



Implementation of IoT for food wastage minimisation

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Abstract

Food wastage started to be a significant issue affecting mankind. This wastage can occur during entire food cycle, including agricultural production, post-harvest handling and storage, food processing, distribution, consumption and end-of-life. Wastage is mainly caused by inefficiencies in the food supply chains and lack of information from each phase in food cycle. In order to minimize this Internet of Things system model, with dynamic shelf life prediction based on kinetic Arrhenius model, was developed and presented in this paper.

Key words: *IoT, shelf life, perishable, wastage*

1. INTRODUCTION

Due to the constant increase of the population and lack of possibility of developing available natural resources the problem of food wastage started to be a significant issue affecting mankind. It represents significant social, nutritional and environmental issue. This is because all over the world one third of food produced for human nutrition is lost or wasted. This corresponds to 1.3 billion tons of food waste per year [1], [2]. Food waste refers to food appropriate for human consumption being discarded, whether or not after it is kept beyond its expiry date or left to spoil. Often this is because food has spoiled but it can be for other reasons such as oversupply due to markets, or individual consumer shopping/eating habits. On the other hand food losses are also interesting to investigate.

The term food losses refers to a decrease in mass (dry matter) or nutritional value (quality) of food that was originally intended for human consumption. These losses are mainly caused by inefficiencies in the food supply chains, such as poor infrastructure and logistics, lack of technology, insufficient skills, knowledge and management capacity of supply chain actors, and lack

of access to markets. The scope of this paper is food wastage which refers to any food lost by deterioration or waste. Thus, the term wastage encompasses both food loss and food waste.

2. FOOD WASTAGE

Food wastage can occur during entire “food cycle”, including agricultural production, post-harvest handling and storage, food processing, distribution, consumption and end-of-life (i.e. disposal) [3]. Food wastage along the food supply chain (FSC) has a variety of causes, such as spillage or breakage, degradation during handling or transportation, and waste occurring during the distribution phase.

There is five system boundaries distinguished in the (FSC) of vegetable and animal commodities. Food loss/waste should be estimated for each of these segments of the FSC. The following aspects are in most cases considered [2]:

- Vegetable commodities and products:
 - ✓ Agricultural production: losses due to mechanical damage and/or spillage during

harvest operation (e.g. threshing or fruit picking), crops sorted out post-harvest, etc.

- ✓ Post-harvest handling and storage: including losses due to spillage and degradation during handling, storage and transportation between farm and distribution.
 - ✓ Processing: including losses due to spillage and degradation during industrial or domestic processing, e.g. juice production, canning and bread baking. Losses may occur when crops are sorted out if not suitable to process or during washing, peeling, slicing and boiling or during process interruptions and accidental spillage.
 - ✓ Distribution: including losses and waste in the market system, at e.g. wholesale markets, supermarkets, retailers and wet markets.
 - ✓ Consumption: including losses and waste during consumption at the household level.
- Animal commodities and products:
 - ✓ Agricultural production: for bovine, pork and poultry meat, losses refer to animal death during breeding. For fish, losses refer to discards during fishing. For milk, losses refer to decreased milk production due to dairy cow sickness (mastitis).
 - ✓ Post-harvest handling and storage: for bovine, pork and poultry meat, losses refer to death during transport to slaughter and condemnation at slaughterhouse. For fish, losses refer to spillage and degradation during icing, packaging, storage and transportation after landing. For milk, losses refer to spillage and degradation during transportation between farm and distribution.
 - ✓ Processing: for bovine, pork and poultry meat, losses refer to trimming spillage during slaughtering and additional industrial processing, e.g. sausage production. For fish, losses refer to industrial processing such as canning or smoking. For milk, losses refer to spillage during industrial milk treatment (e.g. pasteurization) and milk processing to, e.g., cheese and yoghurt.
 - ✓ Distribution: includes losses and waste in the market system, at e.g. wholesale markets, supermarkets, retailers and wet markets.
 - ✓ Consumption: includes losses and waste at the household level.

Amounts of food production volumes of all commodity groups in their primary form is given in the Fig 1. On the other side food wastage differs also according to region. In Fig. 2 it is represented food wastage per capita at consumption and pre-consumptions stages, in different regions. It can be noticed that Europe and North America and Oceania have the highest food wastage per capita.

