

Influence of Transportation Mode to the Deterioration Rate: Case Study of Food Transport by Ship

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Abstract—Food as perishable goods represents a specific and sensitive part in the supply chain theory, since changing physical or chemical characteristics considerably influence the approach to stock management. The most delicate phase of this process is transportation, where it becomes difficult to ensure the stable conditions which limit deterioration, since the value of the deterioration rate could be easily influenced by the mode of transportation. The fuzzy definition of variables allows one to take these variations into account. Furthermore, an appropriate choice of the defuzzification method permits one to adapt results to real conditions as far as possible. In this article those methods which take into account the relationship between the deterioration rate of perishable goods and transportation by ship will be applied with the aim of (a) minimizing the total cost function, defined as the sum of the ordering cost, holding cost, disposing cost and transportation costs, and (b) improving the supply chain sustainability by reducing environmental impact and waste disposal costs.

Keywords—Perishable goods, fuzzy reasoning, transport by ship, supply chain sustainability.

I. INTRODUCTION

MOST previously written articles have taken only the classical approach to inventory theory, based on the economic aspect of supply, into consideration. In the case of transportation of foodstuffs, especially in maritime transport, costs represent a relevant factor in the eventual price of food [27].

The first model used to compute the quantity to order so that the value of the total cost function is minimized was the economic order quantity (EOQ) model which was developed by Ford W. Harris in 1913. Since then, many articles have dealt with this problem. Generally, inventory models treat the problem of inventory deterioration only in a marginal sense when it comes to an economic standpoint. In the case of food inventory (and especially in the past), the economic aspect is often taken into consideration separately from the aspects of preservation and transport [13], [31].

Over the last few years it has been shown that 20% to 60% of total food production is lost in the supply chain [31]. The development of the concept of sustainability in the supply

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chain changes the prospective of researchers' analysis: environmental impact and reduction of waste products become the focus of research in this area. In the case of food inventory, the concept of quality is very important and it must be remembered that food is a physically, chemically and biologically active system and that food quality is dynamic in state and continuously changing [23].

Food quality could be quantified according to its chemical, physical, microbiological, or sensory characteristics. Factors which influence the kinetics of food deterioration are:

- Nonenzymatic browning,
- Vitamin loss,
- Microbial death or growth,
- Oxidative colour loss, and
- Texture loss.

Methods that could be used to explain these phenomena are: (a) differential methods and (b) integral methods [23]. Ghare and Schrader [9] were the first two researchers to consider continuously decaying inventory as a constant demand. An application of fuzzy sets theory to the EOQ model, where the quality of items was imperfect, was studied in detail by [5]. Yao and Su improved the defuzzification method in fuzzy total demand and maximum inventory approach [30].

The fuzzy approach in dynamic pricing models in the food supply chain is used to reduce food spoilage waste and maximize profit [31].

In this article, the concept of quality will be combined with the economic point of view in the case of the maritime transportation of food. Special attention will be paid to the analysis of the relationships between quality - deterioration rate and transportation mode and to the factors which cause deterioration and therefore influence the deterioration rate.

II. TRANSPORTATION OF FOOD BY SHIP

According to the latest UNCTAD report [25], around 80% of global merchandise trade by volume is carried out by sea and handled by ports worldwide and is of pronounced strategic economic importance. A significant amount of these quantities represent cargo with perishability properties. Unfortunately, the exact share is not available. Various types of ships are involved in food transport. Most grains are transported via large bulk carriers, liquid food in large amounts (wine, juices, comestible oils...) are transported by alimentary product tankers, while other food is mostly transported in Cargo transport units (CTU) such as containers or by tracks in case

of Ro-Ro transport.

Food carried as cargo by ship could be damaged or lost during the voyage. The reasons for damage/loss can be divided into maritime and non-maritime risks. Non-maritime risks are those which could occur anywhere while maritime risks are specific to maritime transport. Both types of risk could result in physical, chemical or biological changes in food which then becomes unusable.

