evelopment and experimental validati of SMAS

TTI based Chill Chain Management syst

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ational Technical University of Athens, School of Chemical Enginee
Laboratory of Food Chemistry and Technology

at Chill Chain- Need for better management

at products are perishable and unless processed, packaged, ributed and stored appropriately can spoil in relatively short e. Overgrowth of incidental pathogenic bacteria like *Listeria nocytogenes*, *Salmonella sp.* and *Escherichia coli* followed by ercooking or inadequate preparation may pause a potential ard for the consumer. Despite the proliferation of food safety ulations and the application of safety management systems such HACCP, risk assessment studies show that foodborne disease has ained a main concern in the last decade.

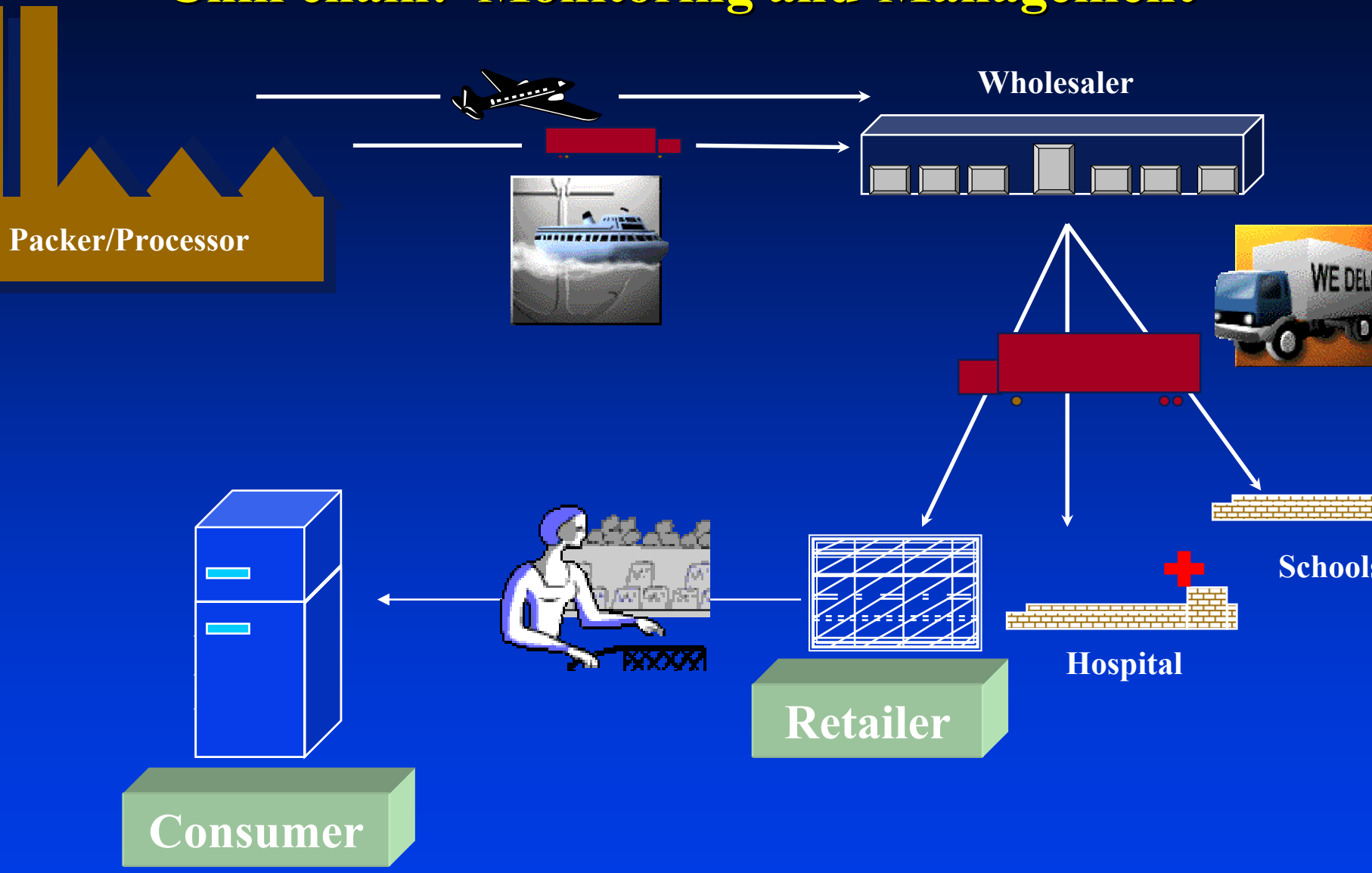
Meat Chill Chain-
Need for better management

s generally recognized by the European industry, retailers,
od authorities and even consumers that the weakest link that
ects directly safety and quality of chilled products is the
ual ***chill chain***. A big percentage of foodborne disease is
e to temperature abuse.

eat Chill Chain- Need for better management

plication of an optimised quality and safety assurance tem for chilled distribution of fresh meat and meat products uires continuous monitoring and control of storage nditions from production to consumption. The systematic nagement of the chill chain and the improved evaluation of ety, quality and shelf life of meat can lead to reduced safety k and increased quality, with a significant health and nomic impact to the European society and market.

Chill chain: Monitoring and Management



From packing to consumer

What is SMAS?

MAS is an integrated chill chain management system,
esigned to lead to an optimised handling of products in terms
f both safety and quality. It is based on the ability to
ntinuously monitor the storage conditions of each product
ith the use of **Time Temperature Integrators (TTI**).

TI are inexpensive "smart labels" that show an easily
easurable, time and temperature dependent change that
mulatively reflects the time-temperature history of the food
oduct. TTI response can be correlated to meat safety and
uality status at any point of the distribution chain providing
n effective decision tool.

The SMAS project

he acronym *SMAS* summarizes the long title of the 3 year (2003-006) action project "Development and application of a TTI based afety Monitoring and Assurance System for Chilled Meat oducts", co-ordinated by the National Technical University of thens (NTUA). Funded by the EC, it is part of the key action of ood, Nutrition and Health. The project basis consists of validated edictive models of predominant meat pathogens growth and netics of the response of selected TTI, all applied in an expanded TI application scheme that translates TTI response to meat icrobiological and quality status.

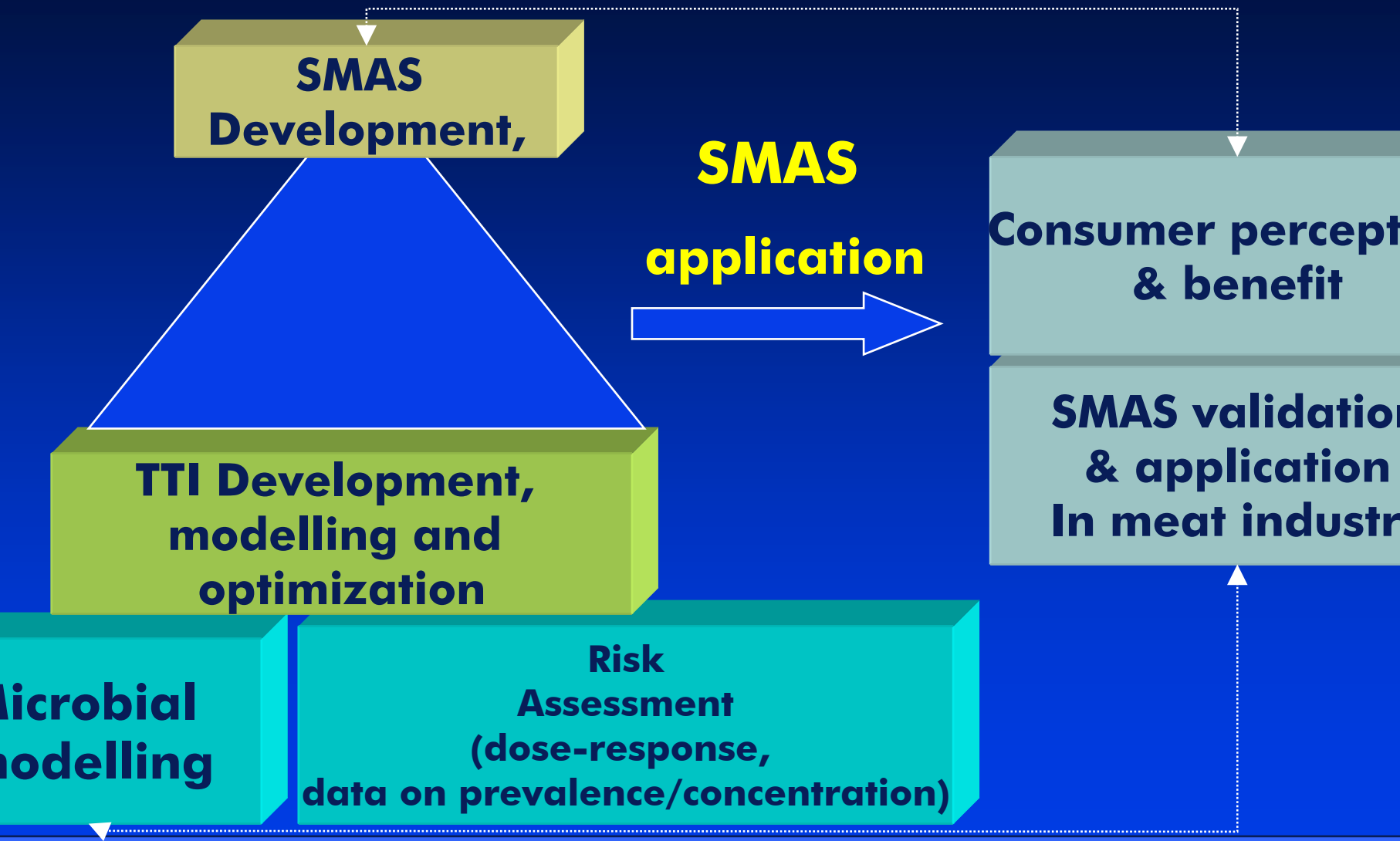
Institutes/Companies are members of the SMAS project, orking on its 6 main interrelating workpackages with the timate purpose to deliver an effective chill chain decision and anagement tool.

OVERALL OBJECTIVE

State of the art of

TTI technology + Quantitative risk assessment

lopment of SMAS, an effective and reliable safety assurance
quality optimization management system for meat products,
extending from production to the table of consumer



hat is the structure of SMAS?

he major expected achievements of the project will be:

Accurate, validated mathematical models for safety and quality related microorganisms of ready to cook meat products. They will provide the meat industry with a tool for product development and safety assurance and the European authorities with a quantitative means for meat product risk evaluation.

The development and study of an assortment of Time Temperature Integrators (TTI) suitable for meat safety monitoring. These TTI will provide the meat industry and retail business with effective tools to monitor the chill chain.

Improved distribution logistics and management of the meat chill chain from the application the ***Safety Monitoring and Assurance System (SMAS)***. SMAS could replace the current "First In First Out" (FIFO) practice and lead to risk minimization and quality optimization.

Increased ability of the meat sector to control its weak link, the chill chain

Current practice: First In- First Out (FIFO)

Disadvantages:

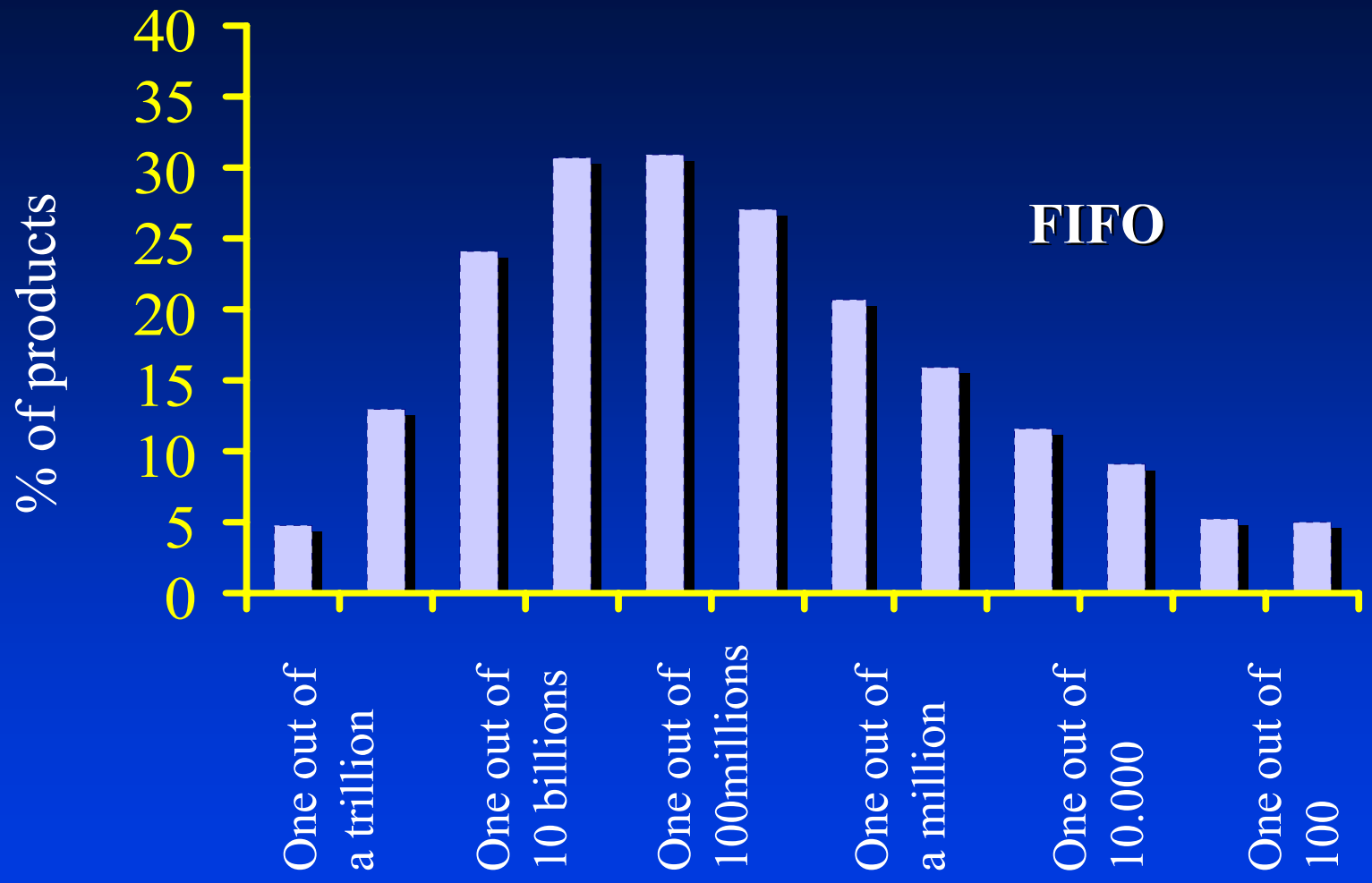
- ✓ ignores variations of product characteristics
- ✓ ignores the REAL time-temperature history of the product

Proposed practice: SMAS

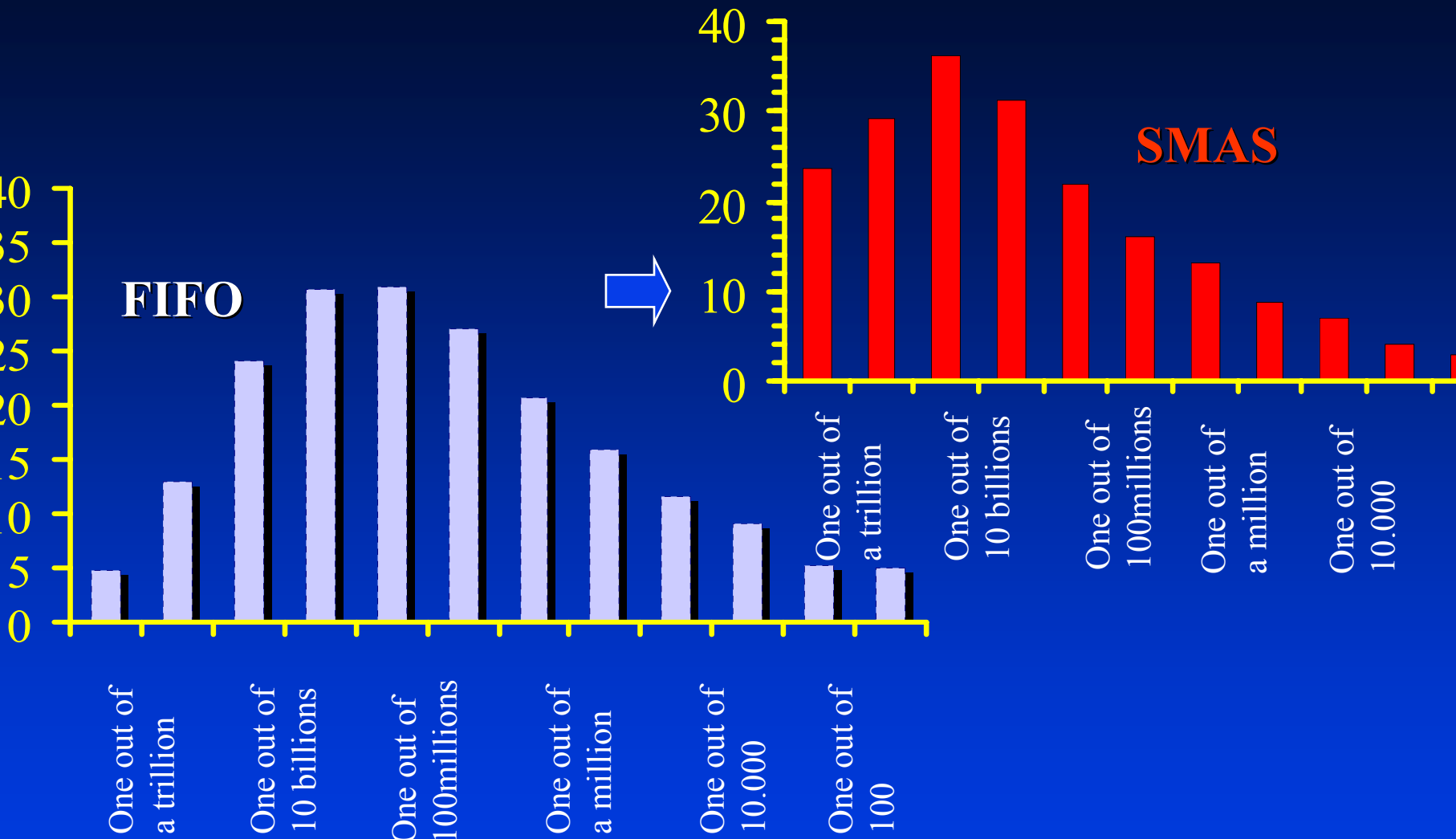
Main Advantages:

- ✓variations of product characteristics are considered
- ✓the REAL time-temperature history of the product is taken into account based on TTI response

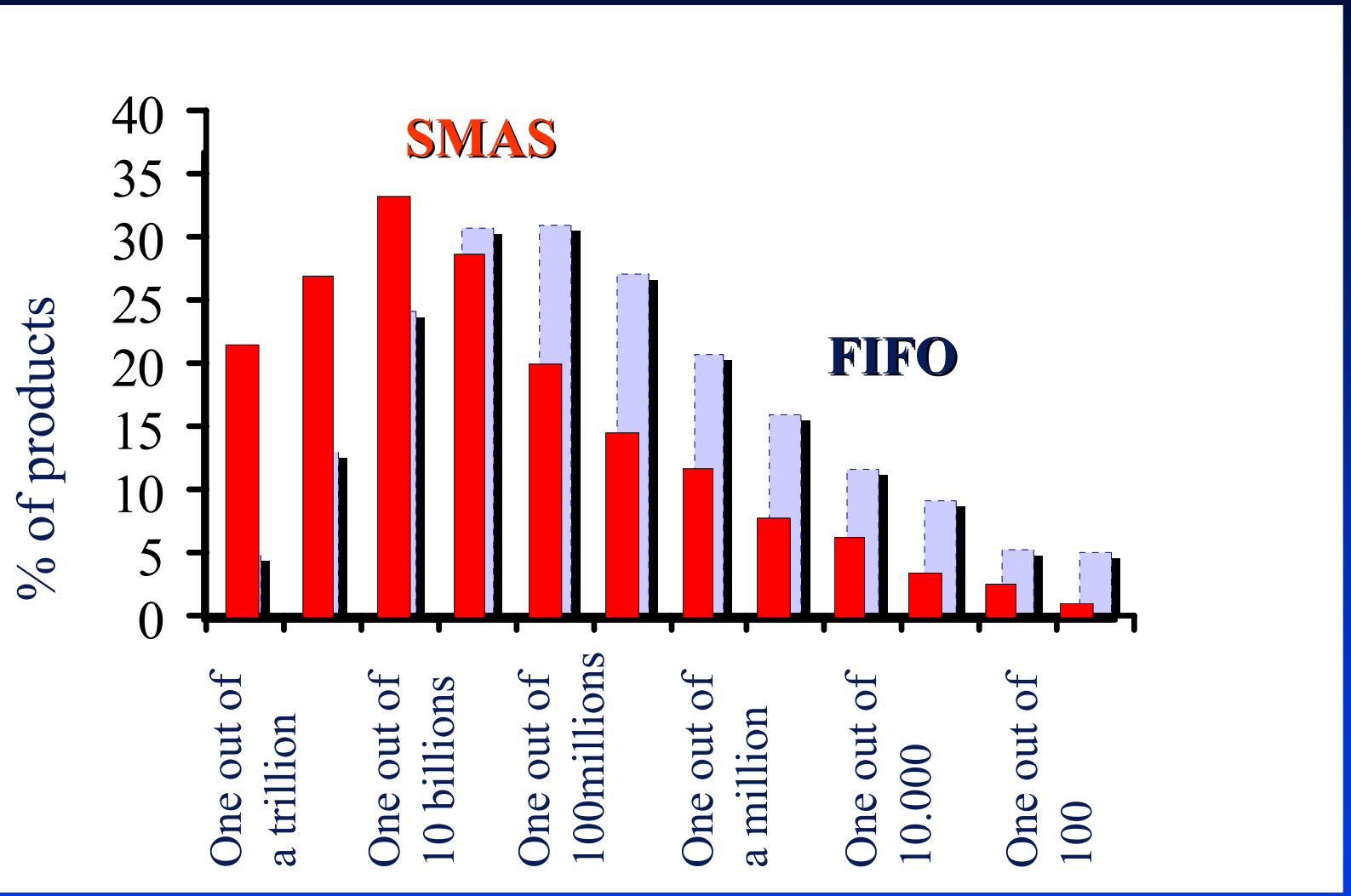
The contribution of SMAS in the chill chain managemen
can be visualized as a minimization of risk for illness an
optimisation of the meat product quality at the time of
consumption



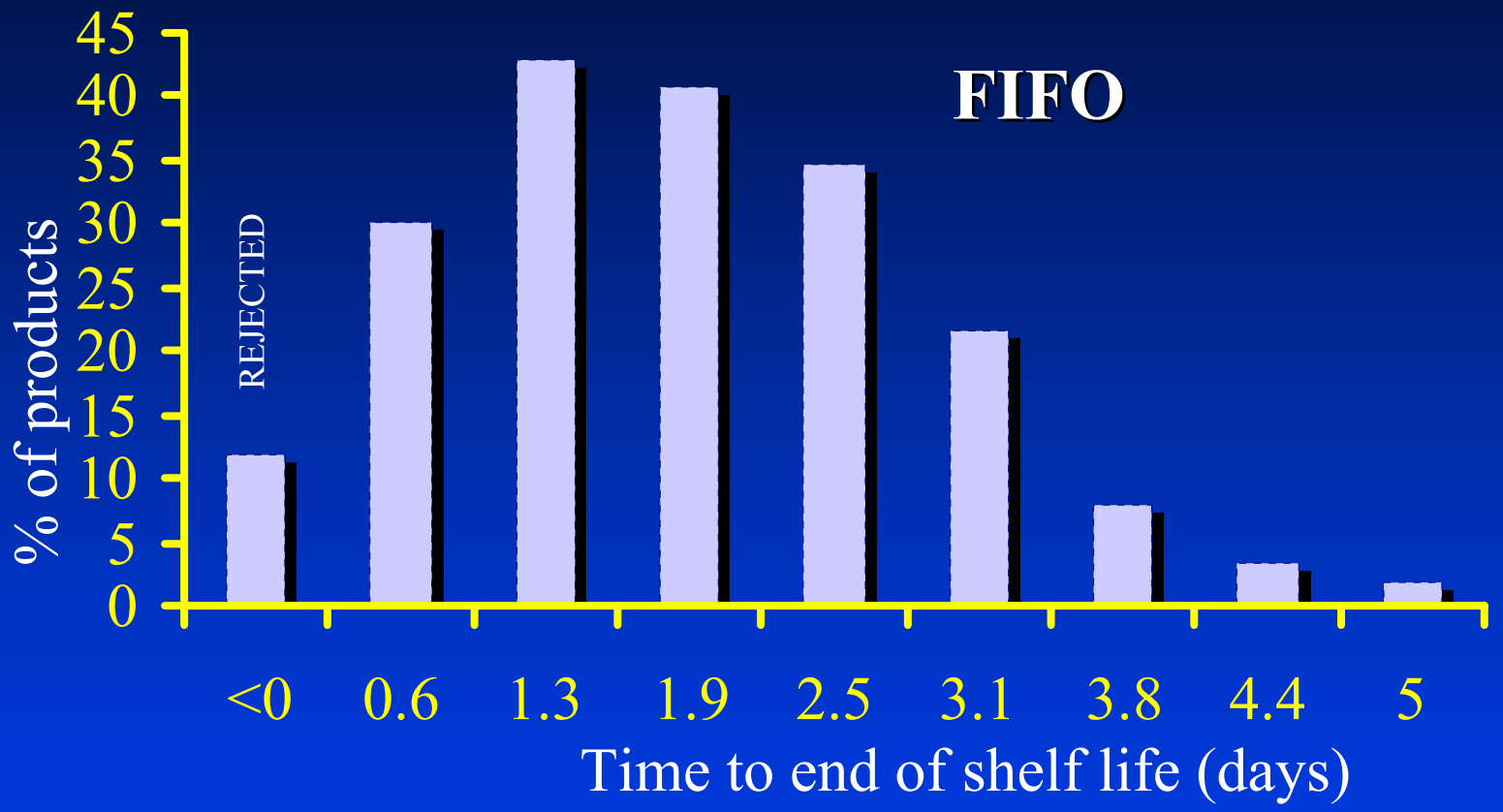
Probability of illness



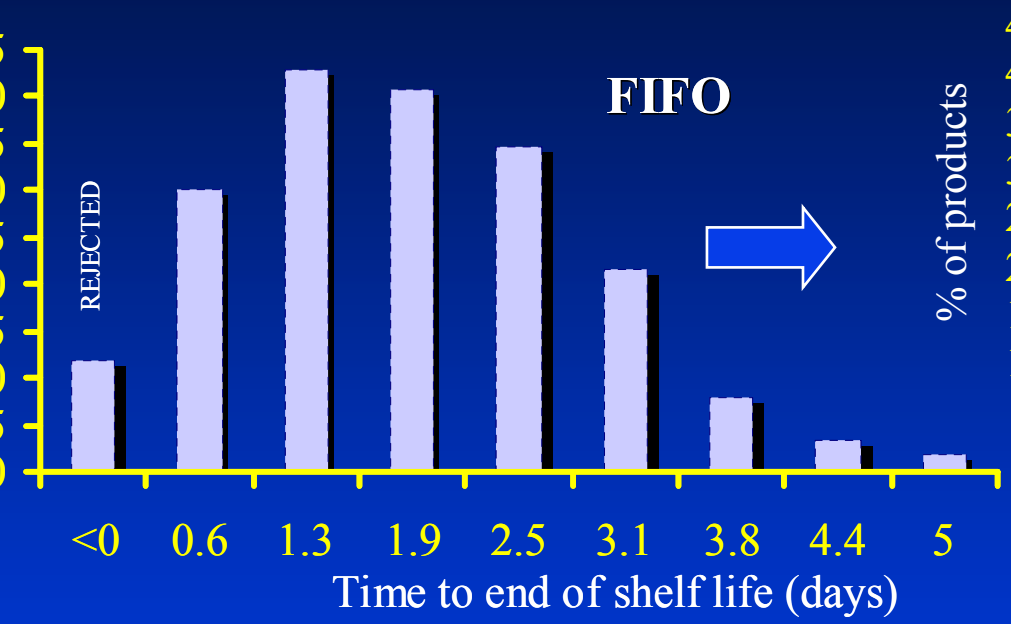
Probability of illness

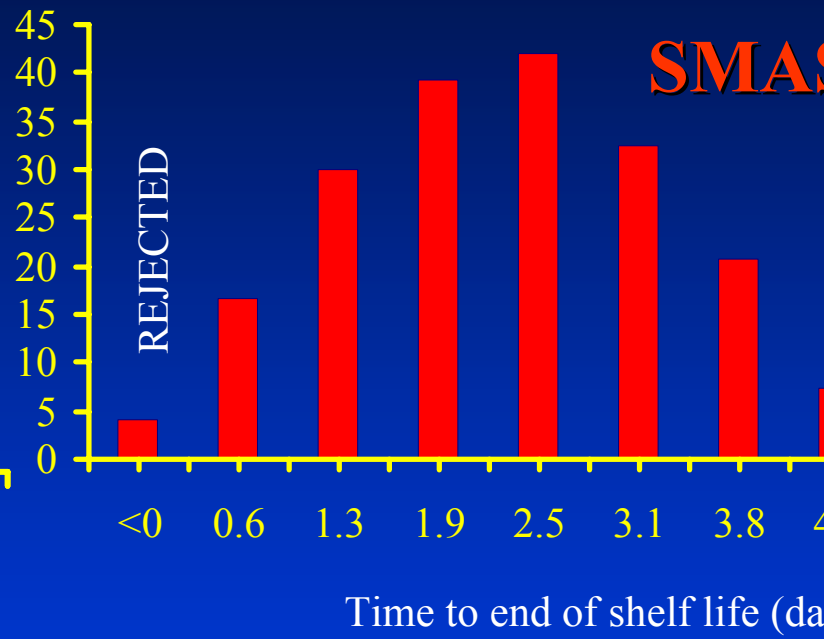


robability of illness

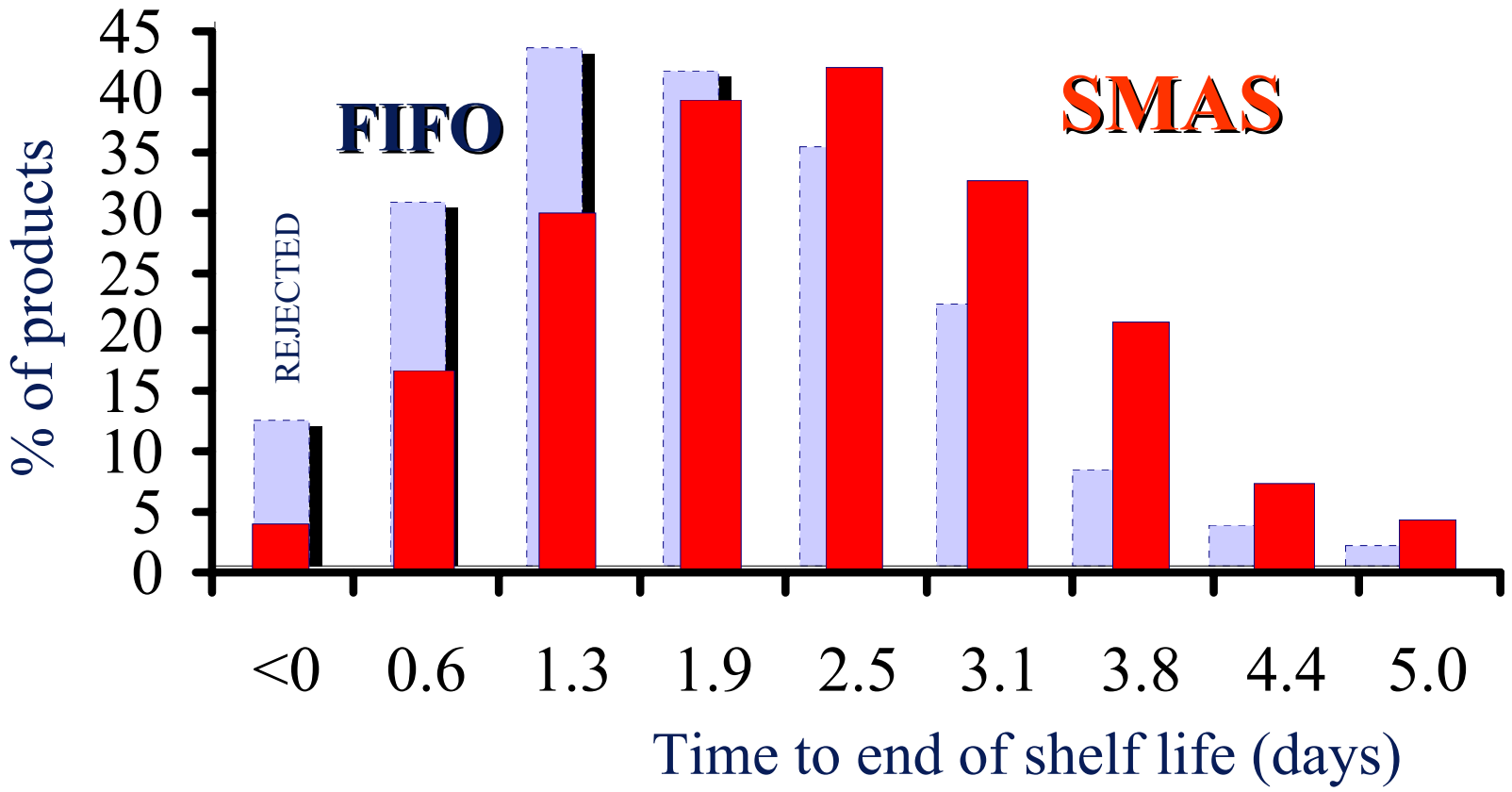


Product quality at consumption





Product quality at consumption



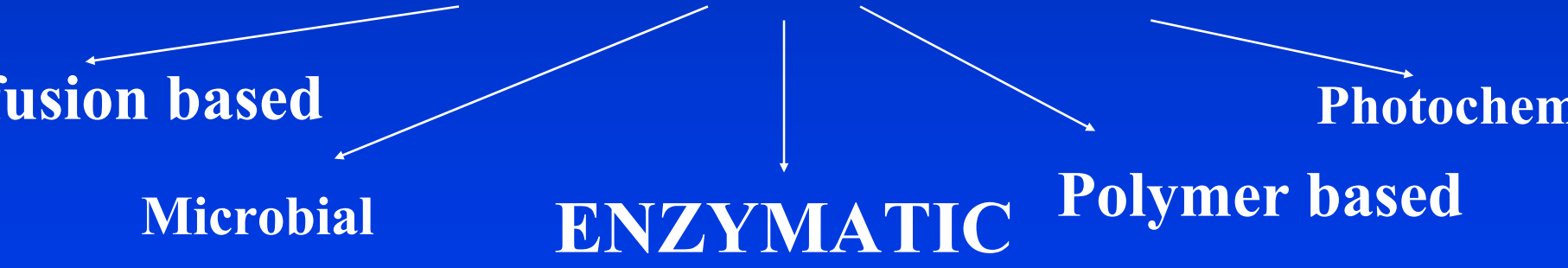
Product quality at consumption

TTI PRINCIPLES
&
APPLICATION

TTI: main principles

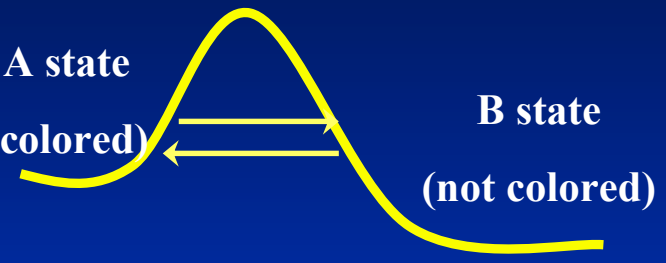
Time Temperature Indicators (TTI) are simple, inexpensiv
devices that can show an easily measurable, time and temperatur
dependent change that cumulatively indicates the time-temperatur
history of the product from the point of manufacture to th
consumer, allowing the location and the improvement of the critica
points of the chill chain