Amounts of wastage along the food supply chain [1] are following: agricultural production, at 33 percent, is responsible for the greatest amount of total food wastage volumes. Upstream wastage volumes, including production, post-harvest handling and storage, represent 54 percent of total wastage, while downstream wastage volumes, including processing, distribution and consumption, are 46 percent. Thus, on average, food wastage is balanced between the upstream and downstream of the supply chain. An analysis of the food supply chain phases by regions reveals that: upstream, losses occurring at agricultural production phase appear homogenous across regions, representing about one-third of each region's food wastage; downstream, wastage occurring at consumption level is much more variable, with wastage in middle- and high-income regions at 31–39 percent, but much lower in low-income regions, at 4–16 percent. Amounts of food wastage for fruits and vegetables commodity group at different stages of FSC in different regions are represented in Fig. 3.

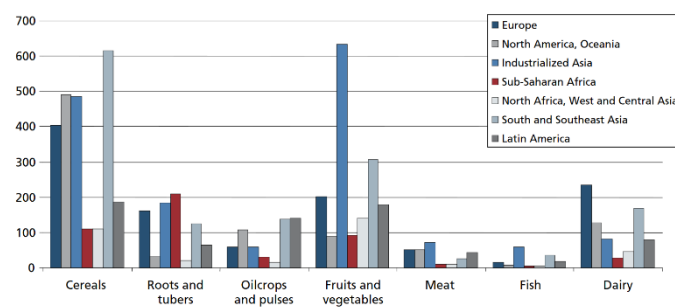


Figure 1. Production volumes per region (million tonnes) [4]

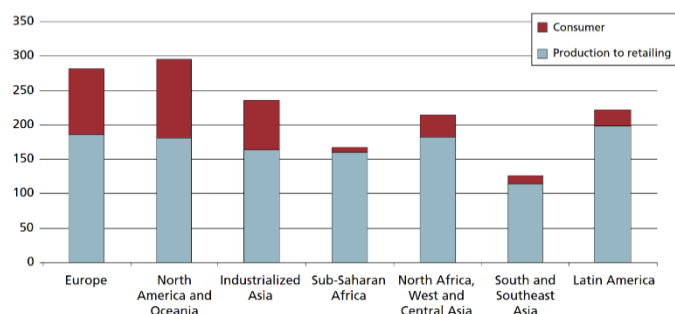


Figure 2. Per capita food wastage (kg/year) [2]

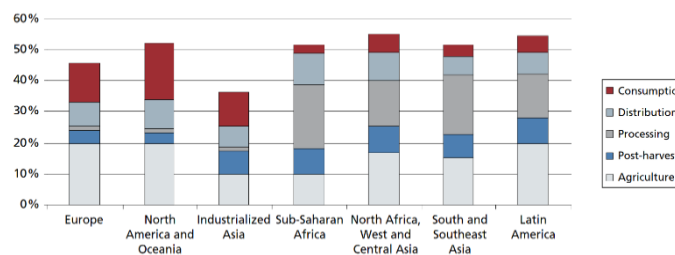


Figure 3. Food wastage in different phases of FCS [2]

It can be concluded that food wastage arises at all stages of the food supply chains for a variety of reasons that are very much dependent on the local conditions

within each country. In high-income regions, volumes of lost and wasted food are higher in downstream phases of the food chain, but just the opposite in low-income regions where more food is lost and wasted in upstream phases. In developing countries, there are indeed significant post-harvest losses in the early stages of the supply chain, mostly because of the financial and structural limitations in harvest techniques, storage and transport infrastructures, combined with climatic conditions favourable to food spoilage. In the most affluent societies, there is a combination of consumer behaviour and lack of communication in the supply chain. For example, with consumers there can be insufficient purchase planning or exaggerated concern over “best-before dates”. As for actors in the supply chain, quality standards too restrictive, according to size or aesthetics, are responsible for a large amount of the food wasted at the end of the chain.

In order to minimize amount of food waste in upstream and downstream a food Dynamic Shelf-Life prediction (DSLPL) should be implemented.

3. SHELF LIFE

Shelf life (SL) of food is the period of time, under defined conditions of storage, manufacture or packaging, for which a food product remains safe and fit for use [5]. The shelf life is a dynamic value related to the actual quality, compositional and environmental factors.

Compositional factors are the properties of the final product including food composition; water activity (a_w); pH value; total acidity; type of acid; redox potential (Eh); available oxygen, nutrients, natural microflora, and surviving microbiological counts; natural biochemistry of the product formulation (enzymes, chemical reactants); use of preservatives in product formulation (e.g., salt); and concentration of reactant, inhibitor, and catalyst [6].