Non-maritime damage is usually caused by external factors such as poor quality food delivered for transport (the foodstuffs in question are already in the initial phase of perishability), inappropriate packaging (boxes, barrels, jerricans, bottles, cans ...) or inner or outer (containers...), various failures on cargo transport units (malfunction of the refrigerating system on frigo containers, bad sensors, electronic failures, software errors...), poor instructions regarding cargo care during the voyage [1], [8].

Typical maritime damage is mainly confined to the non-seaworthiness of the ship in conditions such as the non-water tightness of the ship structure (hull, main deck, hatches...), malfunctions in the ship's power system (main engine, generators, electric and electronic systems...), an inappropriate ship Safety Management System (SMS), inappropriately qualified crew etc. There are also some external factors such as stormy weather, collision with another ship or object, grounding, fire on-board, pirate attack, sinking etc. Granted, all of those situations are rare but they should be taken into consideration as part of the total picture of risk.

Changes in the values of perishable good (food) deterioration rate are more frequent during the transport phase since this can increase the risk of damage, as mentioned above. The risk of deterioration depends on the transport mean type and its characteristics. Clearly some transport means are more risky than others, so it can be generally asserted that the required transshipment and long duration of maritime transport increases the risk of deterioration of goods. In Fig. 1 is presented the resulting deterioration rate during the transport obtained as sum of two factors: standard deterioration rate of specific goods and changes in deterioration rate related to the transport mean. The vertical bars in the graph indicate points of change during transport.

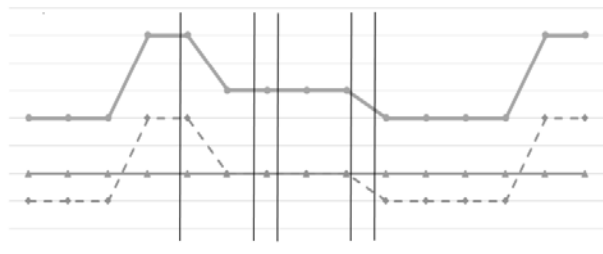


Fig. 1 Deterioration rate values during the transport phase

On the basis of Fig. 1 it is possible to define the distribution function of the deterioration rate. A fuzzy definition of the deterioration rate will be proposed in the next section of the article.

III. MODEL DEFINITION

The inventory model is developed to minimize the total customer cost function as in [3], [4], [10], [20], [26] and [28].

The inventory system involves only one item. The order lead time k , ($0 \leq k < T$), is that "out of stock" is not allowed. The deterioration rate θ , ($0 < \theta < 1$), is approximately constant and there is no replacement or repair of deteriorated units during the period under consideration.

Assumptions, notation and definitions are explained in the following:

TABLE I
 NOTATION

Symbol	Definition
P :	price of the product, €/unit
K :	ordering cost, €/per order
h :	holding cost, €/unit/per unit time
F :	disposing cost, €/unit
C_i :	transportation cost, €/unit/per path length in stage i
x_i :	path length in stage i
Q :	the order quantity for each ordering cycle
$I(t)$:	inventory level at time t
D :	unit time unknown crisp demand
k :	order lead time
T :	length of each ordering cycle

A differential approach is used to explain the replenishment policy of the food as a perishable item [17], [29]. The inventory function decrease is explained by the differential equation:

$$\frac{dI(t)}{dt} = -\theta I(t) - D, \quad 0 \leq t \leq T, \quad (1)$$

with a boundary condition of $I(T) = I_0$. The solution of (1) is

$$I(t) = I_0 + \frac{D}{\theta} (e^{\theta(T-t)} - 1) \quad (2)$$

The authors suppose that the order lead time in the case of the acquisition does not influence the order quantity, but only the time when the order is complete. It is not the concern of the customer that goods decay upon delivery. Hence, the order quantity by cycle is given by

$$Q(T - k) = I(0) = I_0 + \frac{D}{\theta} (e^{\theta T} - 1) \quad (3)$$

The purchasing cost per cycle is

$$PC = P \cdot Q(T - k) = PI_0 + P \frac{D}{\theta} (e^{\theta T} - 1) \quad (4)$$

