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Revision 1



# **Report on first simulation model that predicts the feasibility of communicative packaging concepts**

Deliverable 6.14

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Report 579

## Colophon

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## Abstract

One of the objectives of this part of the SustainPack project (WP 6.3) is to facilitate the implementation process of communicative packaging in the chain of production, storage, distribution and use of packed products. New packaging concepts are more easily implemented if the benefits can be demonstrated. The objective of this study is to investigate the benefits of a quality indicator integrated in packaging.

To do so a case was chosen to monitor and draw conclusions from. This case is the transport of vine tomatoes from the Netherlands to the US by boat. The communicative packaging is a transport box equipped with a sensor that is able to register time, temperature and relative humidity.

In a dedicated simulation program, called Aladin, the distribution chain of vine tomatoes was simulated; using product quality models to predict shrinkage in four different logistical concepts. Shrinkage is defined as the amount of product in a chain, which drops below a certain quality level, causing the product to be lost since it is no longer acceptable for the end user.

Product quality of vine tomatoes mainly depends on four factors: time, temperature, relative humidity and biological variation. The different scenario's predicting shrinkage are divided in two categories:

- OSLO control to reduce shrinkage in the chain. This means the optimal quality, predicted by measuring environmental conditions, is delivered as last to the next step in the supply chain. The effects of different variations in temperature and RH are investigated.
- Anticipating shrinkage and sending products to a discount channel to decrease shrinkage in further parts of the chain (supermarkets).

In both categories the quality in the chain is determined measuring different factors: *i)* only time, *ii)* temperature and time or *iii)* time, temperature and RH.

From the simulation results it can be concluded that under certain circumstances, the use of transport boxes equipped with a temperature sensor can result in significant reduction of shrinkage of the vine tomatoes. Shrinkage reduction can be 4% and a temperature sensor may cost €0.31. Another conclusion from this study is that the impact of relative humidity on the tomato quality is not large enough to justify the implementation of a relative humidity sensor. A third conclusion is that there can be economical benefits when products of inferior but still acceptable quality are sold to a discount channel for 75% of the supermarket price.

## List of abbreviations

Aladin: A(gro) L(ogistic) A(nalysis and) D(esign) IN(strument). A simulation tool that is used to model supply chains, including the effect on product quality.

FIFO: First In First Out. The first product arriving at a part of the chain is also delivered first.  
QTT with time as quality factor

OSLO: Optimal Storage Last Out. Optimal quality, predicted by measuring environmental conditions, is delivered last. QTT with T or RH and time as quality factors

FEFO: First Expired First Out. Optimal quality is delivered last. Quality is known because time, temperature, relative humidity and biological variation are known parameters.

QTT: Quality based Tracking and Tracing. Tracking and tracing with quality as a determining factor.

TT: Tracking and tracing

RH: Relative humidity

T: Temperature

t: time

DC: Distribution Centre

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# 1 Introduction

## 1.1 The Communicative Packaging Concept

One of the objectives of this part of the SustainPack project is to facilitate the implementation process of communicative packaging in the chain of production, storage, distribution and use of packed products. In this report communicative packaging is limited to a package that communicates information relevant for the distribution chain being identification and information related to the quality of the packed product.

New packaging concepts are more easily implemented if the benefits can be demonstrated.

Activities are undertaken to answer two questions:

- How must the communicative technology perform to be applicable?
- What will be the benefits of communicative technology integrated in packaging?

The first question is answered in another report (Deliverable 6.13 [Kre05-2]). This report will answer the second question for one specific Product-Market Combination (PMC), displayed in a case study.

In a pre-study six scenarios have been defined, one of them being The Reliable Box (Deliverable 6.12 [Kre05]). This scenario was chosen to elaborate because it represents a large volume of cardboard packaging.

Distinctive features of The Reliable Box scenario are:

- Large quantities of perishable products (mainly fruit, vegetables and flowers) transported overseas in disposable transport packages.
- Cardboard transport package
- Bulk products
- Quality indicator and identification
- Quality-based tracking and tracing

In Deliverable 6.12, the scenario has been concretised with a Product-Market Combination. An extensive analysis and selection procedure has been followed to find a PMC that, for the scenario Reliable Box, has a large potency of success for communicative packaging. The chosen PMC that is the subject of this report is:

*A communicative transport package for vine tomatoes produced in Europe and distributed in overseas (USA).  
The sensor will be able to register time, temperature and relative humidity.*

The benefits of communicative packaging are expected to be present when Quality-based tracking and tracing can be applied. The concept of Quality-based Tracking and Tracing (QTT) is explained in the next section.

## 1.2 Quality-based Tracking and Tracing (QTT)

A tracking & tracing system makes it possible for the partners in the chain to follow (track) produce and events throughout the chain and to trace the product history. Supply chain partners can find out where the products are at a particular moment and where they have been in the chain. For this system, it is necessary to label the products with an identification code and register the identification as the products move through the chain.

QTT is actually the same as conventional T&T with the addition of an extra aspect: the product quality is measured (with a quality indicator) and also registered so that it is possible to follow the product quality throughout the chain (and of course also trace it back when necessary).

QTT makes communicative packaging useful because information on quality offers several benefits, including important economical benefits. Large amounts of money can be saved when product losses can be significantly decreased through its application.

To reduce product losses (shrinkage), it is essential to know the quality (or even better the remaining shelf life) of products while distributed through the chain, so there something can be done about it. Data from the sensor can be used to predict the quality when the quality decay process of the perishable product is known.

Communicative packaging and QTT enable distribution of products according to an OSLO system (Optimum in Storage (conditions) Last Out) in contrary to the currently used FIFO-concept (First In First Out) which does act upon remaining shelf life only with the factor time. OSLO is a specific part of the FEFO-concept (First Expired First Out), which is based on the actual expiration date.

Other benefits of QTT are improved assurance of food safety and improved customer service through better maturity, colour and taste of food products.

All aspects of QTT are illustrated in an article by Scheer [Sche05].