Environmental factors are those factors the final product encounters as it moves through the food chain including time–temperature profile during processing; pressure in the headspace; temperature control during storage and distribution; relative humidity (RH) during processing, storage, and distribution; exposure to light (UV and IR) during processing, storage, and distribution; environmental microbial counts during processing, storage, and distribution; atmospheric composition within packaging; subsequent heat treatment (e.g., reheating or cooking before consumption); and distributor, retailer, and consumer handling [6].

There several methods for measuring shelf-life as following [6]:

- Sensory panels - Measurement of the changes in eating quality on storage requires the use of sensory techniques. These are usually quantitative quality measures from trained panels. Sensory techniques, whilst powerful and of high direct validity, are expensive and time-consuming, especially for the repeated measures needed for shelf-life assessment. There are substantial

difficulties in ensuring high quality sensory data over long test periods, and instrumental methods can be an important back-up to sensory methods, provided that their limitations are recognised.

- Instrumental methods - Sensory measures of quality changes on storage are an essential measure of perceived quality, but are expensive and time-consuming to operate. They also suffer from high variability when carried out over long time periods, requiring regular panel calibration. If valid instrumental methods are available, they can be of great value in augmenting sensory data. Powerful instruments for measuring physical properties, such as computerised texture analysers and rheometers, and for measuring flavour properties, such as the volatile detectors misleadingly named electronic noses are of value only if the measured parameters can be correlated with relevant sensory attributes.
- Physical measurements - The most commonly used physical tests measure the changes in the texture of products. These changes may be the result of chemical reactions occurring in the product, such as those caused by interaction of ingredients or by environmental influences, such as moisture migration through the packaging. Various instruments are available for texture measurement and instrumental methods of measuring attributes such as hardness, crispness and snap are commonly used during shelf-life testing. Some attributes, such as hardness, can be measured relatively easily by measuring the force required to penetrate a particular distance into the product. However, even in simple cases, the details of the tests, such as type of probe, cross-head speed, sample position and alignment, distance of penetration need to be chosen carefully to obtain the best possible correlation with sensory measurements.
- Chemical measurements - Chemical analyses play a vital role in shelf-life testing as they can be used either to measure the end points of chemical reactions occurring in food during storage, or to confirm the results obtained by the sensory panels.
- Microbiological measurements - here are two important aspects to be considered in determining the microbiological stability of a product;
 1. microbial growth, which leads to the spoilage of a food product
 2. the growth of microbial pathogens that affect the safety of the product.

The water activity, storage temperature, time and pH can be used to predict to a large extent the micro-organisms that are likely to grow in the product. The “time to spoilage” can be determined by storing the product at the appropriate temperature and measuring the microbial load at staged intervals. The time to reach a pre-determined level of microbial count (total count and

level of individual microbes) will be considered to be the end-point. Since it is advisable to leave a safety margin in setting the shelf-life, generally 70% of the time to spoilage is taken to be the storage life.

Since fresh fruits, vegetables, meat and dairy are perishable by nature and their shelf life highly depends on conditions in which these product are kept, an IoT support DSLP system is designed in order to minimize food wastage. The aim of a designed system is to predict the time span that is left in total for transport, storage, and display in the shop and storage in domestic fridges as a function of the environmental conditions to which the product was, or may be, exposed when such information is available.

In order to do adequate prediction of shelf life one should apply different kind of models with statistical and mathematical relationships between three sets of variables: intrinsic (product related) factors; extrinsic (environmental) factors; and implicit factors, the characteristics of the microorganism itself and how it behaves in the presence of combinations of intrinsic and extrinsic factors. Such models need to be based on good experimental data mapping rates of change within given combinations of factors.

These models can be also divided in two groups: theoretical and empirical. Empirical models are in most cases used and they can be further subdivided into probabilistic and kinetic models. Probabilistic models describe the probability of a microbiological event occurring that is independent of time (e.g. the probability of growth or toxin formation ever occurring) or that is time dependent (probability at a given time of an event occurring). Kinetic models describe the rate and extent of growth or inactivation. In practice the different types of kinetic models have included growth, survival (conditions at non-lethal temperatures that will not support growth) and thermal inactivation.

The use of mathematical models can help to reduce the need for storage trials, challenge tests, product reformulations and process modifications, which are labour intensive, time consuming and expensive.