Inventory holding cost takes into account all the particularities (specified in the second section) of holding perishable goods during the transport by ship. The inventory holding cost per cycle is

$$HC = h \int_0^T I(t) dt = h \int_0^T \left[I_0 + \frac{D}{\theta} (e^{\theta(T-t)} - 1) \right] dt = hTI_0 + \frac{hD}{\theta^2} (e^{\theta T} - \theta T - 1) \quad (5)$$

The disposing holding cost per cycle is

$$DC = F(Q(T - k) - TD) = FI_0 + F \frac{D}{\theta} (e^{\theta T} - \theta T - 1) \quad (6)$$

The transportation phase is the part of the whole ordering cycle where the values of the deterioration rate may vary since the order lead time, the number of stages in the transportation process and the transportation path length have the potential to influence food quality. The transportation cost per cycle is

$$TC = \sum_{i=1}^n TC_i = \sum_{i=1}^n C_i Q(T - k)x_i = \sum_{i=1}^n C_i x_i (I_0 + \frac{D}{\theta} (e^{\theta T} - 1)) \quad (7)$$

Therefore, the average total cost (logistic cost), per unit time, per cycle is

$$TC_{tot} = \frac{1}{T}(K + PC + HC + DC + TC) = \frac{1}{T} \left\{ K + PI_0 + P \frac{D}{\theta} (e^{\theta T} - 1) + hTI_0 + \frac{hD}{\theta^2} (e^{\theta T} - \theta T - 1) + FI_0 + F \frac{D}{\theta} (e^{\theta T} - \theta T - 1) + \sum_{i=1}^n C_i x_i (I_0 + \frac{D}{\theta} (e^{\theta T} - 1)) \right\} \quad (8)$$

It is reasonable to assume that $\frac{1}{\theta} \gg T > k$ and to approximate $e^{\theta T} \cong 1 + \theta T + \frac{1}{2} \theta^2 T^2$, so average total cost is

$$TC_{tot} = \frac{1}{T}(K + PC + HC + DC + TC) = \frac{1}{T} \left\{ K + PI_0 + PD \left(T + \frac{\theta T^2}{2} \right) + hTI_0 + \frac{hDT^2}{2} + FI_0 + \frac{FD\theta T^2}{2} + \sum_{i=1}^n C_i x_i (I_0 + D \left(T + \frac{\theta T^2}{2} \right)) \right\} \quad (9)$$

The objective of the model is to determine the optimal cycle length T in order to minimize the average total cost per unit time. The optimal solution T_{opt} must satisfy the following equation:

$$\frac{dTC_{tot}(T)}{dT} = 0 \quad (10)$$

The solution of (10) is

$$T_{opt} = \sqrt{\frac{2K + 2I_0(P + F + \sum_{i=1}^n C_i x_i)}{hD + D\theta(P + F + \sum_{i=1}^n C_i x_i)}} \quad (11)$$

Since deterioration rate θ is not constant during the ordering cycle, it is reasonable to extend this value to fuzzy a variable: using Zadeh's extension principle of a real function [21], [11].

Firstly, it is reasonable to consider the optimal cycle length as a real function of deterioration rate θ , $T_{opt} = T_{opt}(\theta)$. Since deterioration rate is not a crisp value it could be explained as a triangular fuzzy number. Triangular fuzzy numbers are chosen because they are invariant to union, scale, shift and sign operation [2], [18].