## 1.3 The product; vine tomatoes

After harvesting, vine tomatoes start to decline in quality [Nya98; Isl96]. The most important quality parameters of tomatoes are:

- Green stem: the stem should look green and vital as this is an indication for the consumer that the tomatoes are fresh. Dried and yellow/brown stems are not acceptable. The presence or absence of moulds on the stem is also important. The presence of moulds is not acceptable.
- Firmness: this parameter concerns the flesh firmness. Tomato flesh should not be too soft.
- Decay: presence or absence of moulds on the tomato flesh/surface. The presence of moulds is not acceptable.
- Drying out (weight loss): this parameter is not important for consumers but it has an important economical impact as trade between chain participants is based on weight. Since the water content of the air is lower than that of the tomatoes, this results in loss of moisture from the tomato and therefore weight loss.

Green stem and decay are measured visually. However optic techniques and computer image analysis can also be used. Product drying out can only be measured with a balance. Firmness can

both sensorially or instrumentally be measured [Aue99]. At the moment, in practice, instrumental techniques are not yet used to assess the product quality.

#### **1.4 Product quality models**

Product quality decay depends on several aspects, of which the initial product quality, time, temperature and relative humidity are the most important. With initial quality is meant the quality on the moment of harvest, which is a combination of intrinsic quality (genetic) and the environmental factors during growth.

Product quality models are mathematical descriptions of the relationship between these aspects (usually temperature and RH) and the product quality. Based on the temperature and/or RH history which the product has been submitted to throughout the chain, the product quality can be predicted at any moment by applying these quality decay models. In this case, the product quality is not actually measured but calculated based on the monitored ambient conditions, e.g. temperature and RH.

The predicted product quality status can then easily be communicated to the other chain partners. These know the quality of the product they will receive and adjust their logistical decisions based on this information. This logistical principle is denominated Quality-based Tracking and Tracing (see also chapter 3).

In previous research [Boo04] a product quality model for vine tomatoes has been developed as a function of the temperature and RH. It was found that of all quality aspects described in 1.3, the green parts is the factor which restricts the keeping time the most. So this will be the factor which is monitored in the simulations.

The quality of the green parts is classified in a scale from 0 to 5, in which level five means excellent and zero means total decay. In a supermarket the vine tomatoes are usually thrown away at quality level one.

In the figure 1 the quality decay of vine tomatoes at 18°C and 75%RH is shown as an example. For a certain temperature an RH the deviation from the mean values is a result of biological variation.

In the theory section of this report a more thorough view of these models will be given.

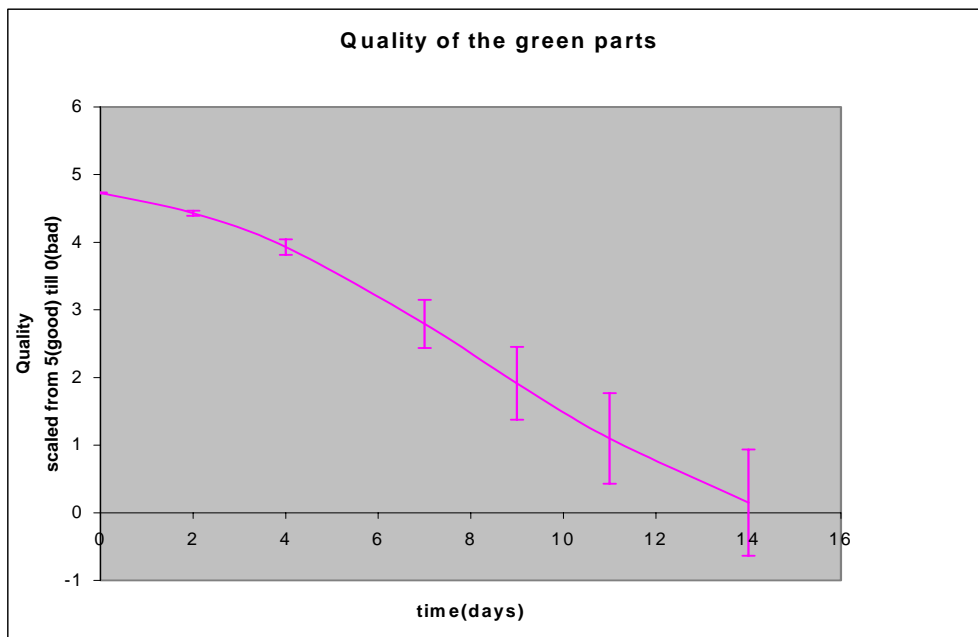


Figure 1 Quality of the green parts of vine tomatoes in time. Vine tomatoes have been stored in a climate room at 18 °C and 75% RH. Quality was measured visually. The deviation from mean values is a result of biological variation.

### 1.5 The chain; export from Europe to USA

In the figure 2 below the tomato chain is presented in a schematic way. From the grower the product leaves to the port in Rotterdam, where customs and loading will take about a day. The transport by container to New York will take 7 days at least. The following customs procedure takes on average 48 hrs, after which the importer can open the container. This part of the chain is all supply driven (push). Every week a ship leaves the port of Rotterdam, independent of the demand in the US.

At the importer the orders from the next part of the chain arrive (the DC of the supermarket chain). This is where the demand driven part of the chain starts. From the DC the product is further transported to the supermarkets.

The main control point in the chain is the DC. In there the products are sorted in a certain way (FIFO or OSLO) so that the products are delivered from this point in an order that is likely to be the most shrinkage efficient.[Kre05]

The discount channel is a part of the chain that is supply driven again. Product below a certain quality limit is sold for a lower price to this discount channel.

The DC and the supermarkets are assumed to be part of the same organisation. This organisation benefits from reducing shrinkage in the supermarkets by using OSLO in the DC.