Kinetic model is one of the models which is most frequently used. Kinetic data is used to evaluate how the deterioration process in food products behaves as a function of time. It is the concept of quantification of the quality of food products based on reaction change [7], [8]. The kinetic equation may be expressed as (1):

$$r_A = -\frac{d[A]}{dt} k[A]^n \quad (1)$$

Following the chemical reactions, k is the kinetic constant, t is time, and n is order of reaction. The change in concentration A of a component of interest is monitored. The quality factors $[A]$ are usually quantifiable chemical, physical, microbiological, or sensory parameters, such as the loss of a nutrient or characteristic of flavour or formation of an off-flavour. The time to reach the value of the quality index (A_{ts}) at a

specified condition (i.e., the shelf life) t_s (2) is inversely proportional to the rate constant at these conditions.

$$t_s = \frac{f_q(A_{ts})}{k} \quad (2)$$

The forms of the quality function of the food can be zero, first-, second- or n^{th} -order reaction. For zero-order reactions, the reaction rate is independent of the concentration of a reactant. First-order reactions depend on a single reactant, and the exponent value is one. For second-order reactions, the reaction rate may be proportional to one concentration squared or to the product of two concentrations [7]. Most reactions that are responsible for shelf life loss based on a characteristic physicochemical, chemical, or microbial index include the following: zero order (e.g., frozen food overall quality, Maillard browning) and first order (e.g., vitamin loss, oxidative colour loss, and microbial growth). Several published research has been applied to the kinetic model to describe the temperature dependence. The quality parameters can be chemical properties such as peroxide value in extra virgin olive oil [9], vitamin C loss in citrus juice concentrate [10], physical property such as color loss in fresh-cut asparagus [11], and weight loss in frozen bread dough [12].

Another simple and frequently used method to find the reaction order is the integration method [13]. The process starts from (1) guess reaction order; (2) integrate; (3) linearize by linear regression; (4) plot experimental data in linearized form; and (5) if data fit a straight line, then guess is right, if not start again. The simple selection is higher coefficient of determination (R^2), and slope is reaction rate constant.

The Arrhenius model is a classical model that relates the rate of a chemical reaction to the changes in temperature. This model is widely applied in several processing and storage tests as affected by temperature [8], [12], and it is represented by:

$$K = K_0 \cdot e^{-\frac{E_a}{R \cdot T}} \quad (3)$$

$$A_{t_0} = A_0 - K \cdot t_0 \quad (4)$$

$$\ln A_{t_1} = \ln A_0 - K \cdot t_1, \quad (5)$$

where K is called a rate constant depending on temperature, product and packaging characteristics; K_0 is a pre-exponential factor, integration constant; R is the gas constant in [J/K* mol], and equal to 8.3141; T is an absolute temperature in K ($273 + ^\circ\text{C}$); E_a is an activation energy in [J/mol], the minimum energy that a system must have for reaction to start; A_0 is initial concentration of reactant; A_{t_0} , A_{t_1} concentration of reactant in t_0 , (storage time before treatment of product) t_1 (storage time after treatment of product) [day].

The (3) represents Arrhenius plot often used to analyze the effect of temperature on the rates of chemical reactions. Equations (4) and (5) are equations that describe chemical reactions of zero and first order.

Concentration of reactant can be measured, while the values K and E_a are estimated on the basis of linear

regression analysis. Product shelf-life can be determined with equations (6) and (7), which derives from previous equations:

$$t_0 = \frac{A_{t_0} - A_0}{K_0 \cdot e^{-\frac{E_a}{R \cdot T}}} \quad (6)$$

$$t_1 = \frac{\ln A_{t_1} - \ln A_0}{A_0 \cdot e^{-\frac{E_a}{R \cdot T}}} \quad (7)$$

t_0 and t_1 are determined in number of [day].

Several elements like: firmness, elasticity or viscosity, moisture content, level of decomposition degree of wilt, the presence of soluble solids, the presence of some significant acids and others, have great influence on the food product shelf-life. All these parameters can be measured using appropriate instruments.

4. IOT FOR FOOD WASTAGE MINIMISATION

Internet of Things (IoT) mainly represents physical entities that have digital counterparts and a virtual representation. In that way things themselves become context aware and they can sense, communicate, interact [14] exchange data, information and knowledge. Introduction of virtual objects as a central means for planning, orchestration and coordination has the potential to revolutionize food product supply chains.

Physical entities in IoT environment are smart objects [15] with following features:

- Have a physical embodiment and a set of associated physical features (e.g., size, shape).
- Have a minimal set of communication functionalities, such as the ability to be discovered and to accept incoming messages and reply to them.
- Have a unique identifier. Are associated to at least one name (human-readable description) and one address (machine readable number or string).
- May have instrumentation to detect physical phenomena (e.g., temperature, humidity) or to trigger actions having an effect on the physical reality (actuators).