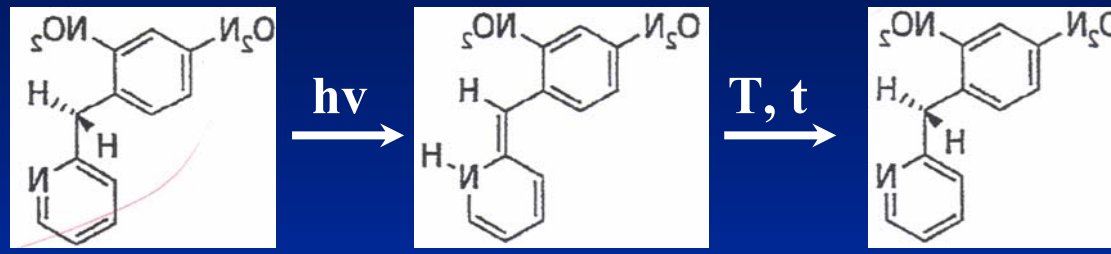
TYPES OF TTI



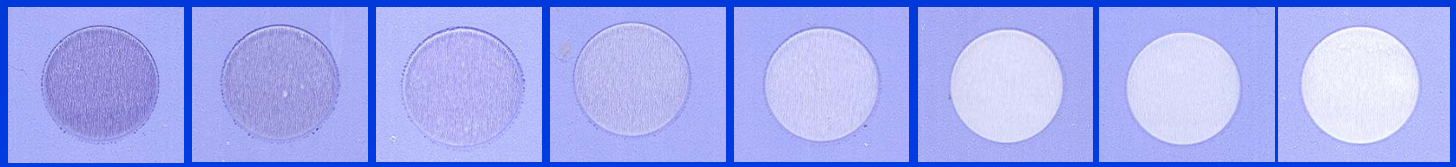
Time Temperature Indicators

Crystal Based Time Temperature Integrators





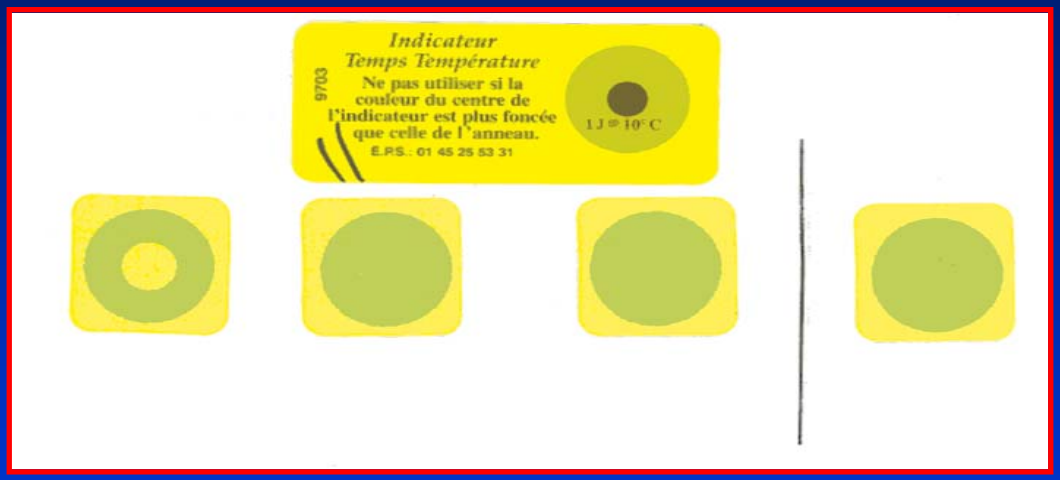
- The active matrix circle can be charged (colored) using a UV lamp
- The decay rate of the central dark blue-purple circle of the TTI is temperature dependent



TTI - Fresh Point

Time Temperature Indicators

TTI



TI - Temptime

ENZYMATIC Time Temperature Indicators

indicator
ts with two
id-filled
ches

The contents are mixed by bursting the seal between the pouches by pressure

After exposure to time and temperature, the contents turn from green to yellow to red

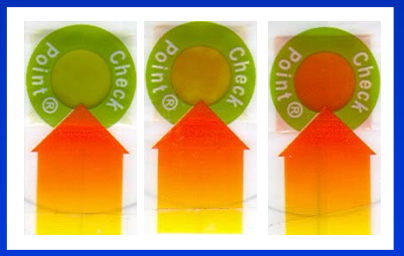
TTI Configurations

icolor TTIs

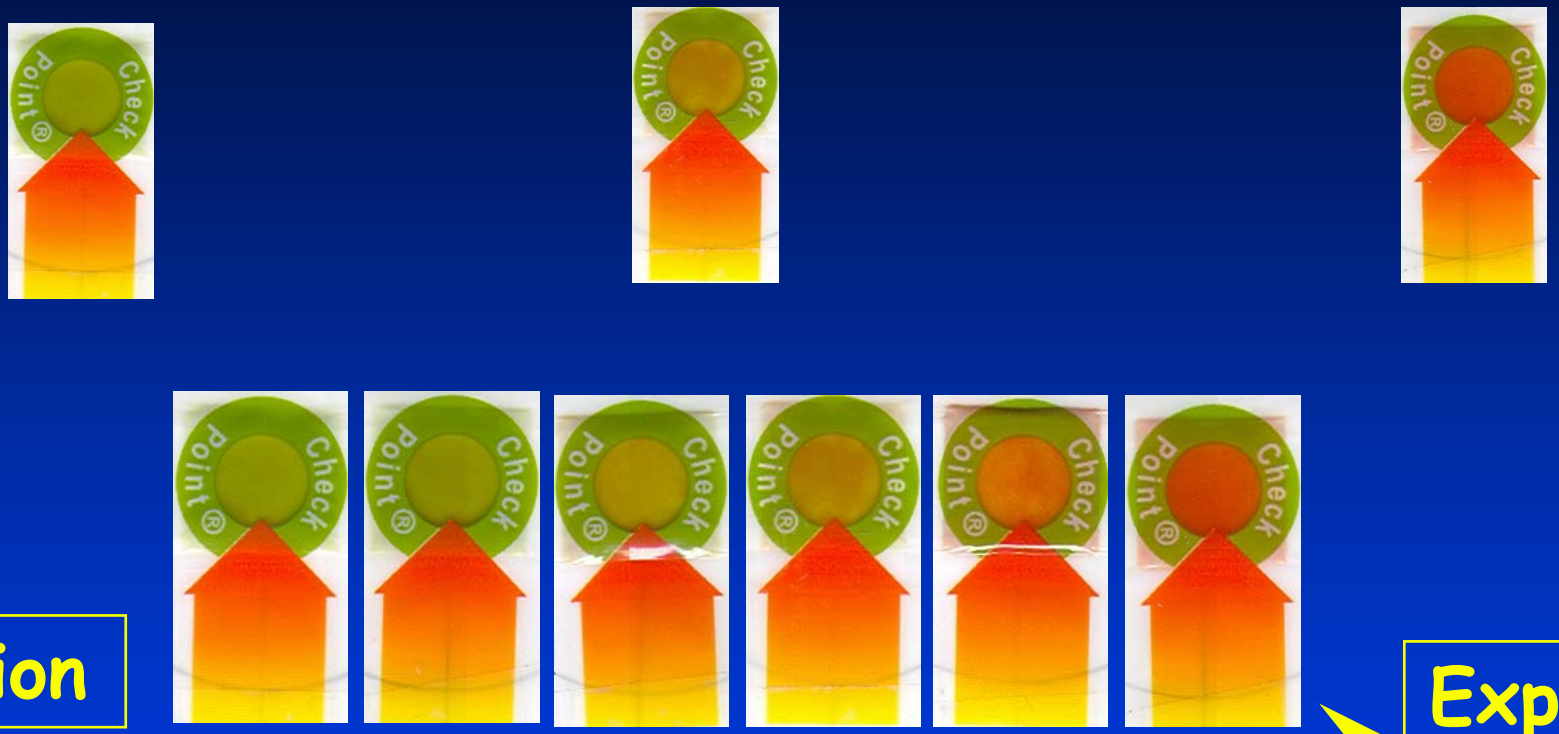
or change from green to yellow

ricolor TTIs

nitial green color changes into an
per or orange red and ends with a final
e red color, giving a much more clear
ception especially to consumers,
re the TTI mediates an alarm
ction in the form of a traffic light



Tricolor response TTI



ternative methods measuring TTI respons

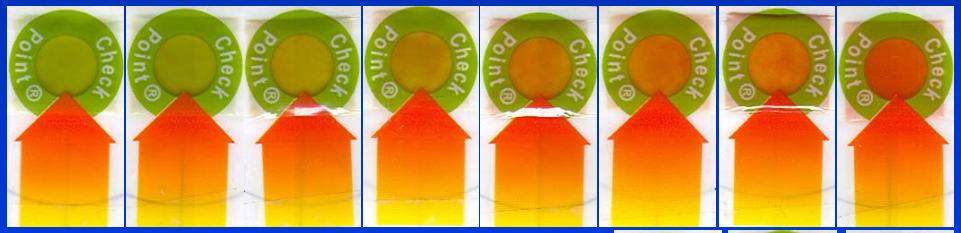
strumental measurement

lormeter such as Minolta CR 200

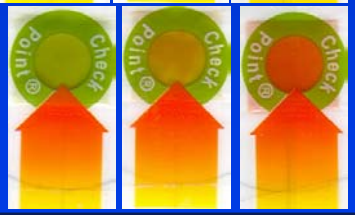
gital imagers such as a scanner

sual measurement

color scale



simple 3 color scale (consumer use)



Measuring devices for TTI response

TTI RESPONSE KINETICS

Response function:

$$F(X) = k\,t$$

Temperature dependence - expressed by Ea

$$F(X) = kt = k_{I_{ref}} \exp\left(\frac{-E_{a_I}}{R}\left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right) t$$

X: measurable change of TTI

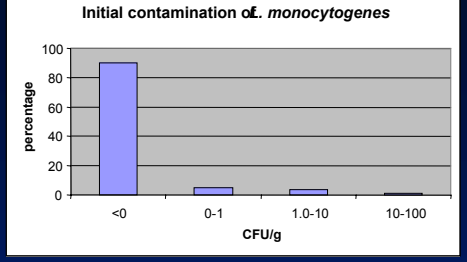
Wide range of TTIs

ifferent TTI designs of various response characteristic
esponse from hours to several weeks at refrigeration
emperatures

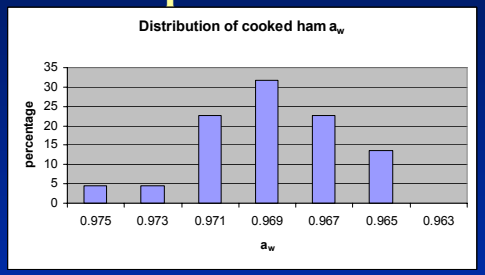
he TTIs temperature sensitivity ranged from 50 to
00KJ/mol covering the respective range of bacteria gro
n meat products

SMAS PRINCIPLES
&
APPLICATION

chill chain scenario



Final product



Storage (12h at 4 °C)

Transport (8h at 6 °C)

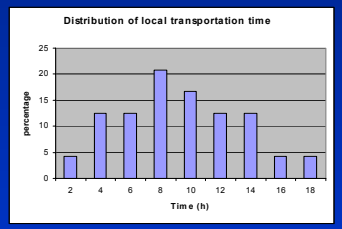
Distribution Center (24h at 4 °C)

Product promo

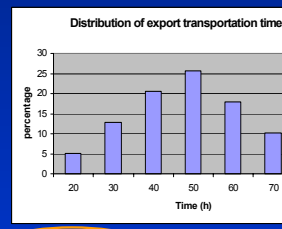
1st Decision po

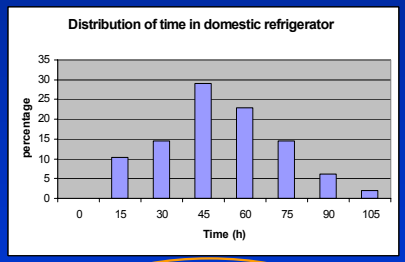
(4 °C)

Local market



Export market





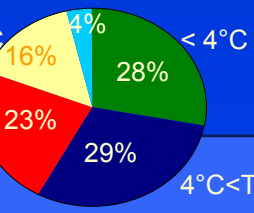
Retail Storage (Super Market)

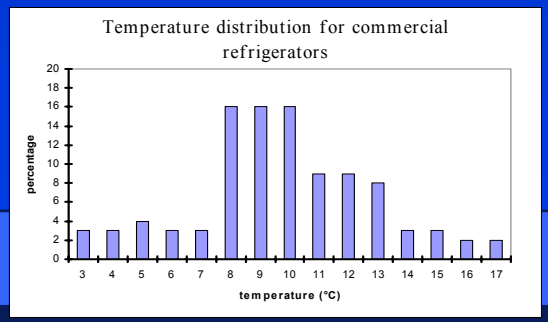
Display Cabinet (6, 18, 30h)

Domestic Fridge

Consumption

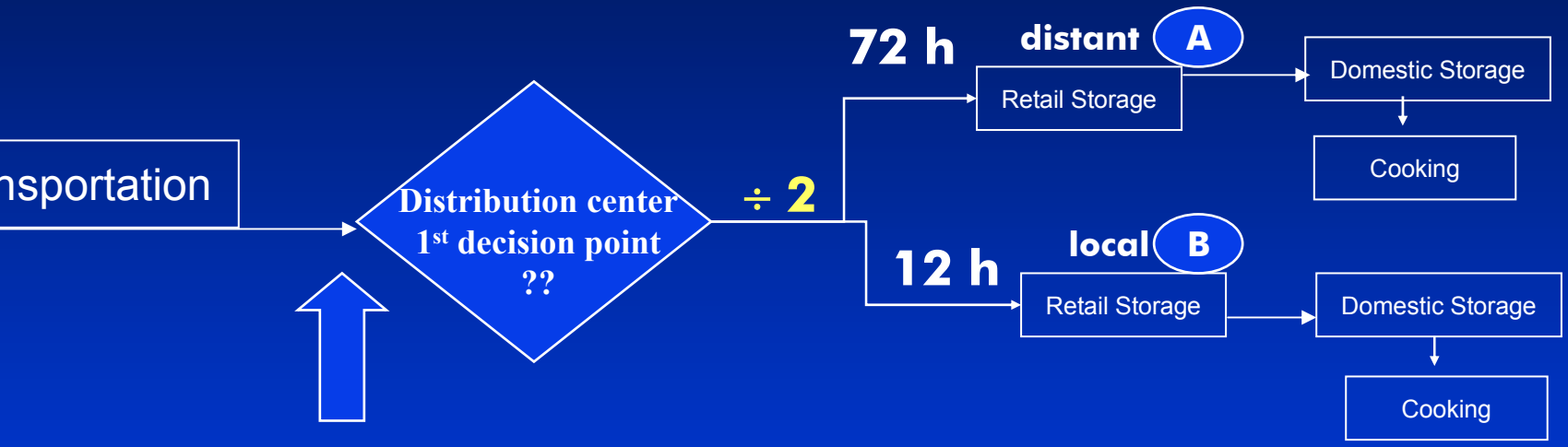
mperature distribution for
lomestic refrigerators
10°C<T< 12°C