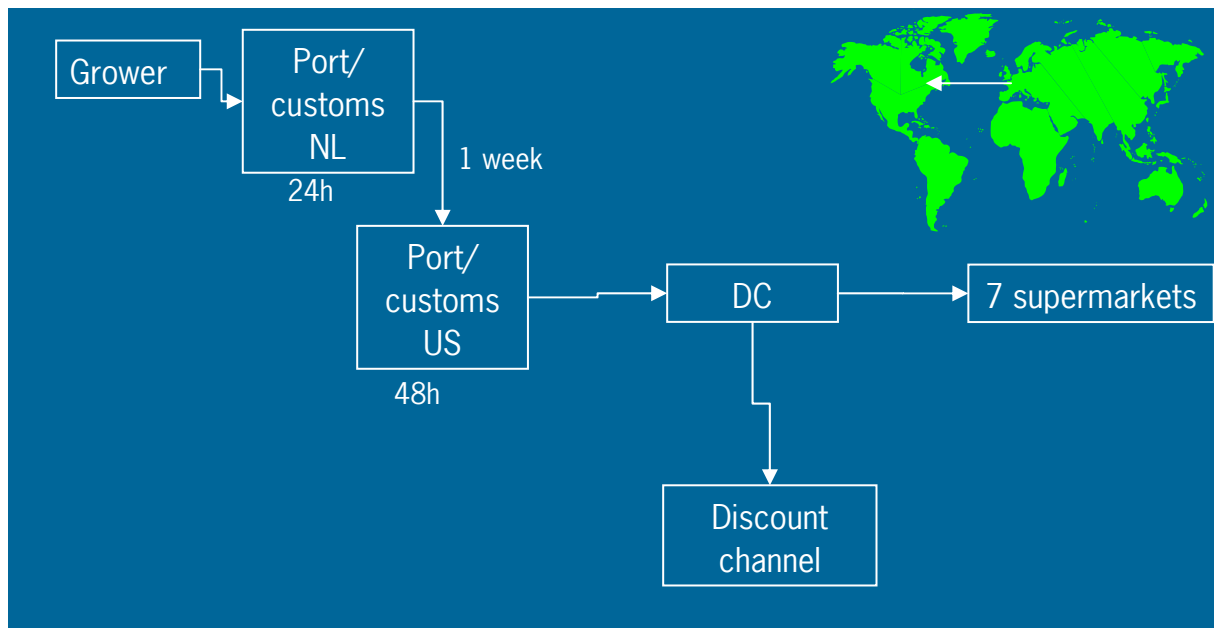


Figure 2 Supply chain of vine tomatoes in container from the Netherlands to the US by boat.



## 2 Problem formulation

The main research questions that will be answered in this report are:

- Does the use of temperature and/or relative humidity sensors on transport boxes of vine tomatoes in the distribution chain from Dutch growers to American retail stores lead to a reduction in shrinkage?

The use of sensors will lead to more information about the quality of the product. The hypothesis is that based on this information, the product flow through the chain can be improved and shrinkage can be reduced.

- Which sensors should be used: temperature sensors or both temperature and RH sensors? Temperature is thought to have the greatest influence on the quality of the vine tomatoes, but the use of additional RH sensors might lead to more shrinkage reduction.
- What would the sensors have to cost to make QTT, especially the OSLO concept profitable?

After the economical value of shrinkage reduction resulting from using sensors in the supply chain is known, the calculation of the maximum cost of a sensor can be made. At which cost level should a sensor be to make it profitable to use it in the supply chain for vine tomatoes.



## 3 Backgrounds

### 3.1 Product quality models

Based on intensive experimentation in previous research projects at A&F, a series of product quality models were developed. [Boo04] A product quality model describes the quality development of a fresh product, dependent on different environment factors. In this paragraph first a closer look will be taken on the quality of vine tomatoes. Next the construction of the product quality model will be explained in more depth.

#### 3.1.1 *Quality aspects of vine tomatoes*

In the quality of vine tomatoes there are different aspects to be taken into account. After harvest, the tomato quality will decrease inevitably. Firmness will decrease, the colour will change from green to red, the green parts will become more and more dry and also rotting and detachment from the vine will take place.

From these quality aspects the green parts are the most sensitive to environmental conditions. Therefore only this aspect of the quality of the vine tomatoes was taken into account in this research. When from now in this report is referred to quality of vine tomatoes, quality of the green parts is meant.

The quality of the green parts is scaled in a scale from level 0 to level 5. 0 Means the green parts are totally dried. 5 Means they are optimal.

#### 3.1.2 *Product quality model of vine tomatoes*

For many perishable food products the main factors on which the quality depends are temperature, relative humidity, biological variation and time. This can be illustrated by the following figure 3. The relative impact of each factor on the quality is specific for every product.

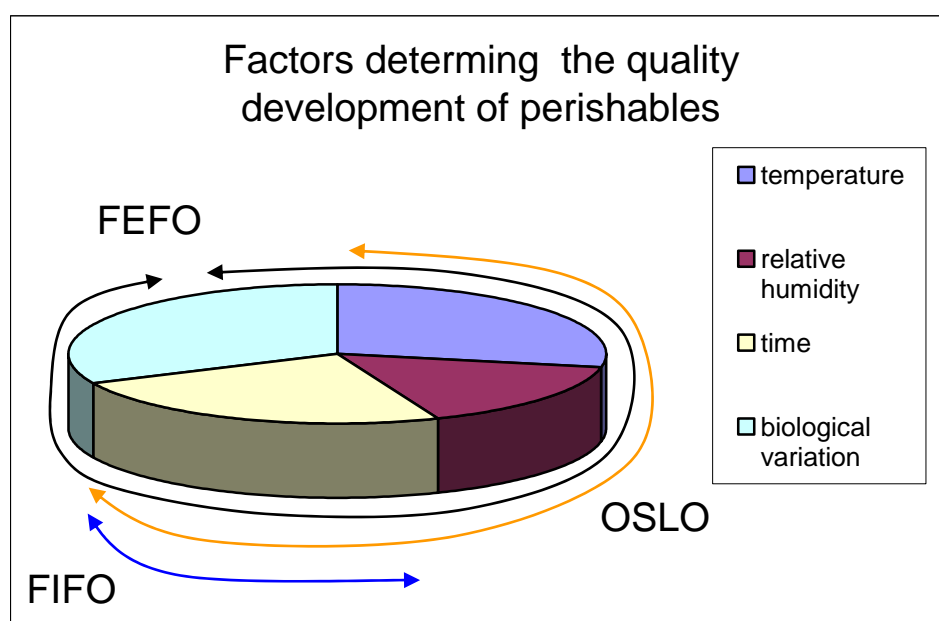


Figure 3 Factors determining quality development of perishables. The relative impact of each factor on the quality is specific for every product.