Since smart objects generate a number of information there is a need for adequate data capturing. Data capturing devices involving data input and collection functionalities are an essential part of IoT system.

The most prominent examples are [16]:

(a) Data collection in entire “food cycle”, including agricultural production, post-harvest handling and storage, food processing, consumption. This collection can be done with sensor networks providing data about production indicators such as e.g. temperature, relative humidity, use of pesticides and fertilizers, driving lanes of farm machines, etc.

(b) Data capturing of transports including data about the position, ambience information from inside and outside the truck such enabling the evaluation of the current situation in transport logistics.

(c) Data capturing of product quality indicators such as humidity, oxygen and nitrogen content or ethylene content in the air around a product as indicator for perishing fruits and vegetables, which is relevant in storage facilities and during transport, and also with users and their perception on quality class of food product.

(d) Data capturing from a products packaging (e.g. logos) for supporting the retrieval of additional information from the cloud.

In order to realize IoT implementation, development of network and services infrastructure is necessary. Developed IoT applications will share infrastructure, and network elements, and a common service platform. Three different phases of these applications are following:

- Collection phase: procedures for sensing the physical environment, collecting real-time physical data about food product and environment and reconstructing a general perception of it. Technologies such as sensors provide sensing of physical objects parameters, while technologies such as IEEE 802.15.4 or Bluetooth are responsible for data collecting.
- Transmission phase: includes mechanisms to deliver the collected data to applications and to different external servers. Methods are therefore required for accessing the network through gateways and heterogeneous technologies (e.g., wired, wireless, satellite), for addressing, for routing, and
- Process, management and utilization phase: deals with processing and analysing information flows, forwarding data to model for DLSP based on kinetic Arrhenius model (3, 4, 5, 6, 7) since it is based on temperature changing, and providing feedbacks to control applications and also alerting users upon unwanted situations (short period of time in which food product must be used).

In IoT implementation the first step is the collection of information about the physical environment/conditions in which the food product is at the moment stored (e.g., temperature, humidity) or about objects (e.g., identity of crop, meat, etc.). Data acquisition is encompassed by using different sensing technologies attached to sensors, cameras, GPS (Global Positioning System) terminals, while data collection is generally accomplished by short range communications, which could be open source standard solutions (e.g., ZigBee, Bluetooth) as well as proprietary solutions (e.g., Z-Wave). On Fig. 4 it is represented a kind of IoT system for collecting data in production, retail, storage and transportation phase of product life cycle. In this system consumer only uses collected information in many phases of life cycle, but not with the purpose of tracking product shelf life.

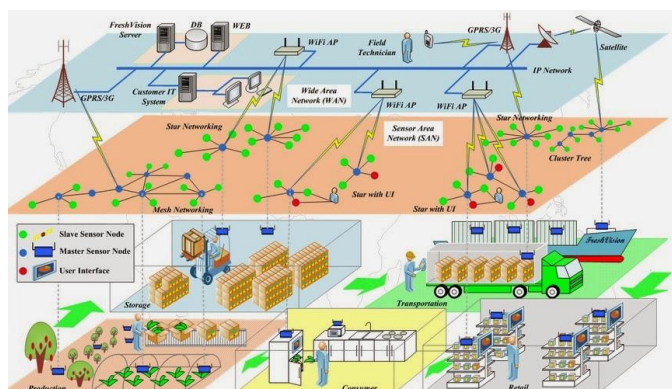


Figure 4. Internet of Things in food chain [17]

Proposed IoT food waste minimisation system enables not only real-time information about status of food product in each phase of life cycle but also prediction of its' shelf life. In this way each stakeholder in life cycle can have prediction of the rest of shelf life in the moment which is of its' interest. In that way he/she can decide whether to keep the plan strategy or change it in order to minimize food wastage. For example if in distribution phase the truck is malfunctioning and the temperature is above the predefined, distributor can have the prediction of shelf life and can decide either to keep with the plan and deliver food to retail or to return it to producer. This is also important for the end user/consumer since he/she can have prediction of the shelf life of already purchased food in house storage (fridge, pantry, cellar, etc.), but also information to plan future purchase in order not to accumulate food and to minimize food wastage.

5. CONCLUSION

Food wastage can occur during entire "food cycle", including agricultural production, post-harvest handling and storage, food processing, distribution, consumption and end-of-life. In order to minimize this event an IoT system can be implemented. In this paper an IoT system with dynamic shelf life prediction based on kinetic Arrhenius model is presented.

Only limitation which must be taken into account is that shelf life determination is valid only for the exact product composition, packaging, and processing conditions combination.

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