in a pallet has a relatively low influence on the product shelf life. This means that a temperature sensor used for calculating the predicted shelf life of a product, can be placed relatively far from the product itself (e.g. on the secondary package or even on the pallet) without jeopardizing the reliability of the resulting shelf-life prediction. However, the results also emphasize the importance of continuous temperature monitoring along the entire chilled food supply chains.

1. Introduction

Perishable food have high levels of nutrients and free water molecules, creating an ideal environment for microbial growth (Adams & Moss, 2008). The temperature surrounding packed perishables along the chilled food supply chain (CFSC) and the initial product temperature (Margeirsson et al., 2012) are, together with the microflora initially present in food at the time of packaging (Jol, Kassianenko, Wszol, & Oggel, 2006; Labuza & Fu, 1995), the most influential factors affecting the shelf life of a food product. Furthermore, temperature abuse and fluctuations are the main reasons for product returns, food waste and financial losses (Labuza & Fu, 1995; Raab et al., 2008). Zöller, Wachtel, Knapp, and Steinmetz (2013) reports that mismanaged temperature during perishable food supply chain distribution can cause up to 35% of product loss. Perishable food products are shipped in refrigerated vehicles and since different types of products, with different ideal temperatures, are often transported in the same vehicle, the inside temperature has to be a compromise between different temperature requirements (Bijwaard, van Kleunen, Havinga, Kleiboer, & Bijl, 2011). Furthermore, depending on the distance from the cooling unit, the indoor airflow patterns, the distance from the walls, the characteristics of the other products transported within the same vehicle, etc., the temperature within a vehicle varies (Grunow & Piramuthu, 2013; Moureh & Flick, 2004). Different activities may also affect the product temperature, e.g., temporary opening of the vehicle doors, temporary interruptions of the refrigeration function (for instance during a boat trip), loading and unloading of the products, etc. (Carullo, Corbellini, Parvis, & Vallan, 2009). Most factors affecting temperature variations during transport also affect temperature variations during storage (for instance, inside a terminal or

* Corresponding author.
E-mail addresses: malin.goransson@plog.lth.se (M. Göransson), ase.jevinger@mah.se (Å. Jevinger), johan.nilsson@bme.lth.se (J. Nilsson).

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warehouse).

The CFSC actors' willingness to share data and information is generally low, and hence the temperature load for perishables from the entire CFSC rarely exists (Aung & Chang, 2014; Eden et al., 2010). Furthermore, temperature is often measured with different methods and technologies causing accuracy variations. Kuo and Chen (2010) and Hafliðason, Ólafsdóttir, Bogason, and Stefánsson (2012) stress the advantages of continuously monitoring temperature throughout the whole CFSC of perishable food products to secure the quality and safety of the food. They also suggest a combined application of online monitoring of product temperature and simple reliable models to predict food shelf life (Hafliðason et al., 2012; Kuo & Chen, 2010). Beulens, Broens, Folstar, and Hofstede (2005) claim that temperature monitoring in CFSCs enables information transparency, which is a critical factor for food safety. Today, temperature monitoring close to the cooling unit inside vehicles and warehouses is common, although monitoring on a pallet level is unusual (Grunow & Piramuthu, 2013). Several studies have found, sometimes extensive, temperature variations within a pallet unit load, during field tests, simulations or experimental studies; these variations create thermal inertia within the pallet (Margeirsson et al., 2012; Moureh, Laguerre, Flick, & Commere, 2002). However, Jedermann, Ruiz-Garcia, and Lang (2009) show that it is possible to estimate the temperature variability inside a truck or a container, and based on this, reduce the number of necessary sensors necessary for reliable temperature monitoring. To the best of our knowledge, only a limited number of published scientific studies investigates how temperature variations within pallet unit loads affect the shelf lives of the different food products. Furthermore, no studies were found to address variations in how far from the product the temperature is actually measured, and how this affects the reliability of the predicted shelf life. Hence, this paper focuses on the following research questions:

- How do different product locations on a pallet affect corresponding product shelf lives?
- How close to the products must the temperature be measured, in order to get reliable shelf life calculations?