Stock Display

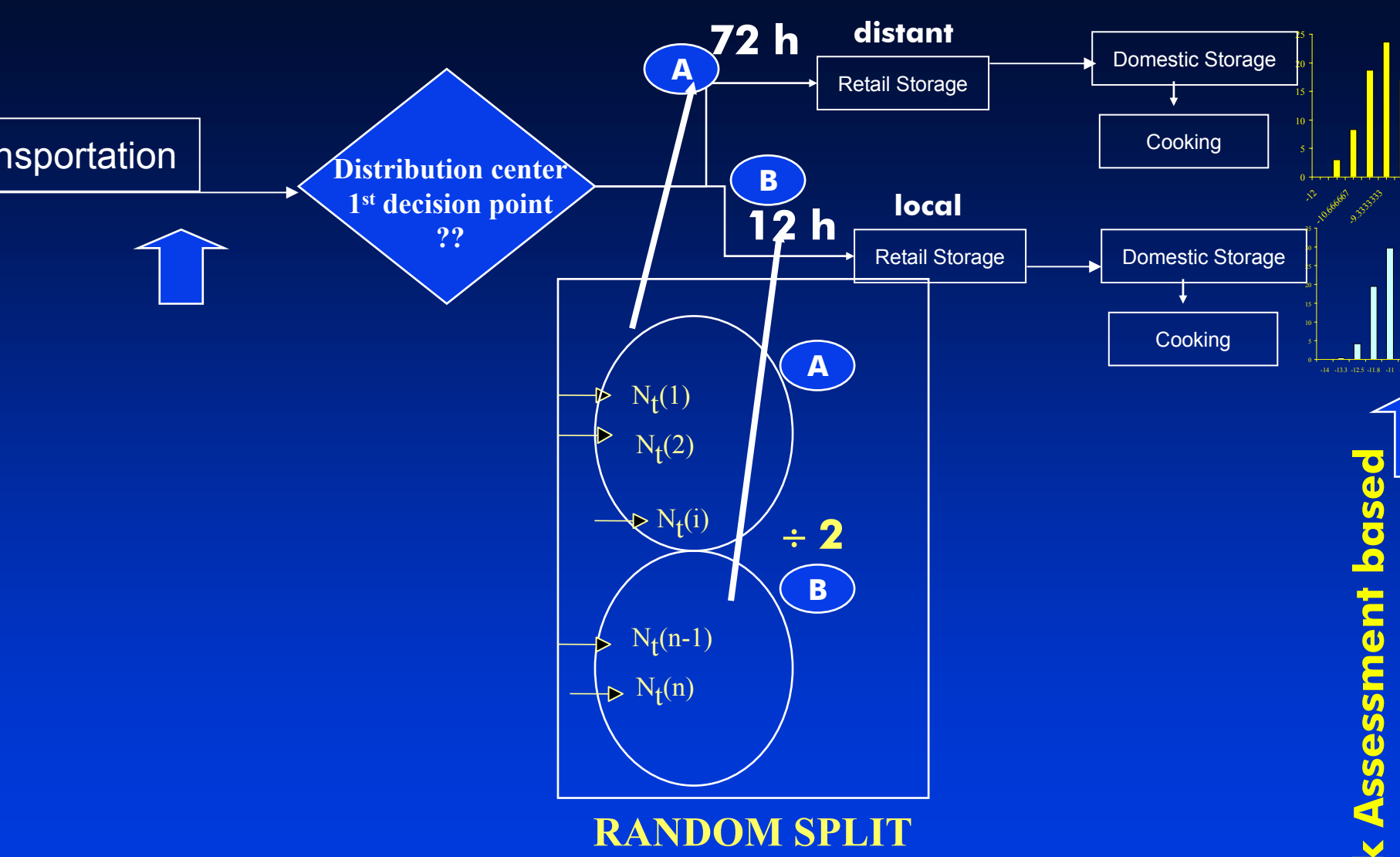
2nd Decision point



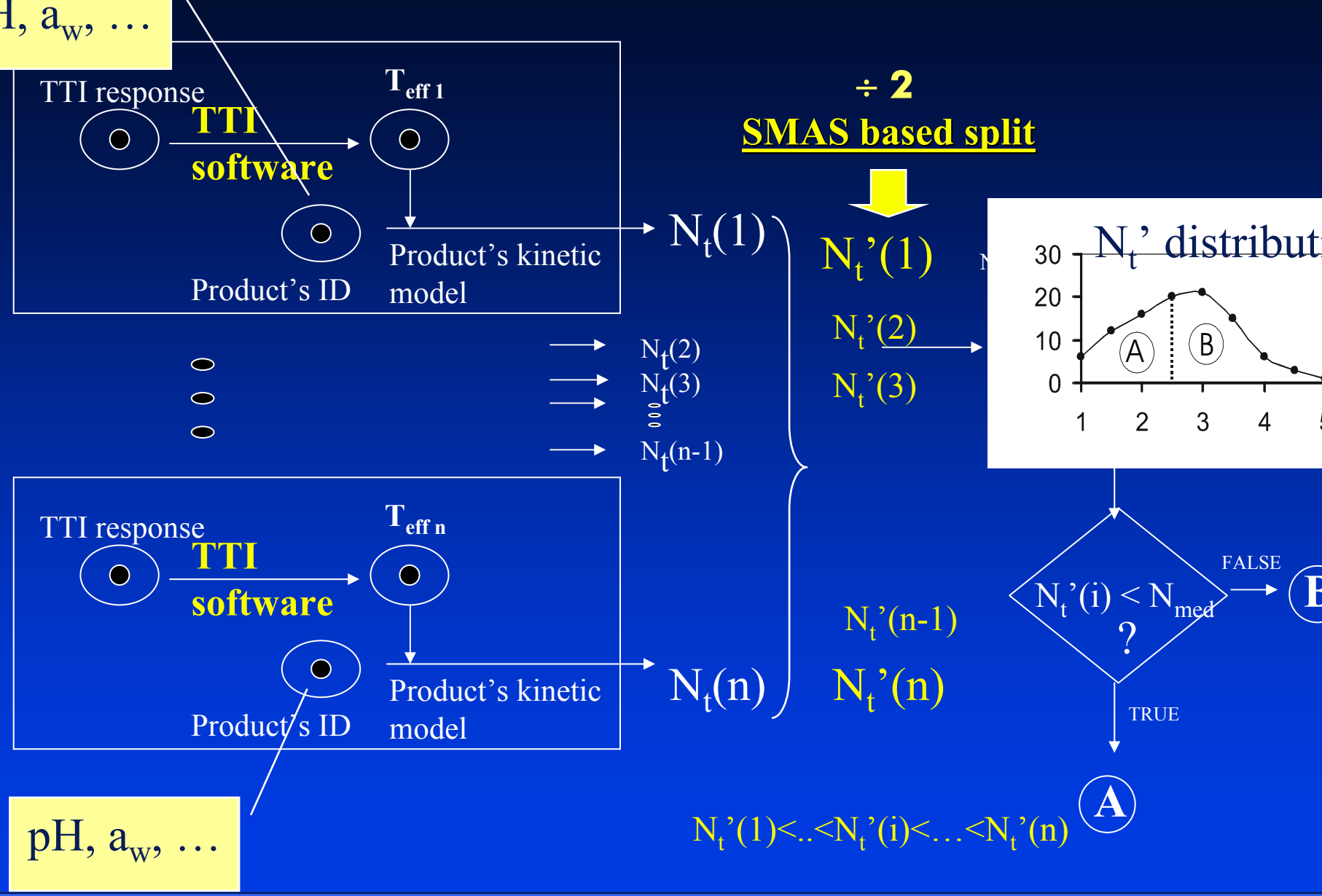
1. **Random Split**

OR

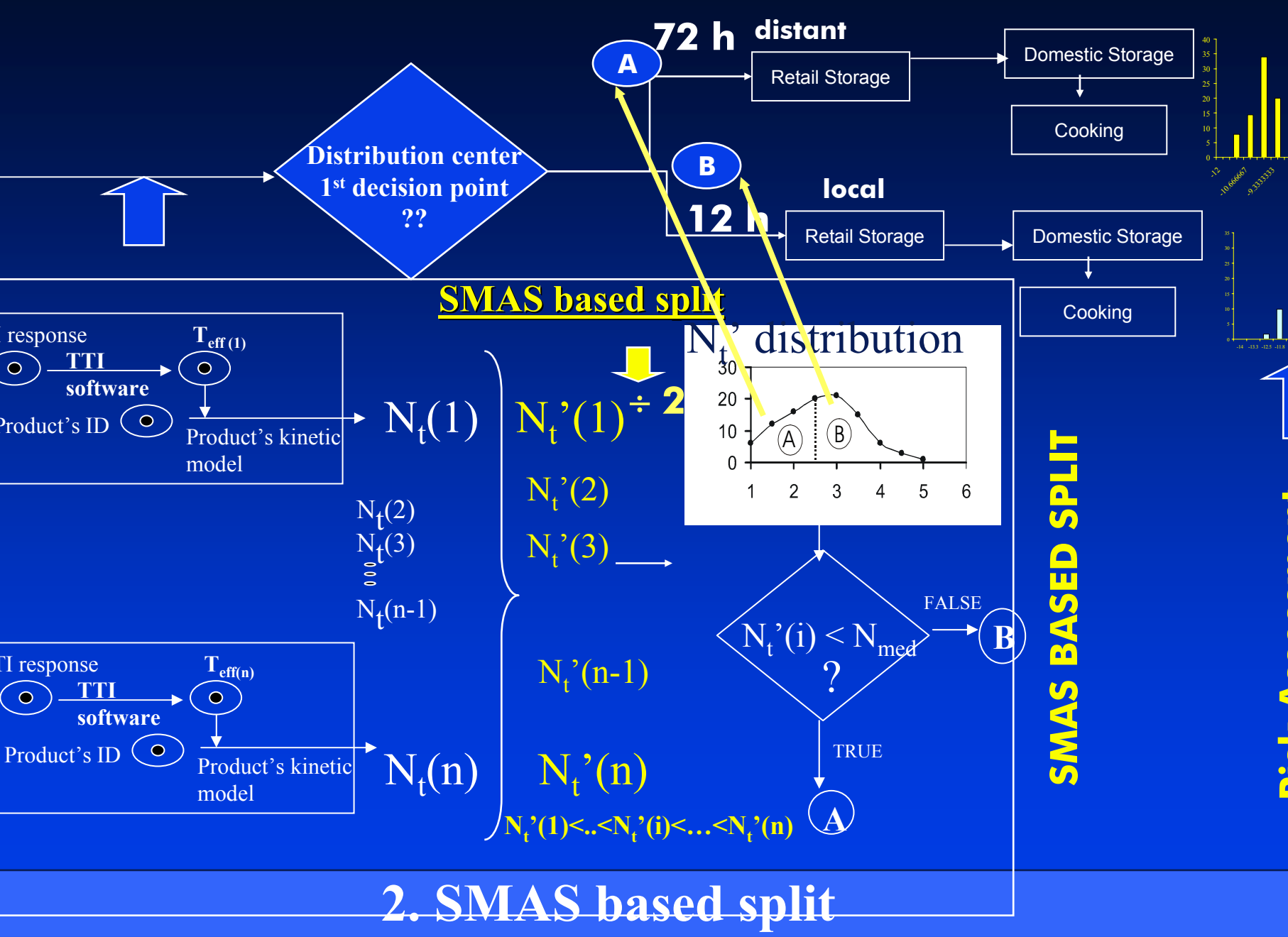
2. **SMAS based split**



1. Random Split



2. SMAS based split



2. SMAS based split

The SMAS Decision Maker Software

The developed SMAS algorithm has been developed in an interactive user-friendly software

The SDM software integrates the meat safety and quality prediction models, the TTI response kinetics and correlation routine

Software input: TTI response and product characteristics

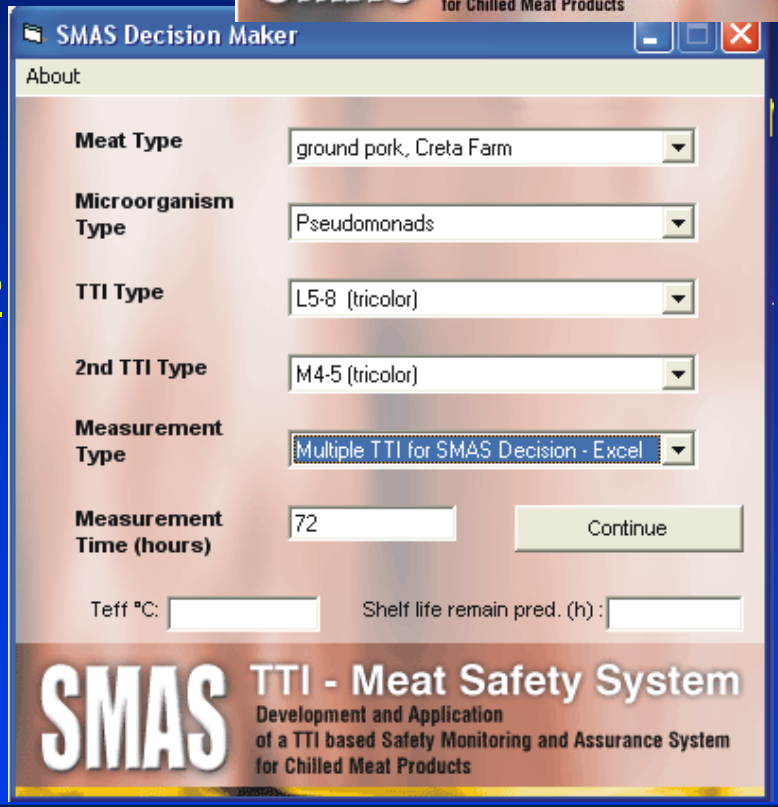
Software output: Integrated temperature history and quality status of each product

Instructions with regards the products' management and further handling in the chill chain

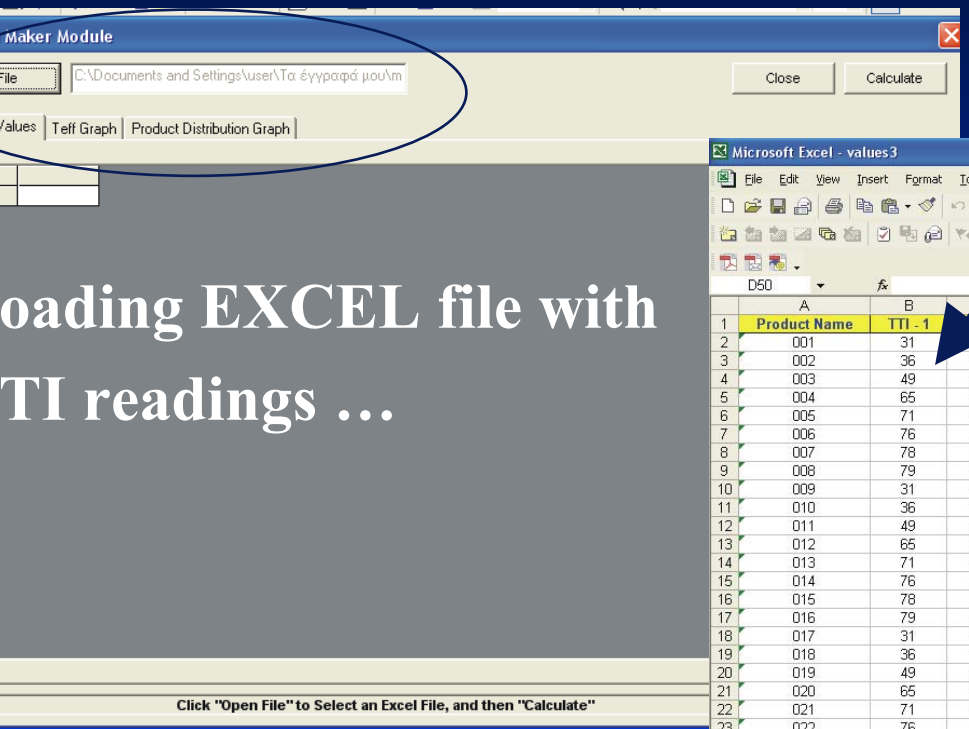
e 'SMAS Decision Maker' software
Chill chain decisions

Information provided by the user:

- Meat product used in the Field Test
- Microorganisms of concern
- TTI type(s) attached on the products
- How are the measurement(s) given?
- EXCEL file where the TTI color readings input
- Time of Decision (h)