In the case of vine tomatoes a relatively large part of quality development is determined by environmental conditions. Biological variation is relatively small, compared to other products like e.g. strawberries. This was checked in various experiments.[Boo04]

The large influence of environmental conditions on vine tomato quality makes this product a suitable candidate to apply OSLO control to. This is the main reason that vine tomatoes was chosen as case study.

The product quality model estimates product quality. When for example the temperature in a supply chain is measured, the quality of the vine tomatoes is calculated using these measurements. For biological variation and relative humidity assumptions are made, since in this example these parameters are unknown.

The more factors are known, the more accurate a prediction of the quality at a certain moment will be.

### 3.1.3 *Temperature and RH in the models*

Several experiments were done to come to a product quality model for vine tomatoes[Boo04].

Vine tomatoes were stored in climate rooms under specific well controlled temperature and RH conditions. Every two days the tomatoes were visually inspected and their quality was classified in a 0-5 scale. The experiments were carried out in the following ranges:

- Temperature: 0-20 °C
- Vapour pressure deficit: 0-600Pa (equal to RH: 50-100%)

This means that the model is valid in the range in which the measurements were done.

In paragraph 3.1.2 the different factors determining quality were discussed. These factors will be discussed in more depth in the next part:

When a tomato is harvested, it starts to decay. Different processes in the tomato cause these effects. Temperature and RH are two factors which can slow down or speed up these processes. This means the impact of the factors temperature and RH depends on time (duration of exposure to the factors).

For example, optimal storage conditions for tomatoes are 8°C and 85% RH. Storage of a product at 8°C for a day has about the same impact on quality as storage at 20°C for a few hours.

This results in Tsum (T integrated over time) and RHsum (RH integrated over time) being used in the model.

The model then looks as follows:

Quality=f(Tsum,RHsum) or

Quality = f(Tsum) when only temperature is measured.

### 3.2 Quality based tracking and tracing (QTT) using OSLO control

The Quality based tracking and tracing concept is based on one main fact: in every batch of products there are differences in quality. This can be caused by biological variation, by differences in temperature and relative humidity and by differences in time after harvesting and combinations of these factors.

#### 3.2.1 OSLO

When these differences in quality are made clear, chain control can be based on quality. In the OSLO-principle. (Optimal in Storage (conditions) Last Out) differences in quality caused by differences in storage temperature and RH are considered. This means an addition to the FIFO-principle (First In First Out), which takes only the factor time into account. In the OSLO-control the quality of each box is estimated with the product quality model. In the tomato case the estimated quality of all transport units is compared and the products with the lowest estimated quality are delivered first to the next party in the supply chain.

#### 3.2.2 Predicting quality in next link in supply chain

Another way of making use of the estimated quality of products in a chain is predicting the development the quality will have further down the supply chain.

In the case study considered in this report, the DC and the supermarkets are part of one organisation. The hypothesis is that this organisation can benefit from selling products with low quality to a discount channel instead of shipping them to the supermarkets. It may decrease the amount of tomatoes that have to be thrown away, increase the quality on the shelf of the supermarkets and result in economical benefits as well.

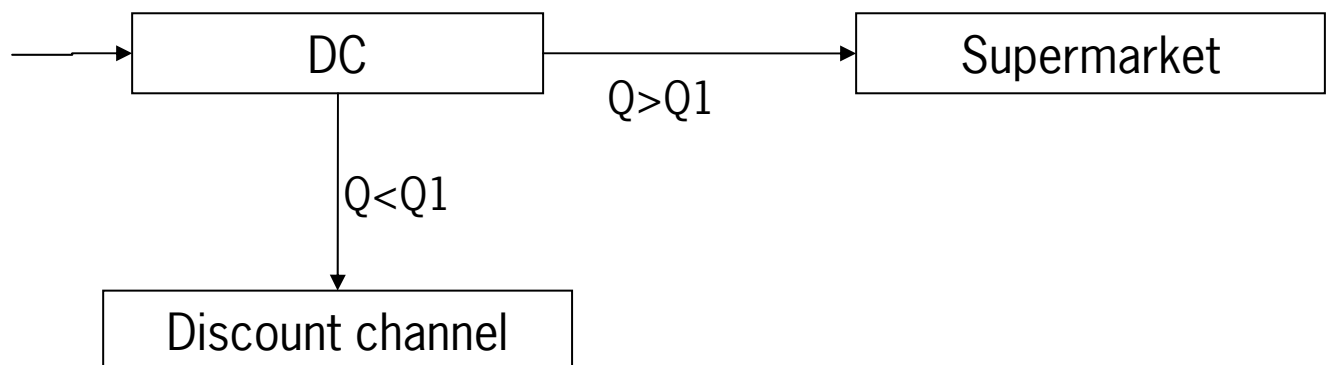


Figure 4 Factor Q1 explained. Vine tomatoes which, at the DC, have a quality below Q1 are sold to the discount channel (for a lower price), because the model predicts that these products will be of unacceptable quality by the time they reach the supermarkets.

With the product quality model, the quality the product will have in the supermarkets at the moment of sale can be predicted at the moment the product is leaving the DC. Q1 is defined as the quality of vine tomatoes in the DC that will result in quality 1 in the supermarkets at sale, which is the minimum acceptance quality.

The expectation is that Q1 reduces shrinkage in the supermarkets. Products, which are predicted to lead to shrinkage are not sent to the supermarkets, but sold to a discount channel party.

Selling products with quality below Q1 for a lower price to the discount channel will probably be economically beneficial, instead of trucking them to the supermarkets only to see there that they are below the acceptance limit.

The product sold to the discount channel will not bring in the full price that it would have in the supermarket, but considering the fact that it would probably not be sold in the supermarket, sending it to the discount channel can lead to cost reduction.

If the value of Q1 is low the economical benefit will be minimal. On the other hand, if Q1 is set too high, products that could have been sold in the supermarkets for the full price are sent to the discount channel. The optimum value of Q1 is found by running the simulation program several times for different Q1 values and determine the Q1 for which the economical benefits are highest.