The first question addresses the magnitude of any variations that might exist between different products on a pallet, in terms of remaining shelf life. The perishable food product distribution are often performed under a period of several days and long distances, hence surrounding temperature variations may affect the quality of outermost and innermost food product on a pallet (transportation unit) in different ways. This question is primarily relevant for transport management and CFSC operations. The second question focuses on how close to the products temperature sensors must be placed, in order to get reliable shelf life calculations. An extensive number of sensors, e.g. on every primary package, entails substantial costs, in comparison to, for instance, having sensors on each pallet only. Previous research emphasize the benefits of increased temperature and quality control of the entire perishable food supply chain distribution. However, to achieve this implementation costs must be minimized. This question is primarily relevant for strategic planning.

The paper presents an experimental study collecting temperature data, and identifying corresponding thermal time constants, from 83 different sensor locations in a pallet fully loaded with primary packages of sliced smoked ham. The thermal time constants are then used in microbiological prediction models to investigate possible food quality variations within a pallet unit load. The investigated packaging system included primary packages placed in returnable crates, which in turn were loaded onto a returnable pallet. Both the returnable crates and pallet have been manufactured by Svenska Retursystem (SRS) (SRS, 2017). In Sweden, a majority (50–60%) of the perishables delivered to retail are packed in SRS returnable crates. Since this is a standardized system, transports based on this system will have the same or similar properties, in terms of air flow patterns. However, since the thermal mass of the primary packages might vary, the results from this study primarily apply to primary packages with similar thermal mass as sliced smoked ham.

This study is based on data collected during the innovation project Dynahmat, "Dynamic shelf life for minimized food waste" (DYNAHMAT, 2016). Dynahmat focussed on solutions for dynamic shelf-life prediction of chilled food products involving the whole supply chain, with the target of minimizing food waste. Within the project, experimental studies and field studies were conducted in mainly Swedish CFSCs using SRS returnable plastic crates and pallets. A returnable crate and pallet system enables the future use of more advanced Information and Communication Technology (ICT) solutions including memories, reloadable batteries, track-and-trace functionalities, etc.

2. Methodology

The practical experimental set-up was designed to determine the thermal time constant at 83 different sensor locations in a pallet fully loaded with returnable plastic crates containing primary packages of sliced smoked ham (Fig. 1). Both the crates and the pallet used in the experiment were of a returnable type. The thermal time constants were identified by studying the temperature change at each sensor location, when the pallet unit load was exposed to instant temperature drops and temperature elevations. The instant temperature drops were obtained by using a refrigerated storage room with a refrigeration fan whereas the instant temperature elevations were obtained by using an ambient storage room without any forced airflow. We believe this is relatively consistent with real cold-chain conditions, i.e. that temperature decrease is caused by a cooling fan and temperature rise is caused by the intrusion of higher temperatures generated without a fan.

The identified thermal time constants were used to estimate the actual temperature at each sensor location, at any given time, as the surrounding temperature varied. In order to generate an accurate temperature value for each sensor location, the influence of the sensor tag dynamics was investigated and taken into account. Thereafter, an analysis of the effects in terms of product shelf life

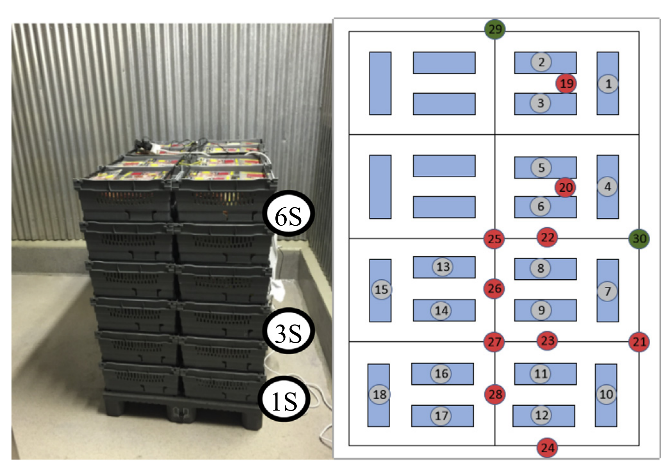

Fig. 1. The left-hand side shows the pallet unit load used in the experiment. The right-hand side shows the locations of the sensors at the first, third and sixth crate layers.