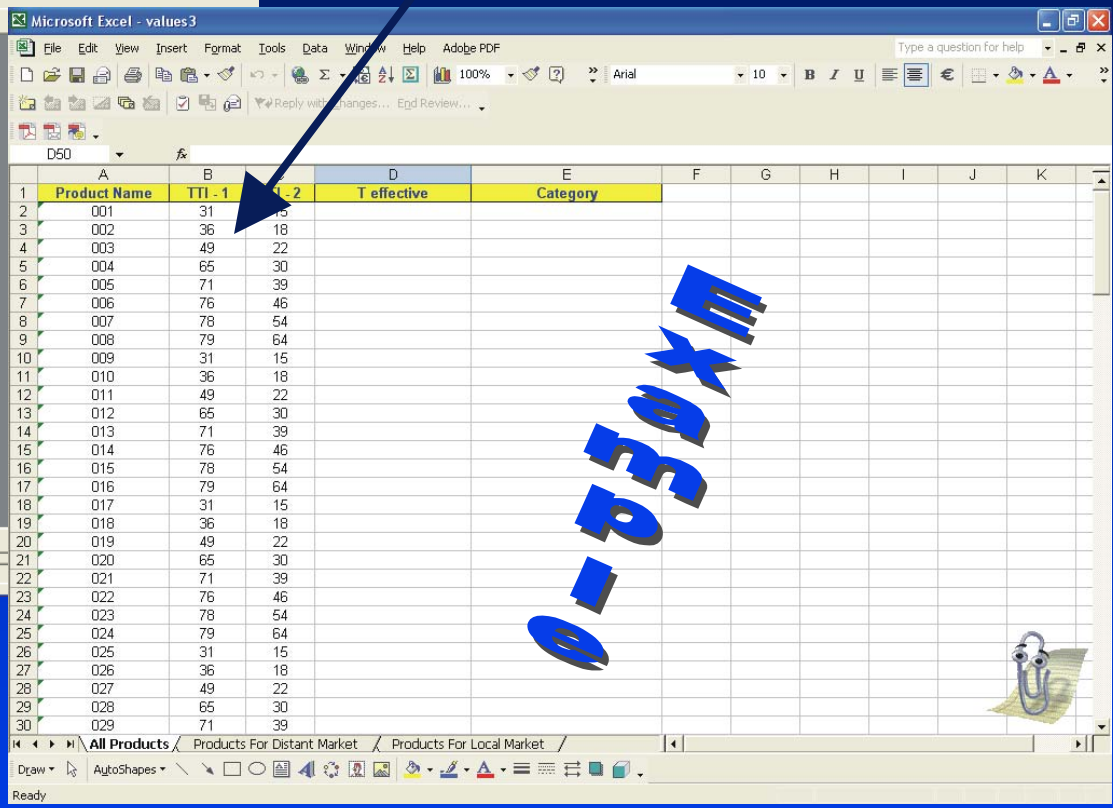


The 'SMAS Decision Maker' software



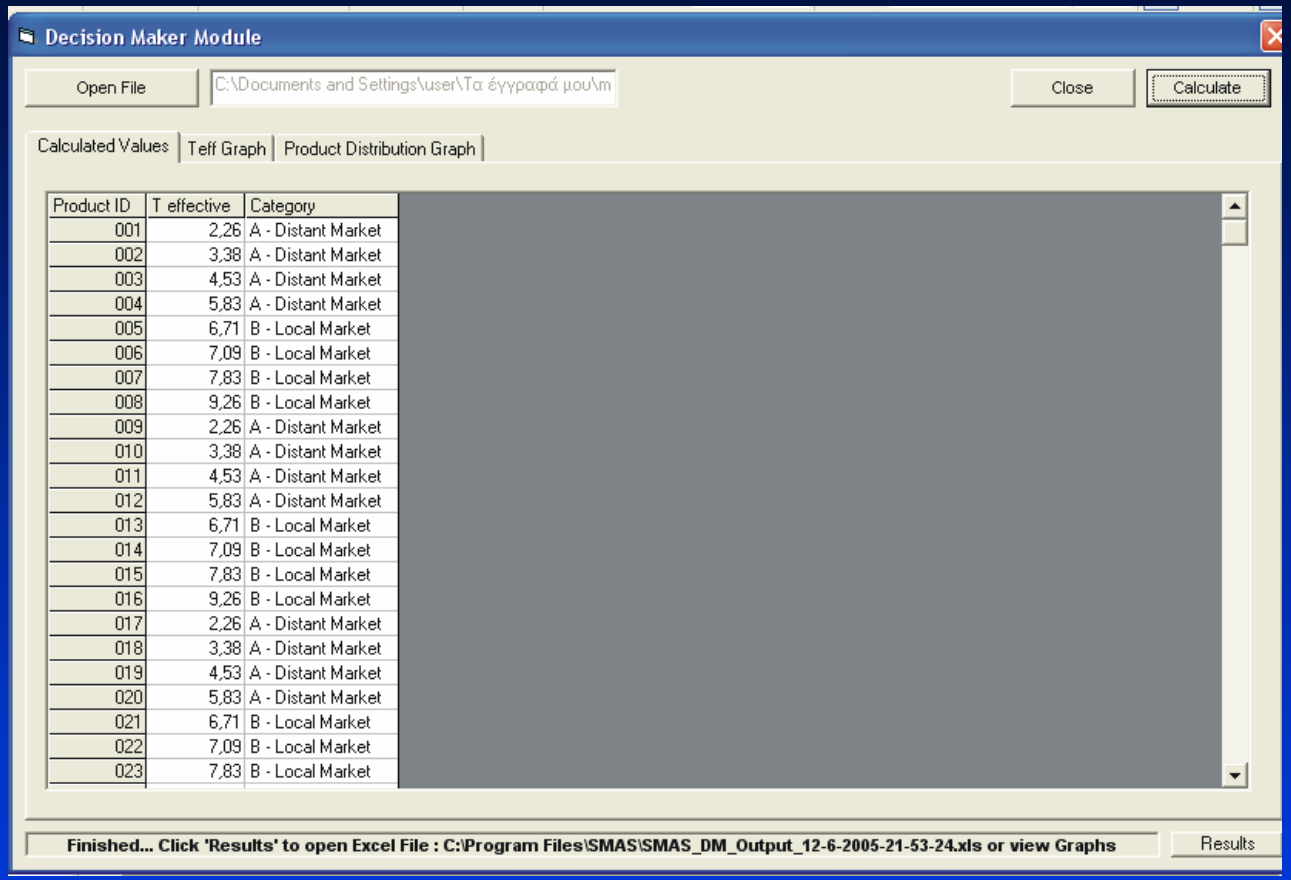
Loading EXCEL file …

TTI readings (CHROMATIC SCALE) filled in an EXCEL worksheet



Excel

The 'SMAS Decision Maker' software



Product ID	T effective	Category
001	2,26	A - Distant Market
002	3,38	A - Distant Market
003	4,53	A - Distant Market
004	5,83	A - Distant Market
005	6,71	B - Local Market
006	7,09	B - Local Market
007	7,83	B - Local Market
008	9,26	B - Local Market
009	2,26	A - Distant Market
010	3,38	A - Distant Market
011	4,53	A - Distant Market
012	5,83	A - Distant Market
013	6,71	B - Local Market
014	7,09	B - Local Market
015	7,83	B - Local Market
016	9,26	B - Local Market
017	2,26	A - Distant Market
018	3,38	A - Distant Market
019	4,53	A - Distant Market
020	5,83	A - Distant Market
021	6,71	B - Local Market
022	7,09	B - Local Market
023	7,83	B - Local Market

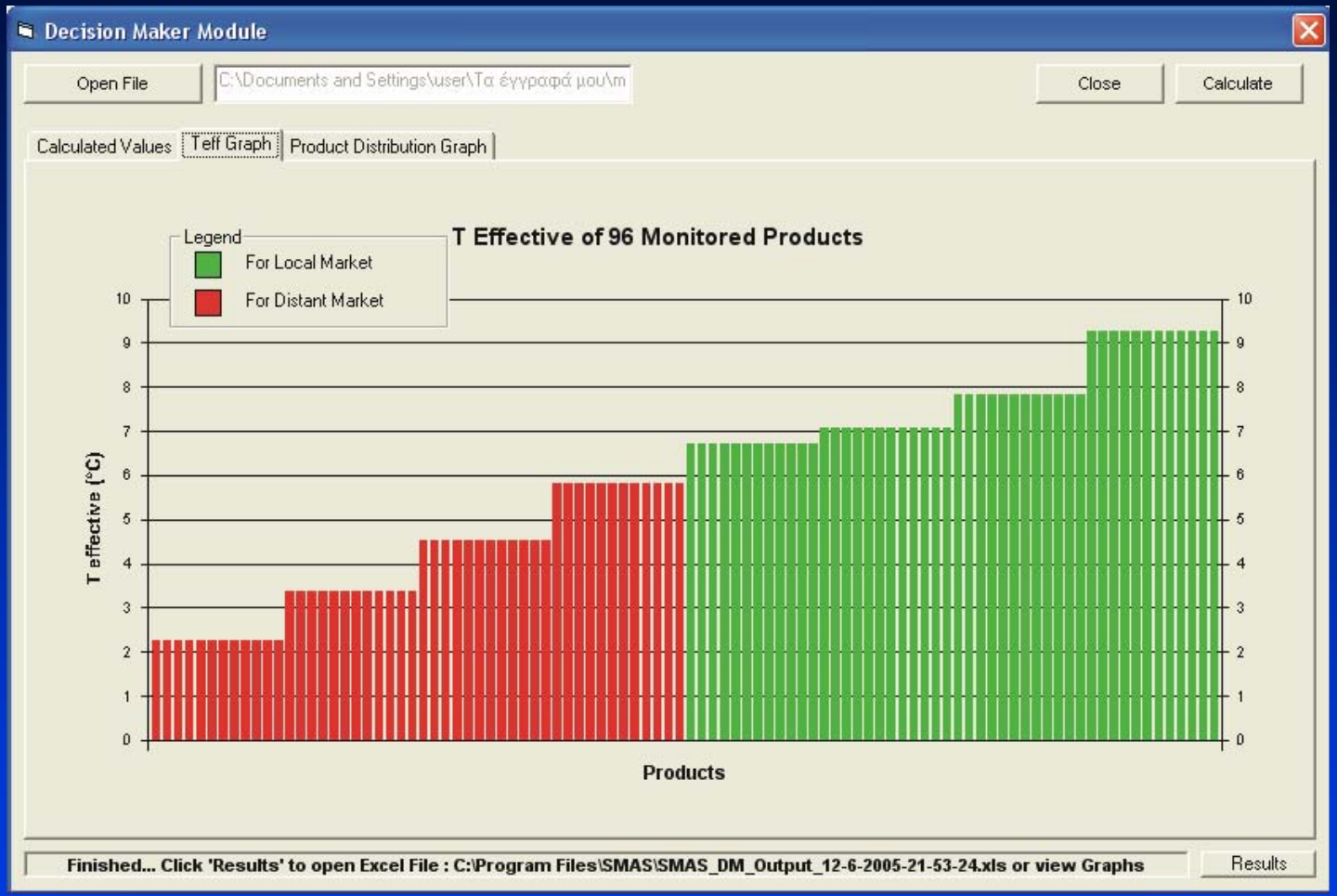
Calculations are made for all products …

- the value of T_{eff} is estimated for EACH product
- A decision is made for their destination

Local market

Distant market

The 'SMAS Decision Maker' software



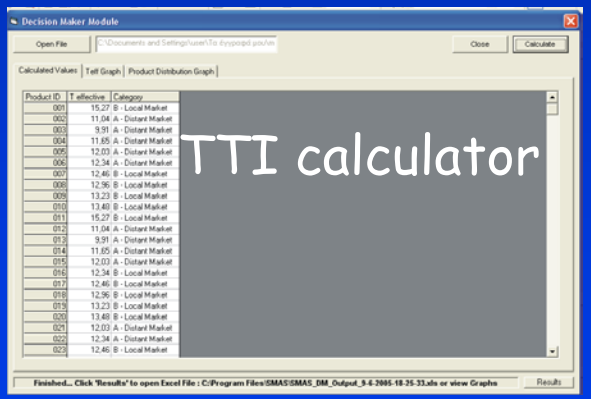
A graph illustrates the values of T_{eff} for all products

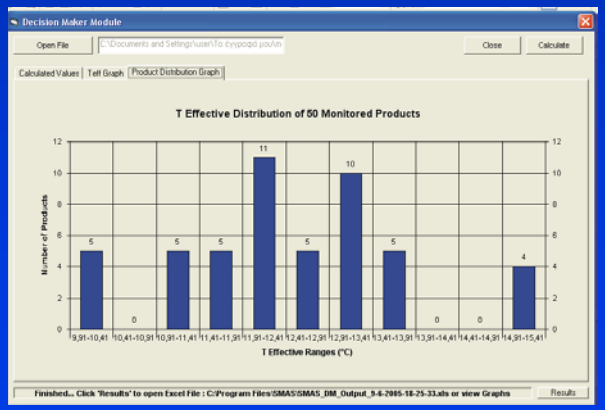
SMAS Decision Software

TTI READINGS

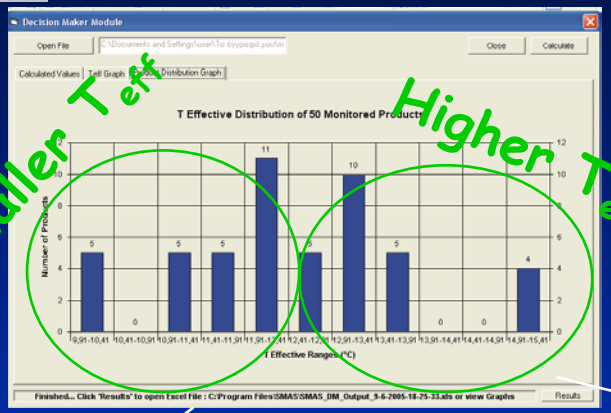
MAIN ISSUE: Instead of using FIFO or random approach,
USE OF REAL TTI READINGS
at the decision point

REAL T_{eff} distribution based on TTI readings





TTI READINGS



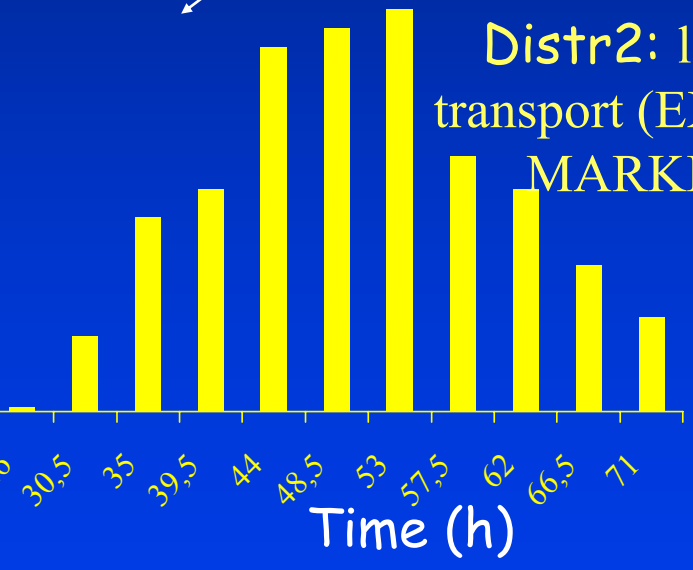
Smaller T_{eff}

Higher T_{eff}

REAL T_{eff} distribution based on TTI readings

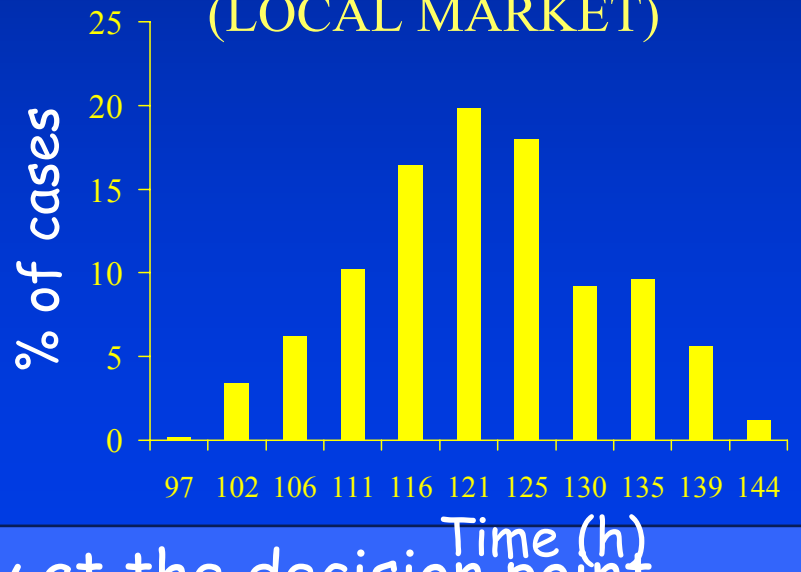
SMAS based split

transport to the RETAIL



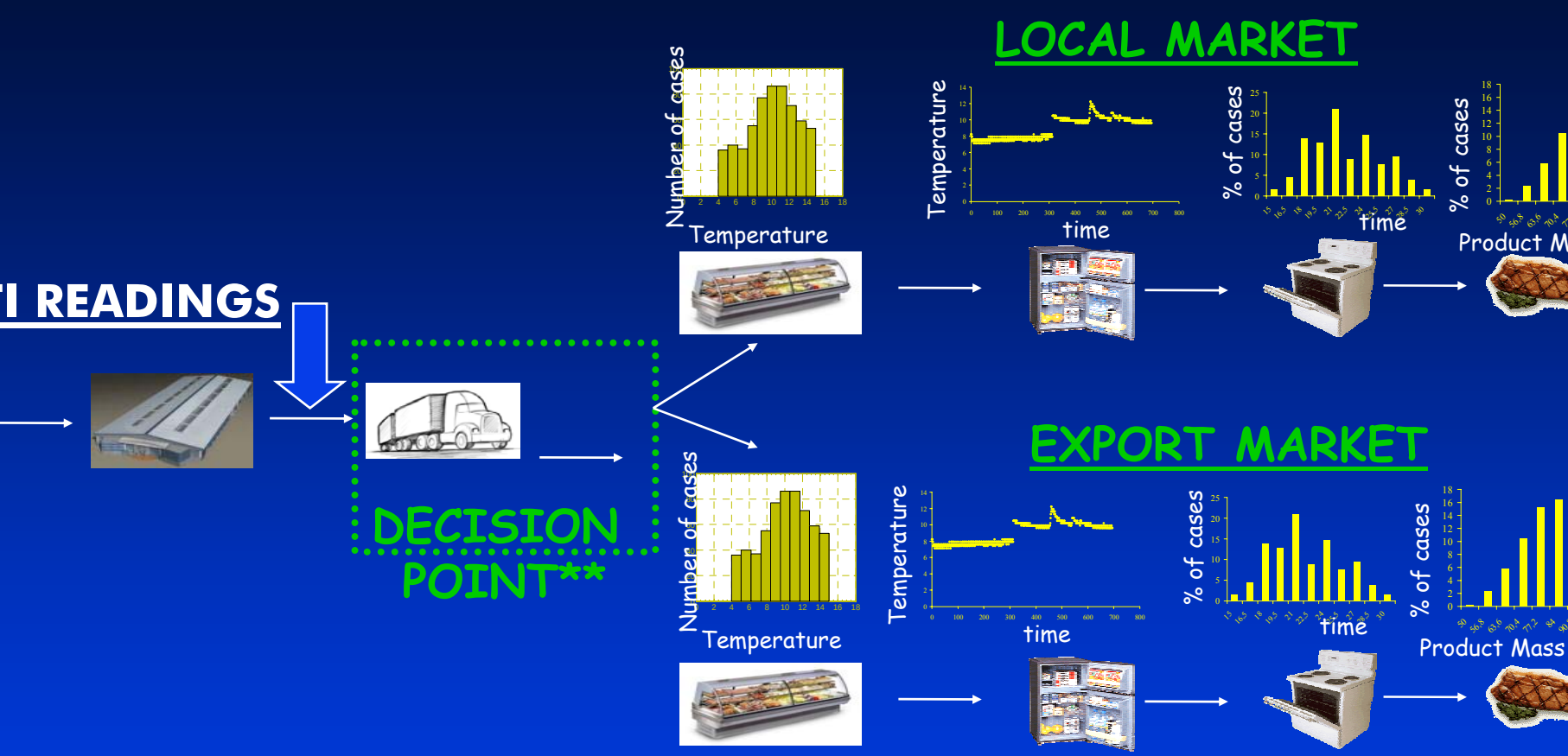
Distr2: longer transport (EXPORT MARKET)

Distr1: short transport (LOCAL MARKET)