### 3.2.3 *Conditions in the supply chain*

For vine tomatoes the optimal storage conditions are 8°C and 85% RH. In the supply chain the conditions are kept on this level as far as possible. After harvest, the product is transported in conditioned container to the port. Till it reaches the importer, it stays in the container at 8°C and 85%RH. Also in the DC the storage conditions are 8°C and 85%RH. Only in the supermarket conditions are worse. Generally product is stored there at 18°C and 75%RH. Throughout the supply chain deviations from the optimal storage conditions can occur. In the tomato chain mainly T and RH variations in time and place are considered. Temperature and RH sensors present on all boxes can measure the actual environmental conditions. These data are the basic input for OSLO control.

## 3.3 Simulations

To test the feasibility of communicative packaging concepts, logistic simulation was used. In the section below simulation in general and the specific simulation used in this research are explained.

Simulation of a chain can:

- Predict the results of a logistic chain, formulated in cost-performance indicators
- Test alternatives
- Perform what-if analyses

Simulation of chains is mainly used in situations where an analytical approach would be impossible. This is the case in systems with uncertainties (stochastic processes), dynamic systems or very complex problems.

Furthermore simulation is used in cases where practical experiments would be impossible because the system doesn't yet exist, the risks would be too high or the costs would be too high.

In the tomato chain, which is the subject of this research, the following characteristics are present:

- The products are dynamic (quality development in time)
- The supply chain is dynamic (changing in time)
- Processes are stochastic (demand and supply have a statistic distribution)
- Pilots are expensive

Therefore, to study fresh produce in the distribution chain a specific tool is used, namely: the A(gro) L(ogistic) A(nalysis and) D(esign) IN(strument), abbreviated Aladin.

Aladin is a logistic instrument in which fresh logistics questions can be answered by doing experiments in a simulated environment.

In Aladin chain conditions, chain control and product quality models are combined in an integrated tool.

Aladin was developed by A&F, using the Enterprise Dynamic environment. In many projects Aladin was used to predict the behaviour of a chain in FEFO chain control.

In the SustainPack project the link with sensorial measurements on transport box level was made, introducing the OSLO concept.



## 4 Simulations

In the Aladin simulation tool, as explained above, the different factors and parameters controlling the chain are entered as input. In the paragraphs below the different experiments/simulations carried out will be explained in more detail.

To find out if temperature and/or RH measurements in the tomato chain are profitable the tomato chain was exactly simulated.

### 4.1 The chain modelled: Characteristics and assumptions

To gain better insight in the modelled chain exactly, in table 1 the characteristics of the chain are presented.

Part of the chain	T(°C)	RH(%)	Time	Amount of product	Additional Information
Grower	n/a	n/a	n/a	Produces 1 container per week	Loaded into container at grower
Customs NL	8	85	24 hrs	1 container per week, push	Product in container
Shipment	8	85	7 days	1 container per week, push	Product in container
Customs US	8	85	2 days	1 container per week, push	Product in container
DC	8	85	Stocked until orders arrive	Inflow: 1 container per week. Orders from supermarkets control outflow	Product unloaded from container and stored in DC.
Truck to Supermarkets/D discount channel	8	85	Few hrs	Dependent on orders	
Supermarket(s)	18	75	Dependent on demand	Demand driven(pull): 7 supermarkets ask for average 20 pallets per week	Each supermarket orders when stock<1 pallet. Order quantity is 2 pallets
Discount channel	n/a	n/a	n/a	Dependent on what is left (supply driven from importer)	In case of quality prediction in the chain, the product with quality<Q1 is send from Importer to discount channel.

Table 1 Characteristics of the tomato chain based on interviews with agro-distribution experts who know the production and distribution chain of vine tomatoes well.

Furthermore the product quality model (a part of it is shown in figure 1) is entered as input in the simulation. In the Aladin simulation an assumption of the biological variation is made, based on experiments, in order to get a good idea of how control on only a part of the quality factors affects shrinkage in the chain.

In each part of the modelled chain a spatial distribution in Temperature and RH is assumed (a normal distribution with standard deviation sigma). Time variation of the factors is translated to a spatial distribution.

## **4.2 Experiments simulated**

The DC (distribution centre of the supermarkets) is the part of the chain where quality based logistic control takes place. By applying FIFO, OSLO with T, or OSLO with T and RH control, the order in which the products leave the DC is controlled based on the different quality determining factors (t, T, RH).

### *4.2.1 Shrinkage in the chain at different variations in temperature and RH*

To quantify the influence of the variation in temperature and RH, the variation range of these factors is changed in different simulation runs. This variation was applied to the following parts of the chain: The transport by container overseas (customs NL, customs US and shipment) and the DC. The aim of these simulated experiments is to quantify the shrinkage reductions in the chain with various control of the quality determining factors.

### *4.2.2 Sending product to the discount channel to decrease shrinkage in further parts of the chain*

In a second series of simulated experiments the use of predicting in the DC which product will lead to shrinkage in the supermarkets is investigated. (see §3.2.2) To do this a series of simulations has been run for different values of quality acceptance limit Q1. In these experiments is assumed the price of the product sold to the discount channel is 50% of the normal selling price.

## **4.3 Measurements used for comparison**

As a reference to the simulated temperature and RH distributions in a container during the shipment from the Netherlands to the US, the results of a previously done experiment were used. In this experiment for a week the temperature and RH variation in a container filled with perishable product (bell peppers) were measured. From these experiments was concluded that the spatial distribution in the container is 0.28°C and 2.5% RH.

The temperature variation is in three directions. In the boat container, the temperature near the door is higher than the temperature close to the cooling element on the other end. The temperature at the bottom of the container is lower (9.1°C) than in the top (9.6 °C) but the highest temperature is in the middle (9.9 °C).

## 5 Results and discussion

### 5.1 Shrinkage in the chain at different variations in temperature and RH

Using Aladin the amount of boxes, of which the vine tomatoes have reached the unacceptable quality level 1 while distributed or in the supermarket, are estimated for 4 principles of control. The boxes with bad quality tomatoes are called shrinkage and expressed as percentage of the total amount of transported boxes. In figure 5 the results of the different simulations varying the T-variation in the supply chain, from 0.28°C (measured in experiment) to 2°C are shown. RH variation in these simulations is kept constant at 2.5%.