Fuzzy deterioration rate $\tilde{\theta} = (\theta_1, \theta_2, \theta_3)$ is a triangular fuzzy number with a membership function:

$$\mu_{\tilde{\theta}}(x) = \begin{cases} \frac{x - \theta_1}{\theta_2 - \theta_1} & \theta_1 < x \leq \theta_2 \\ \frac{\theta_3 - x}{\theta_3 - \theta_2} & \theta_2 < x \leq \theta_3 \\ 0 & \text{otherwise} \end{cases} \quad (12)$$

The membership function of the fuzzy extension of the optimal cycle length function $\tilde{T}_{opt}(\tilde{\theta})$ is defined as:

$$\mu_{\tilde{T}_{opt}}(\tau) = \sup_{\tau = T_{opt}(\theta)} \{ \mu_{\tilde{\theta}}(\theta) \} \quad (13)$$

This definition (13) highlights the fact that the deterioration rate is not constant. The fuzzy definition of variables allows one to take into account these variations. In the next section the authors will explain how the appropriate choice of the defuzzification method permits one to adapt the results as far as possible to real supply chain cycle conditions.

IV. DEFUZZIFICATION METHODS REVIEW AND CLASSIFICATION

Defuzzification is not a universal operator that could be used in the same way for each fuzzy value; it is important to adapt the method to the properties of the function (shape and asymmetry) that will be put in evidence in the next use [12], [16]. The choice of an appropriate method of defuzzification allows one to determine the solution that reflects the particularities of the perishable good/food supply chain as much as possible.

The most commonly used defuzzification method is Centre of Gravity or (COG) Centre of Area (COA) acting as the expected value on the assumption that the membership function is like a probability distribution and so it is endowed with all the properties of the expected value.

In reasoning systems, defuzzification methods that compute the first, middle, average, random or last value in the core of the fuzzy set are generally used. These methods could be applied also to discrete sets.

The most commonly used methods in this category are:

- First of Maxima (FOM),
- Last of Maximum (LOM),
- Mean of Maxima (MeOM),
- Middle of Maximum (MOM),
- Random Choice of Maximum (RCOM), and
- Basic Defuzzification Distributions (BADD) is an extension of COG and MOM.

In the case of continuous fuzzy sets or functions of controllers methods the next defuzzification methods are used:

- Adaptive Integration (AI) upgrades the COG defuzzification method so that all non-relevant regions of the output demine are skipped. The calculation steps are reduced to minimum [6], [7].
- Extended Center of Area (ECO) is also a COG upgrade [19], [22],
- Fuzzy Clustering Defuzzification (FCD) [12]
- Generalized Level Set Defuzzification (GLSD),
- Signed distance method (SDM) is often used in the case of logistic-inventory problems, since the expected value of total cost function is equal to the signed distance of the fuzzy total cost function to the origin. With respect to the "centroid" methods, the computed crisp values of the functions have greater membership grades [15], [29], [5], [6], [32].

There are also other defuzzification methods but they are not applied to inventory theory in the literature. These methods are linear or weighted adjustments of the explained

methods.

V. USING DIFFERENT DEFUZZIFICATION METHODS ON FUZZY OPTIMAL CYCLE LENGTH AND A COMPARISON OF CRISP RESULTS

In this paragraph some variants of the asymmetric triangular membership function for deterioration rate will be proposed that will take into account the storage conditions of goods. These conditions often change during transport stages, as explained in the second section of the article, since in the case of food transportation (perishable goods) from the Far East to Europe or vice versa, there could be a change in the deterioration rate, so the ordering cycle length could also change. Some of these cases will be presented below:

A. Symmetric Triangular Membership Function of Deterioration Rate

This is the case when deterioration rate is a normal Gaussian distribution with a peaked distribution function. This determines the amplitude of the triangle membership functions [24]. In practice, this means that the conditions of food storage during transport are stable, so the deterioration rate in that period is almost constant or undergoes only minor changes. Fuzzy triangular deterioration rate is defined as a symmetric fuzzy number $\tilde{\theta} = (\theta - t, \theta, \theta + t)$ with a base amplitude $2t$.

In this case, since the total cost function is monotonic, on the basis of (13) the membership function $\tilde{T}_{tot}(\tilde{\theta})$ is also symmetric triangular.

All the defuzzification methods give the same value equal to the top of the triangle. In this case, food quality is constant during transportation since maritime and non-maritime causes of freight damage are limited and supervised.