Application of SMAS policy at the decision point

SMAS Assessment Software



** 1st study: Application of SMAS policy at the decision poi
2nd study: FIFO policy at the decision point-random spli

e 'SMAS Assessment' software

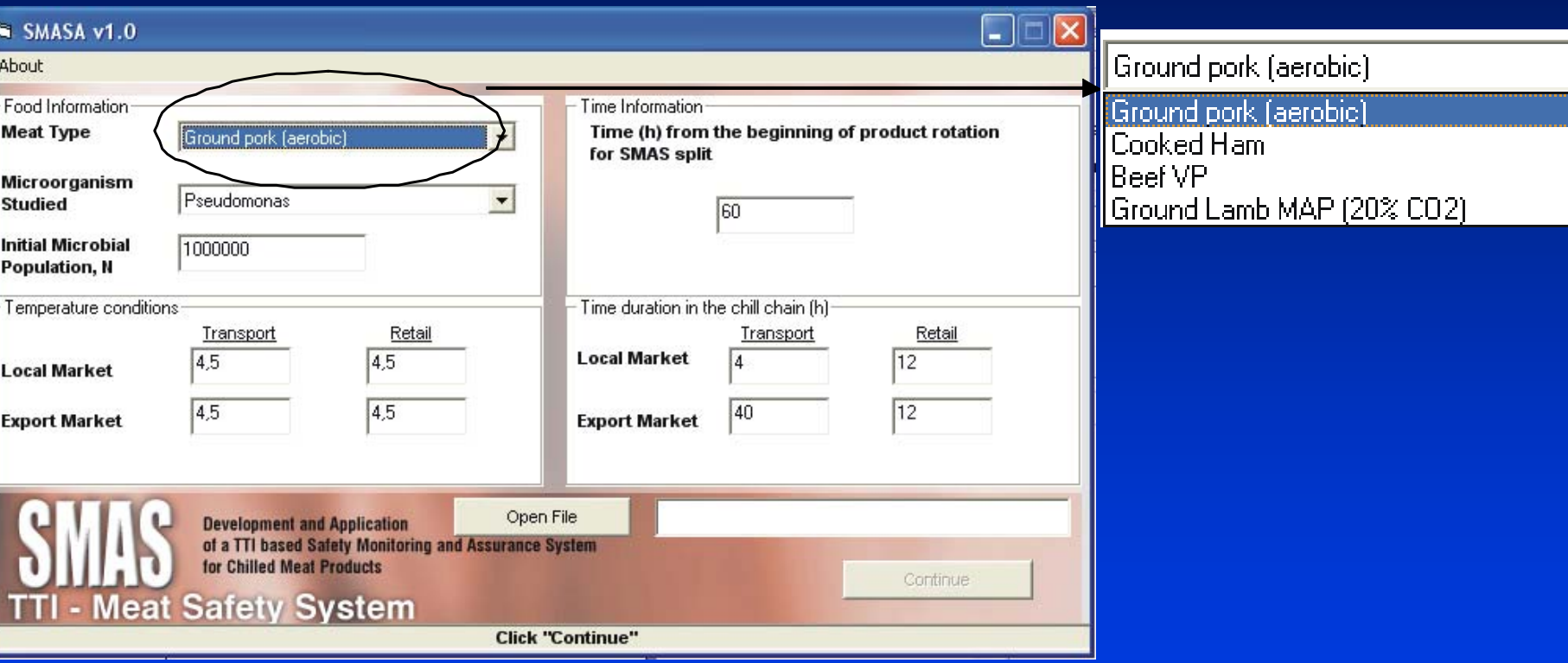
Information provided by the user:

1. Meat product used in the Field Test
2. Microorganisms of concern
3. Initial microbial load
4. Temperature Conditions in the chill chain
5. Time of split (h) [SMAS point]
6. Time in the chill chain after split
7. TTI readings at split time (folder)

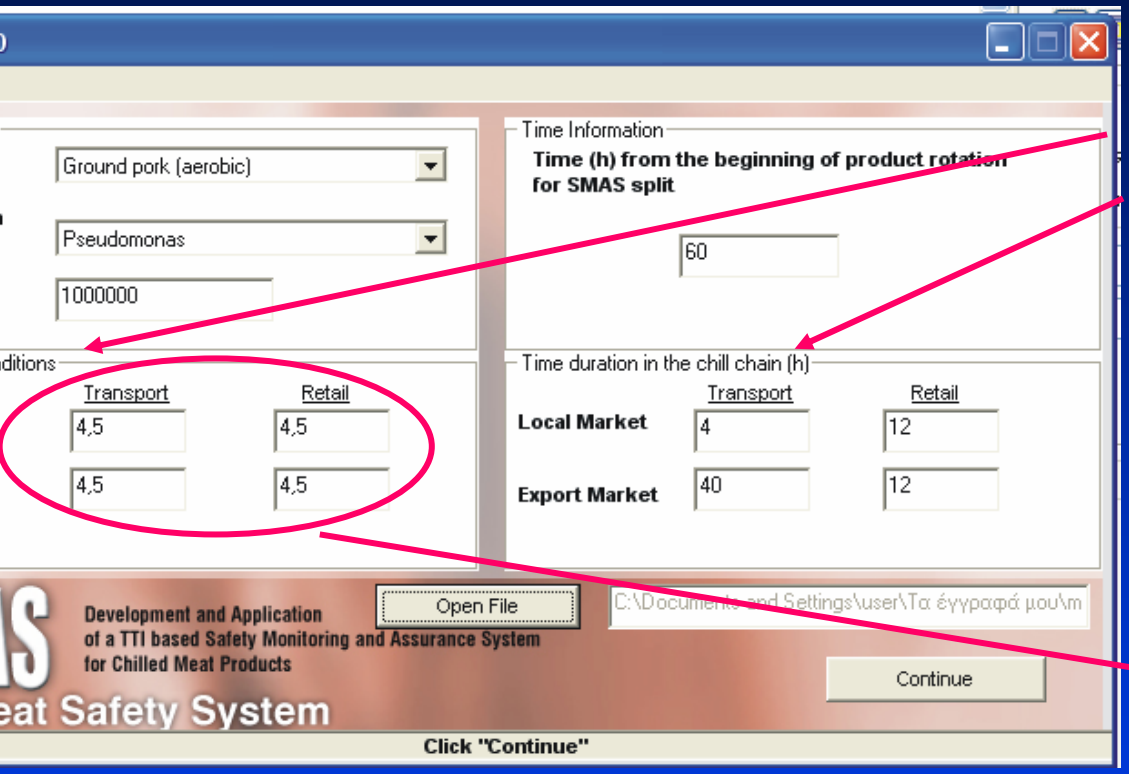
Algorithm developed in MATLAB Environment – interface developed using Visual Basic tools

The "SMAS" Assessment" software

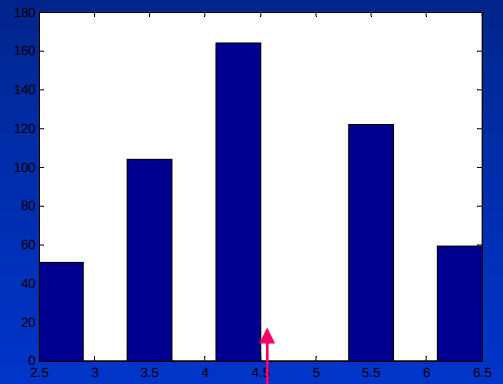
Introductory screen



The 'SMAS Assessment' software



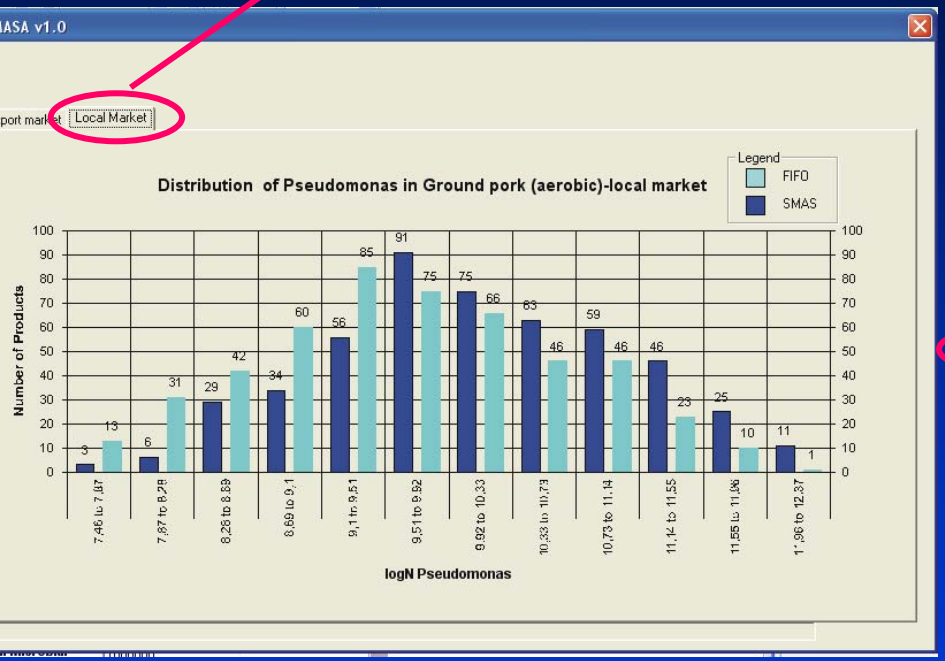
Instead of single-value para
temperature distributions ar
(based on data from SMAS



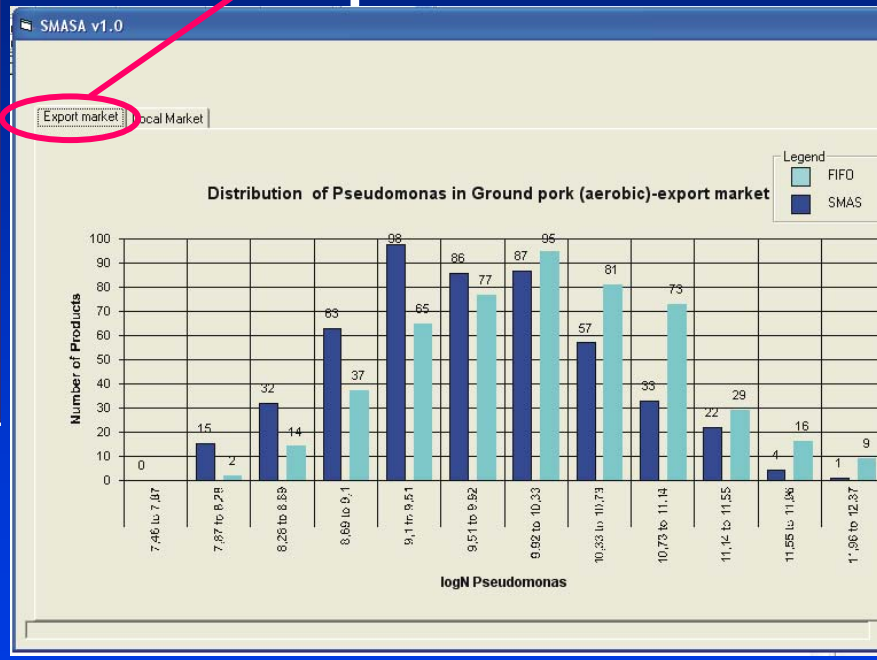
Mean value

The SMAS Assessment results - probability plots

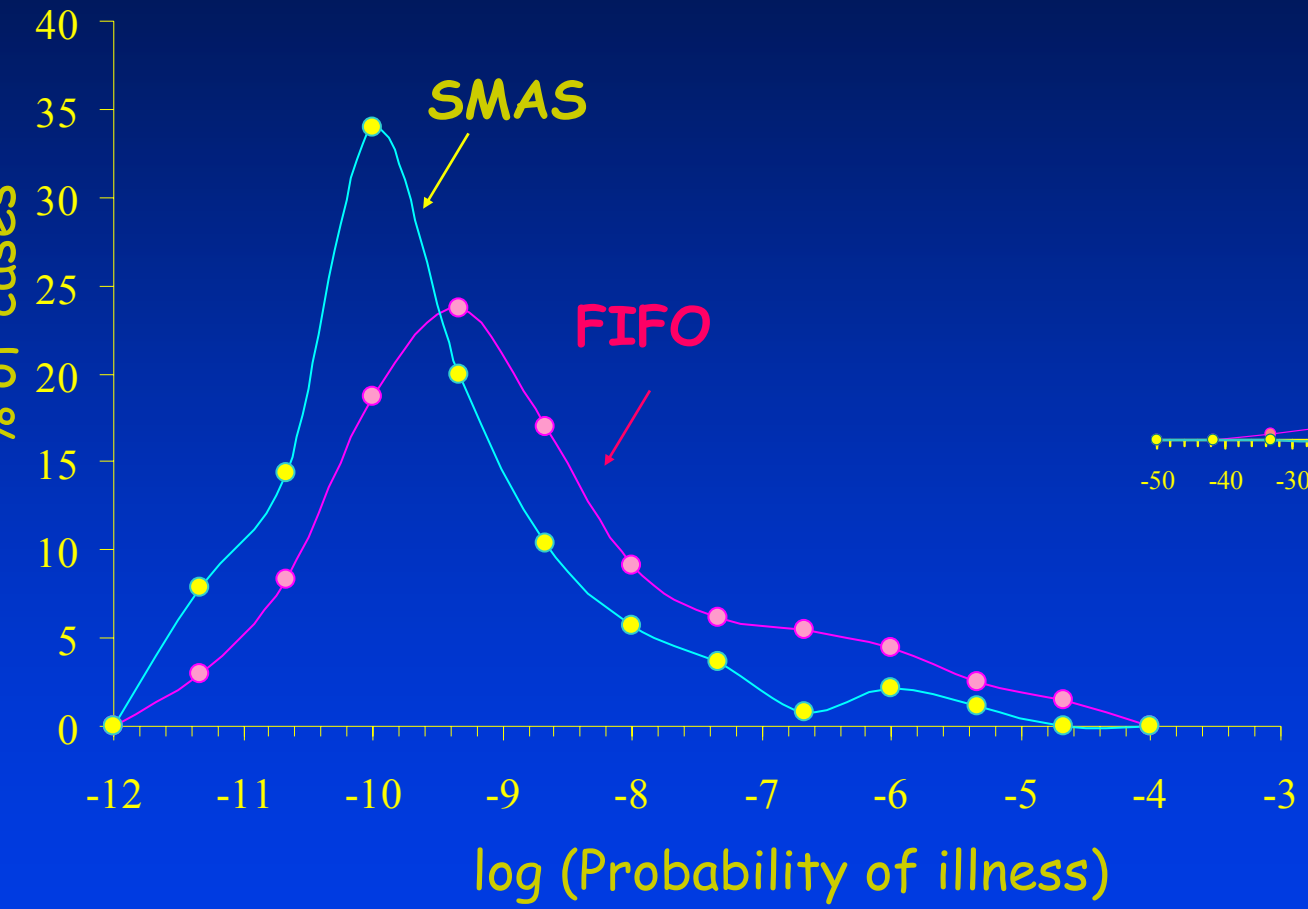
Local market

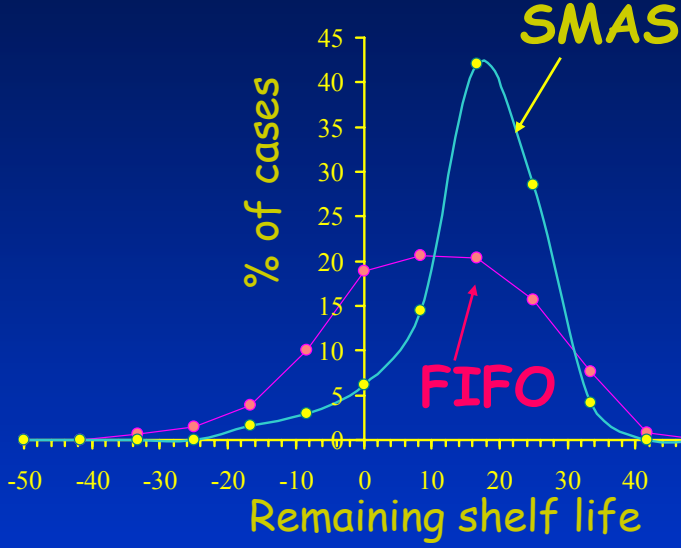


Export market



Assessment with SMAS Software





Results (output) of SMAS software

Safety Monitoring and Assurance System (SMAS) Validation in real chill chain studies

TTI Application on real meat products

"Field" Tests

Field Test 1

Product: Pork Cuts (MAP 60% CO_2)

TTIs: Enzymatic TTIs-2 types: L4-11 & M4-6 VITSAB

Temperature Conditions: ranging from 2 to 14°C

Bacteria measured: Lactic Acid Bacteria

Field Test 1
Microbial growth study

- Modified atmosphere packed fresh pork cuts (60% CO_2)
- Growth data of spoilage bacteria of pork cuts stored at 3 isothermal conditions (0, 5, 10°C), estimation of μ_{max}, lag phase (Baranyi model)
- Development of a predictive model for the effect of temperature and CO_2 on *Lactic acid bacteria* growth on por cuts

Lactic acid bacteria	
μ_{ref} (h^{-1})	0.374
Std error	0.011
E_a (kJ/mol)	101
Std error	8.5
R^2	0.969

$$\mu_{\max} = \mu_{ref} \exp\left[\frac{-E_a}{R}\left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right]$$