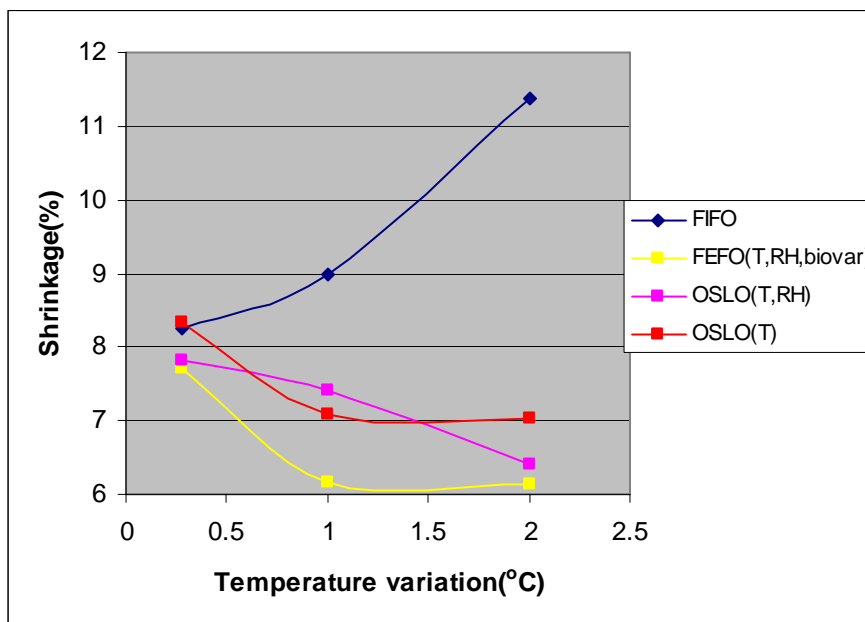


Figure 5 Shrinkage at different T variations for four principles of control: FIFO, OSLO(T) OSLO(T,RH) and FEFO(T,RH, biovar). RH variation was 2.5% in all simulation experiments.

For the hypothetical case in which all quality determining factors are known, shrinkage is as low as possible for this distribution chain. All factors influencing product quality are known and optimal control is possible.

If T variation increases, the impact of temperature on the quality variation becomes higher. Measuring temperature can then contribute a more effective control of distribution of products (sending products with lower quality first to the supermarkets) and shrinkage is reduced. There is no additional effect of measuring RH which could be expected since RH variation was kept constant in these simulations.

For the FIFO control the following can be observed: shrinkage is rising continuously with rising T variation. For FIFO only the factor time is used to control the chain. With higher T variations differences in quality are more profound but unknown in FIFO, which leads to worse chain control and higher shrinkage.

From figure 5 can be concluded that, if spatial temperature variation in the chain is 2 °C, in case transport boxes are equipped with a temperature sensor and the data are used for OSLO control of distribution, shrinkage is 4% less than in case of FIFO control.

Also simulations have been performed in which the RH variation in the supply chain was varied. T variation was kept constant at 0.28°C in these simulations. The results are shown in figure 6.

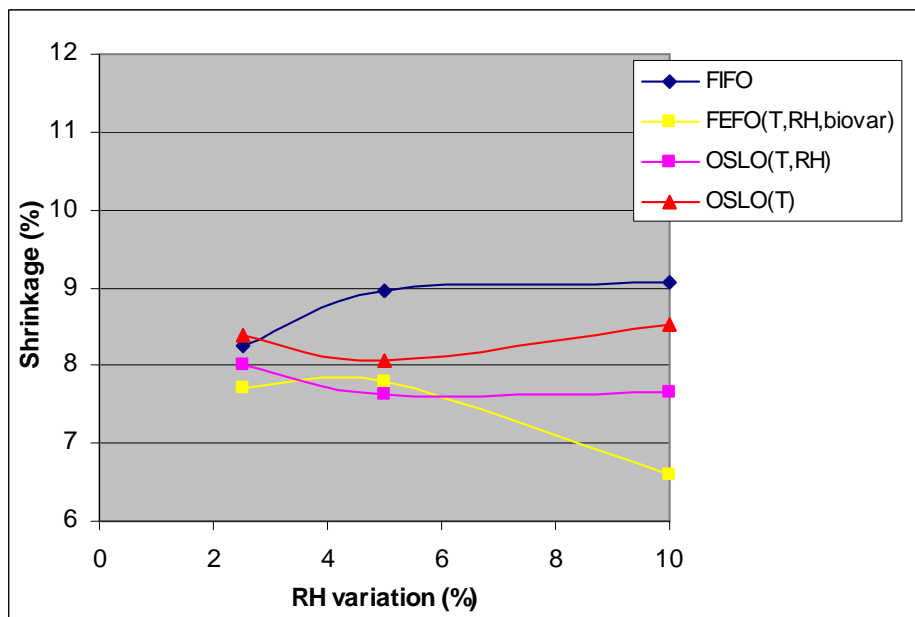


Figure 6 Shrinkage at different RH variations for four principles of control: FIFO, OSLO(T) OSLO(T,RH) and FEFO(T, RH, biovar). T variation was 0.28°C in all simulation experiments.

Apparently the RH has only a small influence on the quality. Even at high RH variations, FIFO control is still accurate and only slightly worse compared to OSLO. Adding an additional RH sensor to boxes already containing a temperature sensor reduces shrinkage with less than 1%.

## 5.2 Sending product to the discount channel to decrease shrinkage in further parts of the chain (the supermarkets)

In the tomato case study the DC and the supermarkets are part of one organisation. The hypothesis is that this organisation can benefit from selling products with low quality to a discount channel instead of shipping them to the supermarkets. It may decrease the amount of tomatoes that have to be thrown away, increase the quality on the shelf of the supermarkets and result in economical benefits as well.

In figure 7 the results of the simulations, predicting the quality in further parts of the chain (the supermarkets) is presented.