B. Asymmetric Triangular Membership Function of Deterioration Rate

In this case deterioration rate is a normal Gaussian distribution with an asymmetric distribution function. Fuzzy triangular deterioration rate is defined as an asymmetric fuzzy number $\tilde{\theta} = (\theta - t_1, \theta, \theta + t_2)$ with a base amplitude $t_1 + t_2$. On the basis of (13) $\tilde{T}_{opt}(\tilde{\theta}) = (T_{opt}(\theta) - \tau_1, T_{opt}(\theta), T_{opt}(\theta) + \tau_2)$ is an asymmetric triangular fuzzy number.

In Table II crisp values of the optimal cycle length obtained with different defuzzification methods are presented.

TABLE II
 CRISP VALUES COMPUTATION

Defuzzification Method	Crisp Value
CoG	$T_{opt}(\theta) + \frac{1}{3}(\tau_2 - \tau_1)$
FOM	$T_{opt}(\theta)$
LOM	$T_{opt}(\theta)$
MeOM	$T_{opt}(\theta)$
MOM	$T_{opt}(\theta)$
RCOM	$T_{opt}(\theta)$
SDM	$T_{opt}(\theta) + \frac{1}{4}(\tau_2 - \tau_1)$

In statistics the skewness coefficient measures the asymmetry of the data distribution with respect to its mean. The skewness value can be positive or negative.

In the case of a negative value the left tail is longer and the mass of the distribution is concentrated to the right of the distribution. In this case it is left-tailed and the corresponding triangular fuzzy number is that of $\tau_1 > \tau_2$.

Point $T_{opt}(\theta) + \frac{1}{2}(\tau_2 - \tau_1)$ is the middle of the fuzzy triangle number base. Thus $\tau_2 - \tau_1 < 0$ and $T_{opt}(\theta) + \frac{1}{2}(\tau_2 - \tau_1) < T_{opt}(\theta) + \frac{1}{3}(\tau_2 - \tau_1) < T_{opt}(\theta) + \frac{1}{4}(\tau_2 - \tau_1) < T_{opt}(\theta)$ and the membership grades are also in that order.

With regards to membership grade, it is reasonable to use the SDM defuzzification method. The obtained results are very close to [14] and [16].

Methods such as FOM, LOM, MeOM, MOM and RCOM give a membership grade of 1 but do not take into account all the data and can therefore easily lead one to arrive at the wrong results which could negatively influence the ordering cycle period and the storage procedure used during maritime transport.

Therefore, the selection of a proper defuzzification method plays the same role as the detection of an appropriate Measure of Central Tendency for the data set.

In the case of a positive skew, the right tail of the distribution is longer and the mass of the data is concentrated to the left of the figure. The distribution is said to be right-tailed and the corresponding triangular fuzzy number is that of $\tau_1 < \tau_2$. In this case it is possible to reach the same conclusions as in case of negative skewness.

Practical asymmetry of the perishability data distribution means that during transport, the conditions of food storage change so much that the value of the deterioration rate changes significantly and the change persists during the whole transport phase. This requires greater care to prevent the rapid deterioration of goods. This situation could be caused by poor quality goods (food) or by unexpected malfunctions in the ship's power system.

VI. CONCLUSION

The proposed model uses fuzzy triangular numbers to adapt the deterioration rate, as much as possible, to real values detected during the maritime transport phase. Those values, as explained in the article, are not constant since they are related to weather conditions, ship conditions and the professionalism of the crew.

Defuzzification method is an important model factor that could increase membership grade and minimize the total cost function taking into account the shape of the deterioration rate distribution function and therefore the condition of the merchandise.

The proposed model could be a starting point in the creation of a more efficient ordering model and could see the formation of a transport policy which takes into account the physical and biological particularities of perishable goods (food). This method is focused at the same time on the economic aspect with the goal of reducing total costs and to the environmental aspect since evidence has shown the relation between the conditions of maritime transport and the condition of goods. The result would be a positive influence on the reduction of

merchandise deterioration and waste production.

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