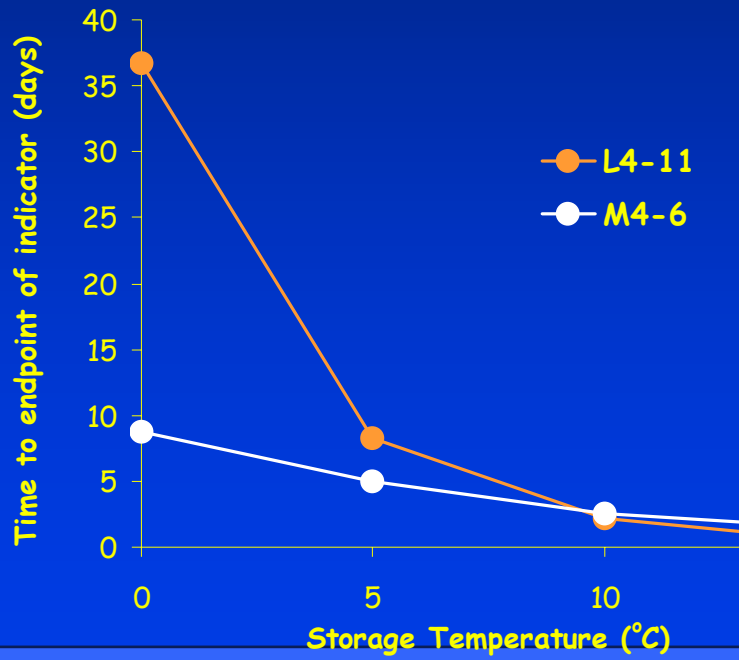
Field Test 1
TTI Study

2 TTI tags were used for each meat sample

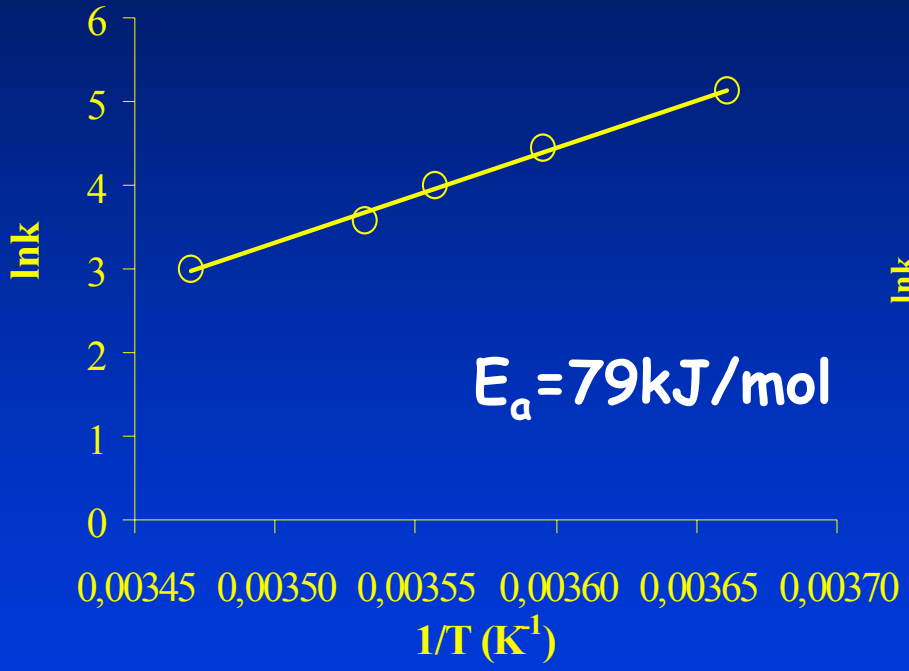
2 Enzymatic TTI Types used: L4-11 & M4-6
(Vitsab A.B, Malmo, Sweden)

M4-6 was designed to expire within 7 days at 5°C

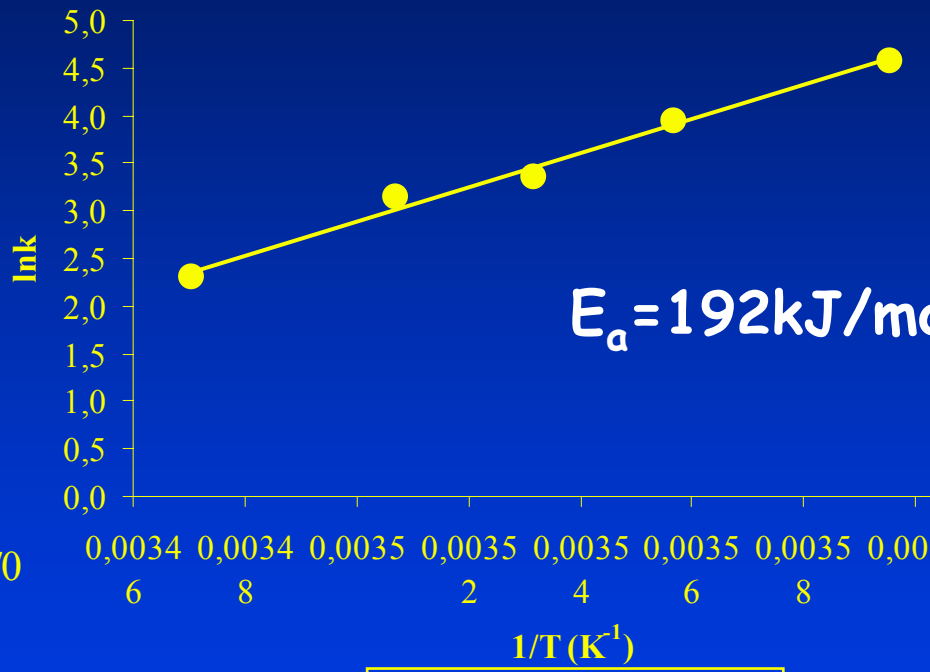
L4-11 having a higher activation energy (E_a=192kJ/mol), thus being more temperature sensitive, expire within 2 days at 10°C serving as indicator at the time of SMAS decision



TTI Kinetic Study- Arrhenius Plot



M4-6 TTI



L4-11 TTI

SMAS Field Test 2

oduct: Ground lamb (MAP 20% CO_2)

TIs: L4-11 & M4-10

emperature Conditions: ranging from 2 to 10°C

acteria measured: Lactic Acid Bacteria
Listeria Monocytogenes

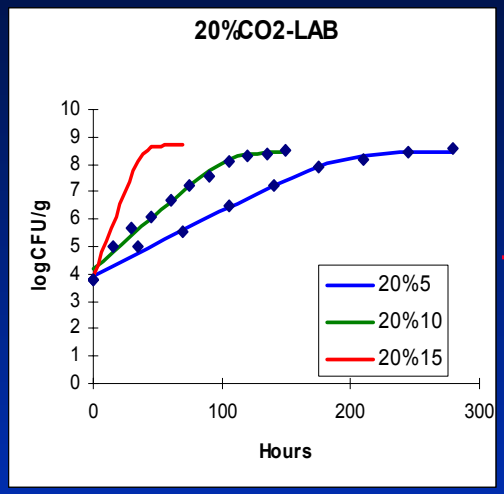
Field Test 2

Microbial growth study

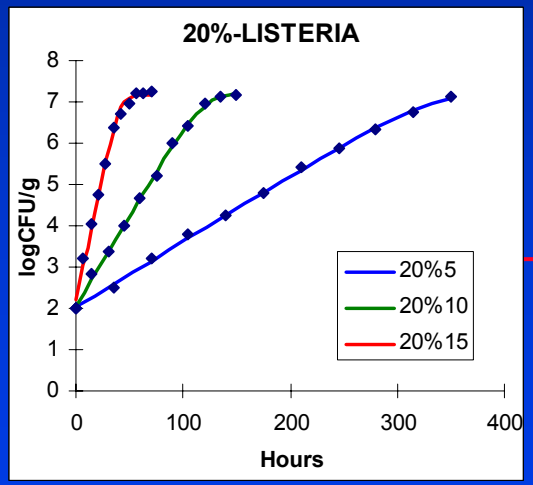
Storage in the range 5 – 15° C

. Lactic acid bacteria
. Total aerobic microflora
. Pseudomonas
. *Listeria monocytogenes*

LACTIC ACID BACTERIA and *Listeria monocytogenes* GROWTH IN MAP *GROUND LAMB*



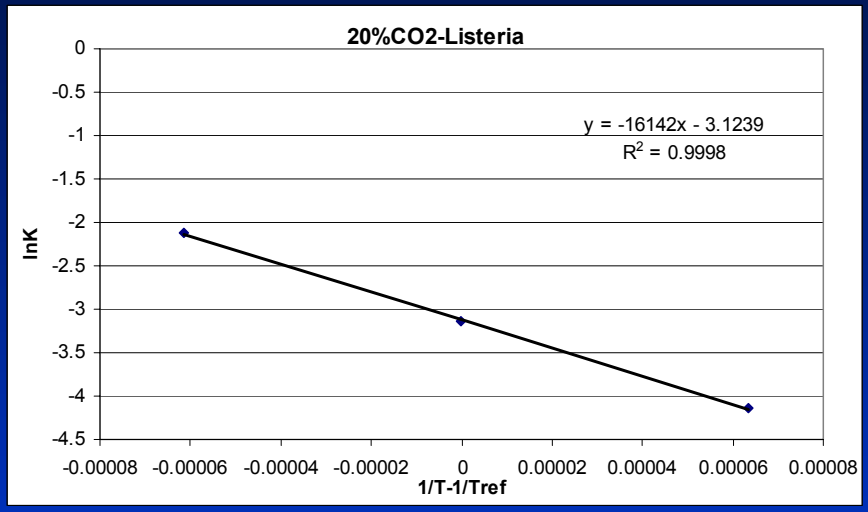
MAP 20% CO_2	
TEMPERATURE (°C)	K_C (hr^{-1}) LAB
5	0.023
10	0.041
15	0.125



20%CO_2	
TEMPERATURE (°C)	μ_{max} (h^{-1})
5	0.016
10	0.043
15	0.119

SMAS Field Test

TEMPERATURE DEPENDENCE OF Growth rate for 20%CO_2 *MAP Ground lamb*



ctic acid bacteria		*Listeria Monocytogenes*	
(h^{-1})	0.017	μ_{ref} (h^{-1})	0.101
J/mol)	93.6	E_a (kJ/mol)	134.2

$$\mu_{\max} = \mu_{ref} \exp\left[\frac{-E_a}{R}\left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right.$$

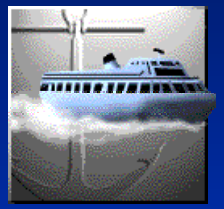
SMAS Field Test

Temperature Conditions during the Field Test

- On half samples, enzymatic TTIs were attached at the time of packing
- All products entered the regular transportation route to the central distribution centre of the manufacturer
- Then the samples were stored in the research food laboratory, in programmable cabinets simulating the conditions of the real chill chain to the point of consumption

Field Tests Design

72 packages of meat

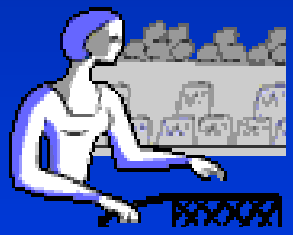


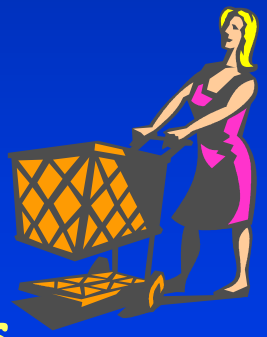
Distribution center (decision point)

Labora
simula
condit

Local market

Export market





consumers

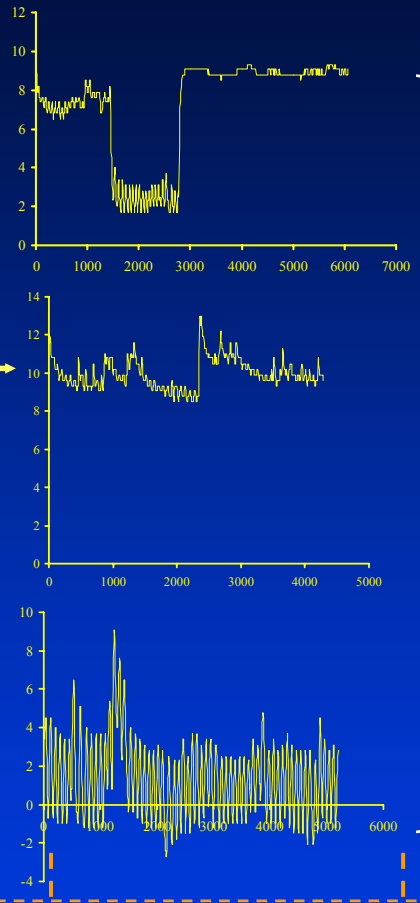
Field tests Design

60 packages without TTIs

ackages

60 Packages
2 TTI tags attached on each package

1st step



2nd step
72/64 h at various T conditions

SMAS based split

Decision point

TTIs reading

3rd step

Local market
24, 48, 72h

Export market
96, 120, 144h

4°C

8°C

4°C

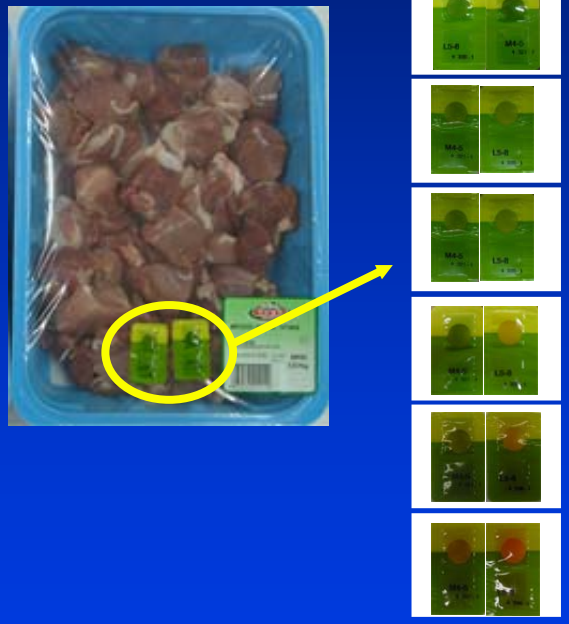
8°C

Microbiological analysis
4th step

MAS Field Test - Ground lamb

TTI readings at the time of decision (SMAS based split)

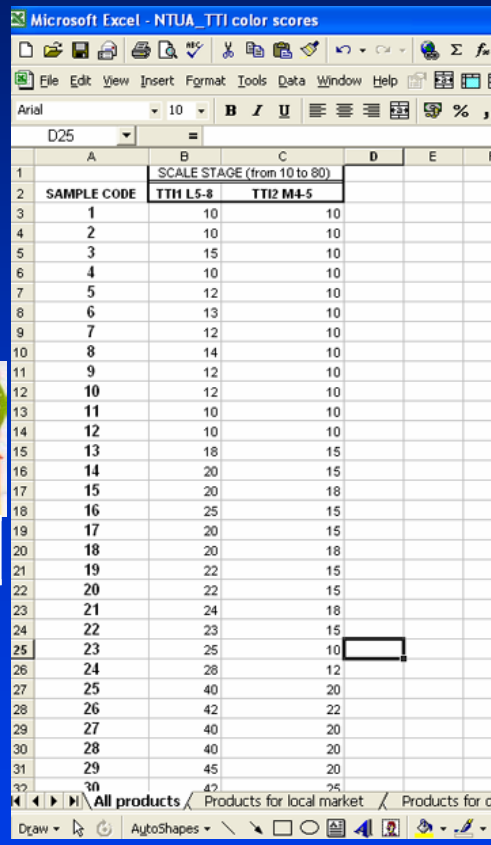
After 72 (or 64) hours **SMAS samples** were split according to the TTI color readings, using the 8-stage color scale and the 'SMAS Decision Maker' software



SDM Software input:

TTI color readings

using the 8-stage color reference scale



	A	B	C	D	E
1		SCALE STAGE (from 10 to 80)			
2	SAMPLE CODE	TTI1 L5-8	TTI2 M4-5		
3	1	10	10		
4	2	10	10		
5	3	15	10		
6	4	10	10		
7	5	12	10		
8	6	13	10		
9	7	12	10		
10	8	14	10		
11	9	12	10		
12	10	12	10		
13	11	10	10		
14	12	10	10		
15	13	18	15		
16	14	20	15		
17	15	20	18		
18	16	25	15		
19	17	20	15		
20	18	20	18		
21	19	22	15		
22	20	22	15		
23	21	24	18		
24	22	23	15		
25	23	25	10		
26	24	28	12		
27	25	40	20		
28	26	42	22		
29	27	40	20		
30	28	40	20		
31	29	45	20		
32	30	42	25		

IFO samples were split randomly

SMAS Field Tests – Microbial Testing Timetabl

er the TTI color readings all SMAS samples:

e sorted according to their temperature history (software output)

PLIT into 2 subgroups: the more temperature abused belong to 'Pro
r local market', the rest of them belong to 'Products for distant m