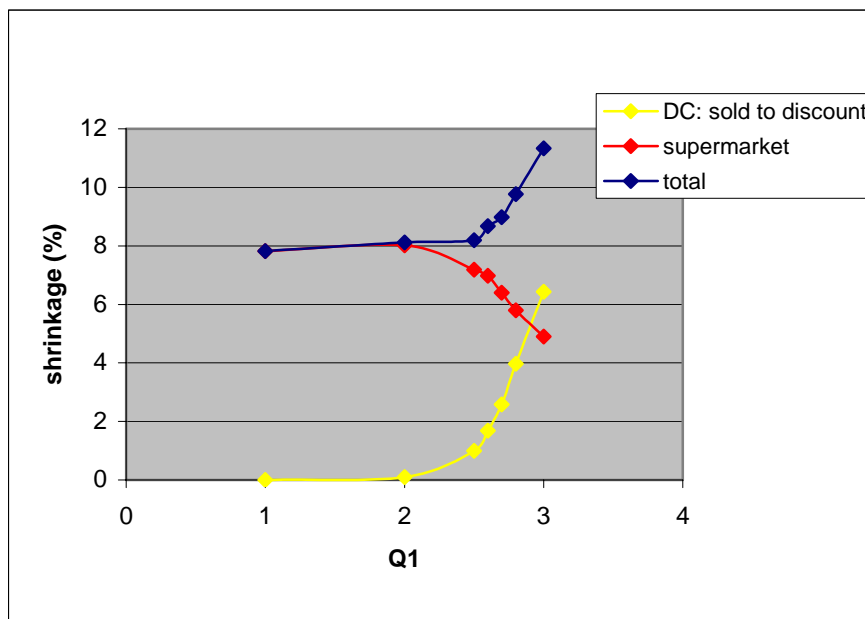


Figure 7 Total shrinkage, shrinkage in the supermarkets and shrinkage at DC (due to selling of products with quality below Q1 to discount channel) for different Q1 values. Temperature variation is 0.28 °C and RH variation is 2.5% in all cases.

With increasing Q1 the shrinkage in the DC increases. This is not caused by loss of products (throwing them away) but by sending these products to the discount channel. Supplying the discount channel is not a task of the DC and as such these products are considered shrinkage. As Q1 increases, the shrinkage level in the supermarkets drops as expected. Supermarkets receive tomatoes with higher quality (higher than Q1). Thus they have to throw away fewer tomatoes. But, more important, the quality of the tomatoes on the shelf is higher, which will have a positive effect on the image of the supermarkets.

The total amount of shrinkage though rises with increasing Q1 value.

This increase of shrinkage could be acceptable if the revenues due to selling the product to the discount channel and the drop in transport costs counterbalance that.

In figure 8 and 9 the cost balance of shrinkage is shown, expressed as €, it is assumed that the discount channel pays 50% (fig.8) or 75% (fig.9) of the customer price in the supermarkets. The shrinkage in DC and supermarkets is split up. The benefits of the company (containing the DC as well as the supermarkets) are reflected by the total amount of shrinkage.

From the results presented in figures 8 and 9 it can be concluded that, for this specific case study, economical benefits can be obtained if tomatoes with quality below 2.5 are sold to a discount channel for at least 75% of the supermarket price. Benefits are higher in case Q1 is higher but this implies also more shipping and storing of tomatoes by the DC which will not be sold in the supermarkets of the DC organization.

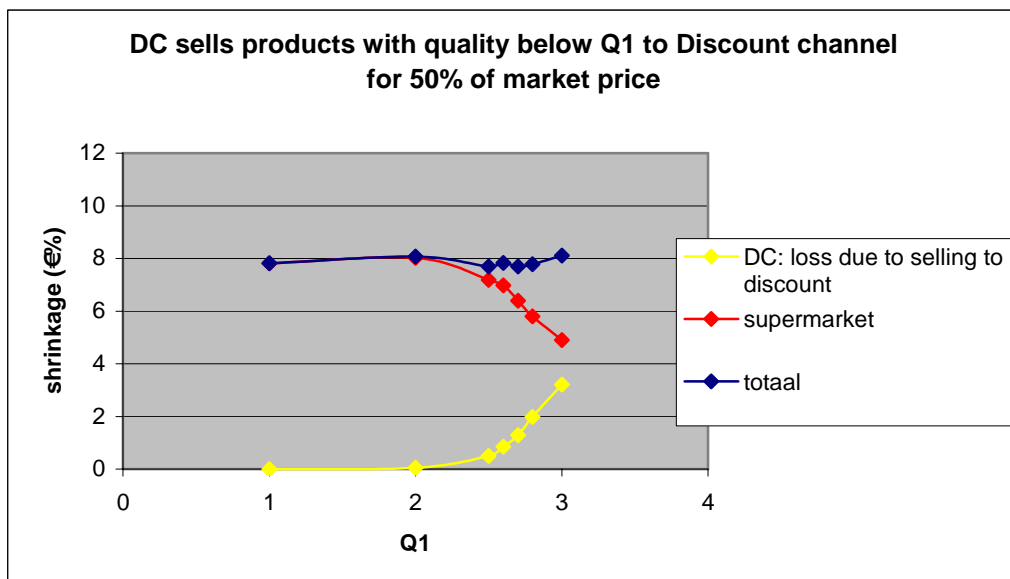


Figure 8 Total shrinkage, shrinkage in the supermarkets and shrinkage at DC (due to selling of products with quality below Q1 to discount channel) for different Q1 values. Shrinkage in Euro% representing the economic effect of this mode of operation. The discount channel pays 50% of customer price in the supermarket. Temperature variation is 0.28 °C and RH variation is 2.5% in all cases.

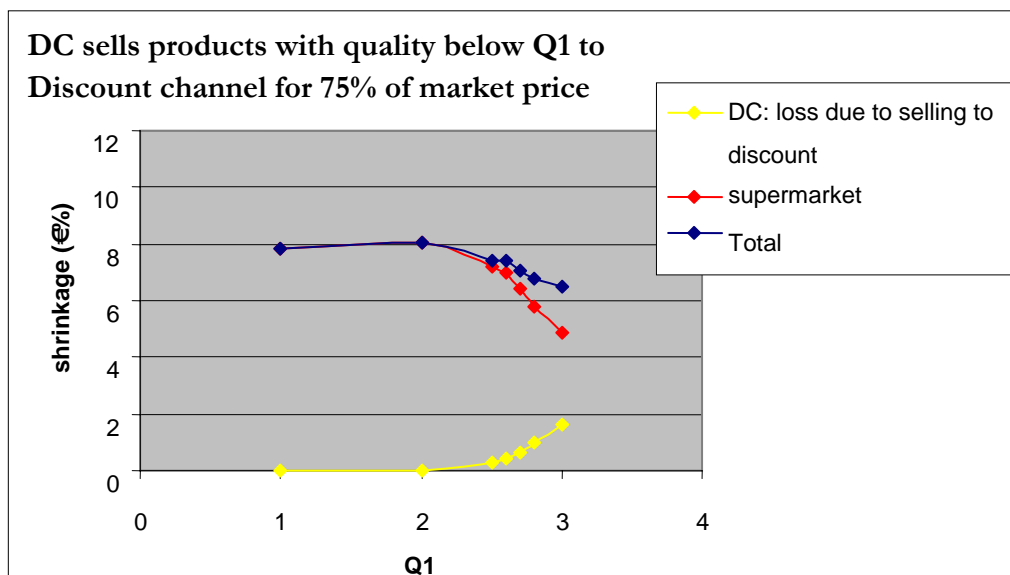


Figure 9 Total shrinkage, shrinkage in the supermarkets and shrinkage at DC (due to selling of products with quality below Q1 to discount channel) for different Q1 values. Shrinkage in Euro% representing the economic effect of this mode of operation. The discount channel pays 75% of customer price in the supermarket. Temperature variation is 0.28 °C and RH variation is 2.5% in all cases.

### 5.3 Estimation of acceptable cost price for a temperature sensor.

In section 5.1 it is concluded that if spatial temperature variation in the chain is 2 °C, in case transport boxes are equipped with a temperature sensor and the data are used for OSLO control of distribution, shrinkage is 4% less than in case of FIFO control. It is clear that economical benefits of the OSLO concept can only be obtained if the investment and operational costs are lower than the cost savings obtained with the reduced shrinkage.

Annually 11218 tons of vine tomatoes are exported to the US, which are 2.2 million boxes, with a sales value of about €17 million. 4% of these tomatoes do not have to be discarded due to unacceptable quality if the OSLO concept is applied. The cost savings are thus 4% of the sales value which is € 637 thousand.

Investment and operational costs for OSLO are the following:

- Temperature sensor on every box.
- Identification code (ID) on every box (for T&T)
- Readers for collecting the ID and T data.
- Infrastructure for transferring data into information and information into actions
- Automatic picking of boxes in a storage room (DC)
- Automatic stacking and un-stacking of pallets

For reasons of simplicity, it is assumed that temperature sensors will only be introduced on a large scale after tracking and tracing systems (for identification of products) are in place. This is a very likely scenario since T&T is already regulated by European law and many tests with RFID labels are carried out these days. FIFO control also requires a T&F system.

After T&T is in place, the main extra costs for OSLO are automatic stacking and un-stacking of pallets and the costs of the sensor. Robots for stacking and un-stacking pallets can be used for all products in the DC.

For vine tomatoes the cost savings of € 637 thousand need to be in balance with the costs of accommodating 2.2 million boxes with a temperature sensor. The cost of each sensor is than 31 cents maximum.



## 6 Conclusions

### 6.1 Conclusions for the vine tomato case

Simulation runs have been carried out to investigate the benefits of communicative technology integrated in packaging. To perform the simulations a case study was selected that would most likely show the benefits of communicative packaging.

After an extensive pre-study the most promising product market combination was chosen to concretise the case study. The selected case is the following: Use of a communicative transport package for vine tomatoes produced in Europe and distributed in USA. The sensor on the package will be able to register time, temperature and relative humidity. The sensor data are used to distribute the tomatoes from the distribution centre in the USA to the supermarkets according to the OSLO control (Optimal Storage Last Out). Distribution according to FIFO control (First In First Out) is taken as reference.

From the simulation results it can be concluded that under certain circumstances, the use of transport boxes equipped with a temperature sensor can result in significant reduction of shrinkage of the vine tomatoes. The simulations indicate that the reduction of shrinkage can be 4% if the spatial temperature variation in the chain is 2 °C. In this case the temperature sensor may cost €0.31 for cost effective operation (presumed infrastructure and tags for tracking and tracing are already in place).

In addition, the simulation results show that the use of transport boxes equipped with a relative humidity sensor additional to a temperature sensor will not result in significant reduction of shrinkage of the vine tomatoes. It appears that the impact of relative humidity on the tomato quality is not so large.

Detailed knowledge of storage conditions (and thus of the quality) of the vine tomatoes can be used to predict the quality in the supermarkets while the products are still at the DC and act upon that. The results of the simulations show that there can be economical benefits when products of inferior but still acceptable quality are sold to a discount channel for 75% of the supermarket price. Additional advantage of this system is that the (mean) quality on the shelf of the supermarkets is higher improving the image of the supermarkets.

### 6.2 General conclusions

The tomato case has been selected as a case likely to show the benefits of communicative packaging. Based on the conclusions in this report, communicative packaging can only be successful in other product market combinations if the following conditions are applicable:

1. Product quality is more sensitive to temperature or to relative humidity than vine tomatoes are
2. Time in the distribution chain is long enough for temperature and/or humidity to have a significant effect on the quality
3. Biological variation of the product will not predominate the effect time, temperature and/or relative humidity have on quality.
4. Spatial variations in storage conditions are high.
5. Price of product is high or food safety is at stake.
6. Sensor is applied that can measure quality (including biological variation) of the product.

When considering the range of possible product-market combinations to apply communicative packaging, the following analysis can be done:

- The tomato case is fairly similar to export of bell peppers and apples (condition 1 does not apply)
- Products like strawberries are very temperature sensitive but have a large biological variation (condition 3 does not apply)
- Meat and fish are products with a quality that is very sensitive to temperature but distribution conditions are usually characterized by short lead time or sub-zero temperatures (condition 2 does not apply)
- Spatial variations in temperature can be high for air flights but only for limited periods of time (condition 4 applies but condition 2 does not)

Therefore it can be stated that there are no other large scale product market combinations where the use of communicative packaging can lead to more benefits than the one studied in this report. However for niche products or special distribution conditions the conditions mentioned above may be applicable and the application of communicative packaging can lead to large benefits. The simulation program Aladin can then easily be used to quantify the benefits of communicative packaging.

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