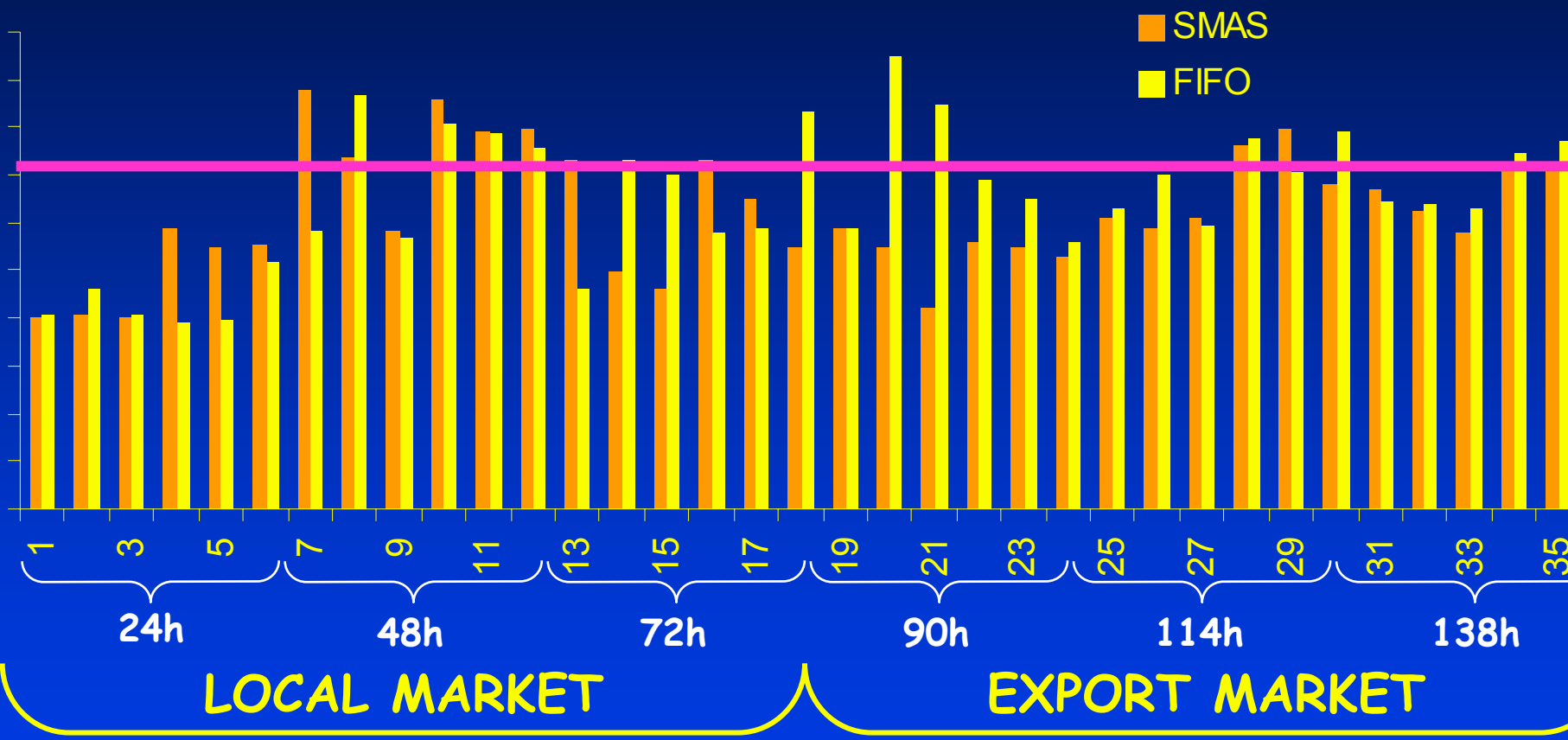
th groups (local & export) are stored in two different temperature
,8°C)

he microbiological analysis timetable is according to the split:

Local Market			Export Market		
t_1	t_2	t_3	t_4	t_5	t_6
24h	48h	72h	90h	114h	138h

SMAS FIELD TEST 1 RESULTS

robiological analysis shows the different distribution of microbial load in
ps (FIFO & SMAS)

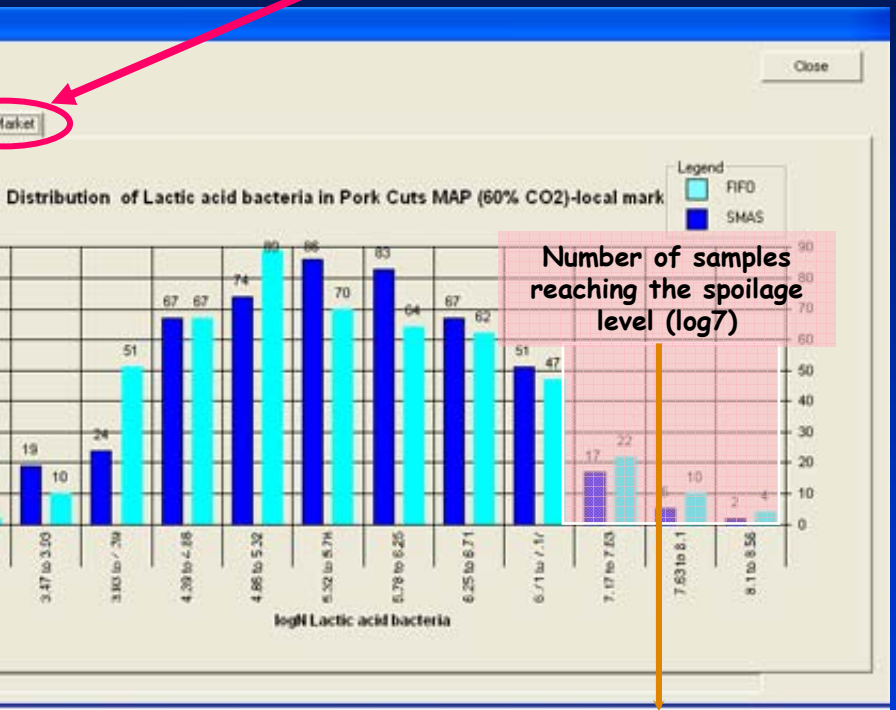


33% samples reach the spoilage leve
of log7 with FIFO approach and 16
when SMAS split is applied

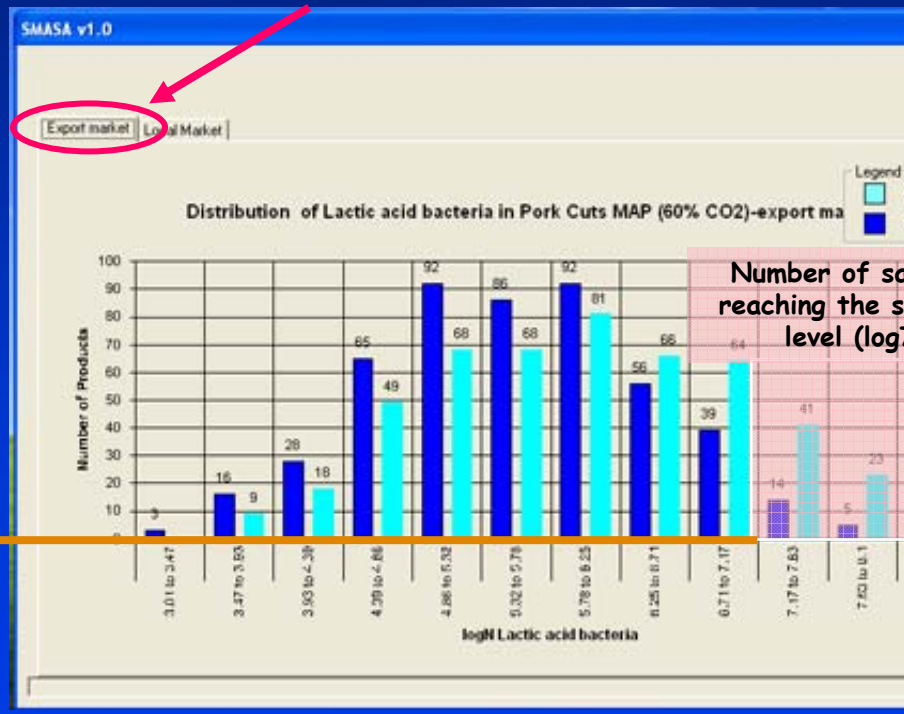
MAS Field Test – Pork cuts

The "SMAS" Assessment Software results probability plots

Local market



Export market

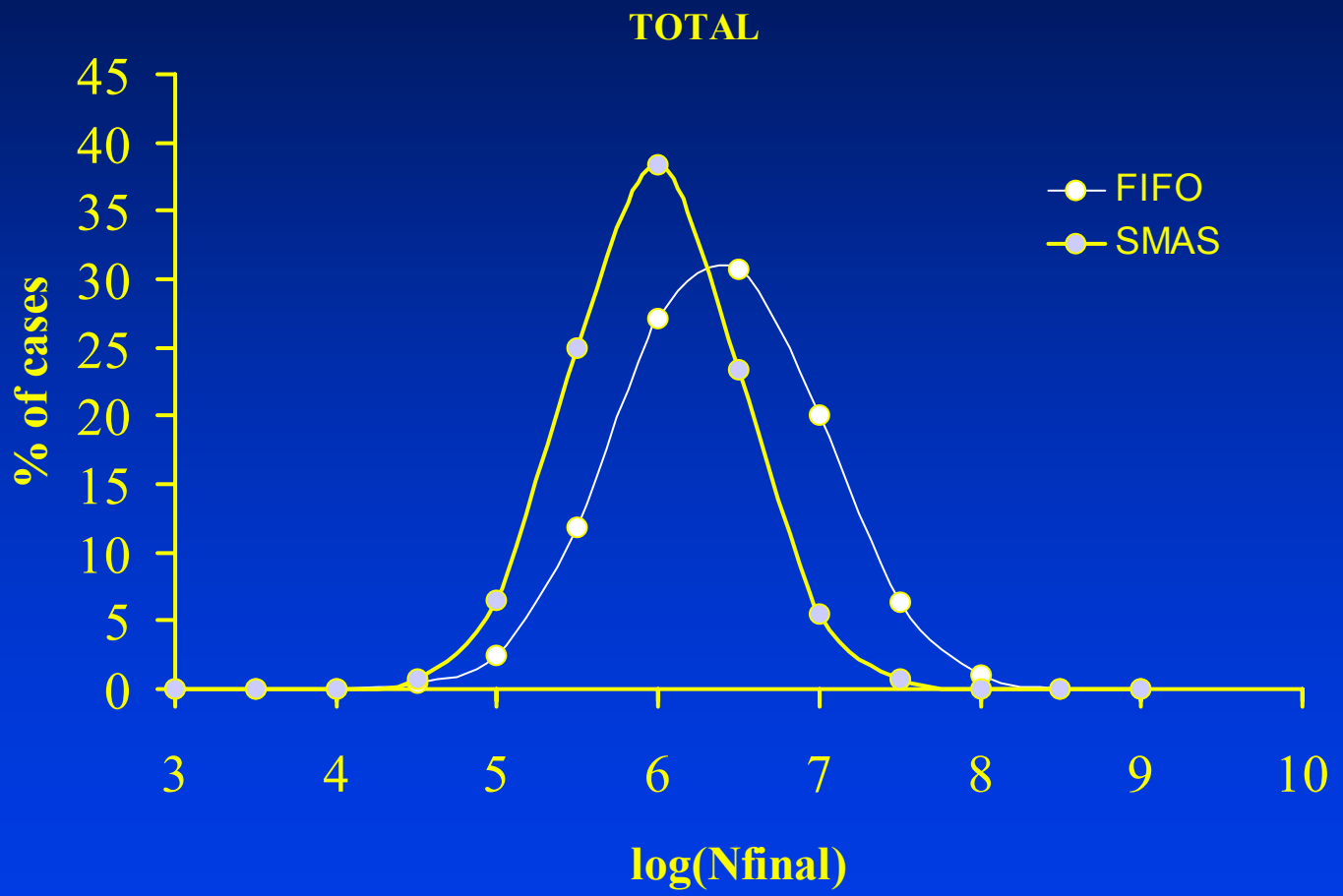


Market

amples reach the spoilage level of
ith FIFO approach and 17% when
split is applied

MAS Field Test 1-Pork Cuts

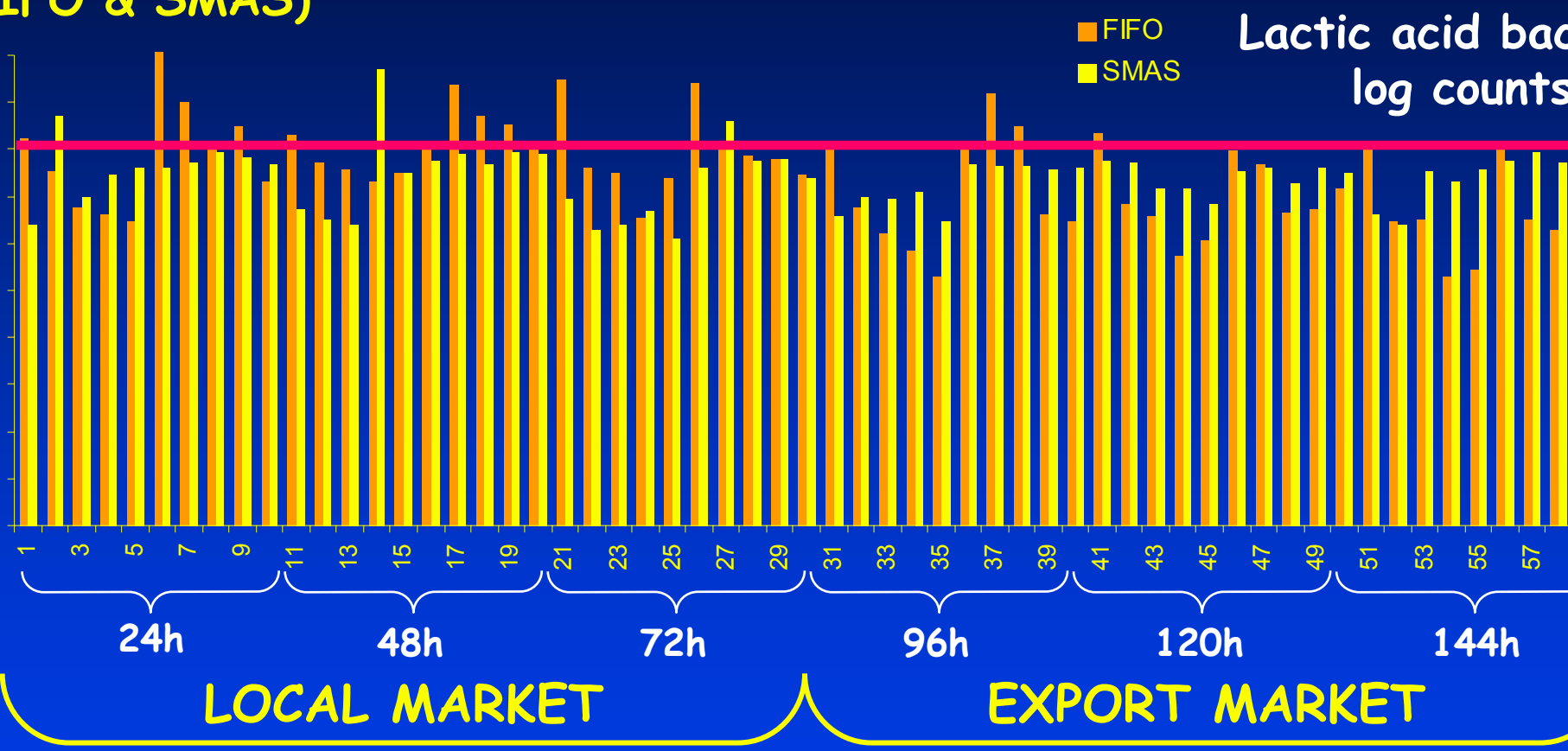
luating the effectiveness of the TTI based SM system using a Monte Carlo simulation approac



MAS Field Test 1-Pork Cuts

SMAS FIELD TEST 2 RESULTS

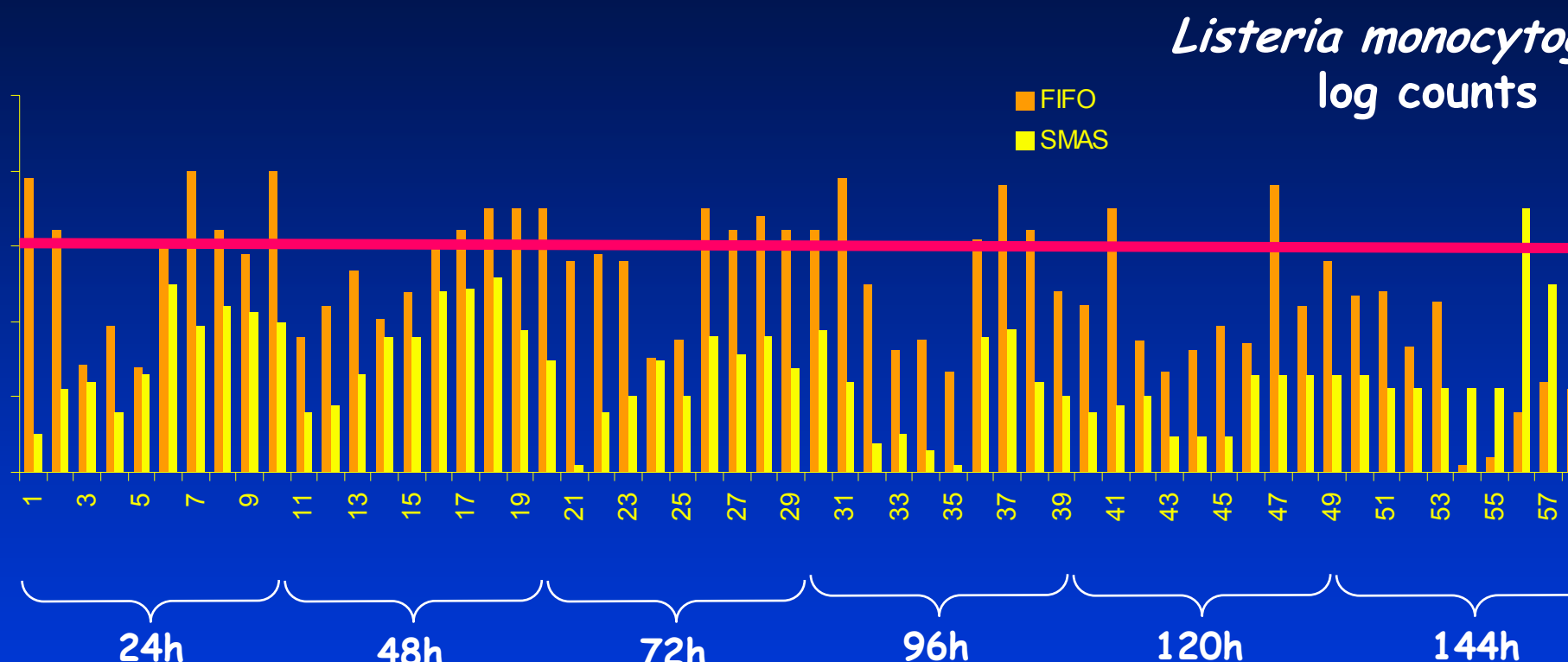
lculated microbial log counts for each date of microbiological analysis
ow the different distribution of microbial load in the 2 groups
IFO & SMAS)



MAS Field Test 2 - Ground lamb

22% samples reach the spoilage leve
of log8 with **FIFO** approach and **5%**
when **SMAS** split is applied

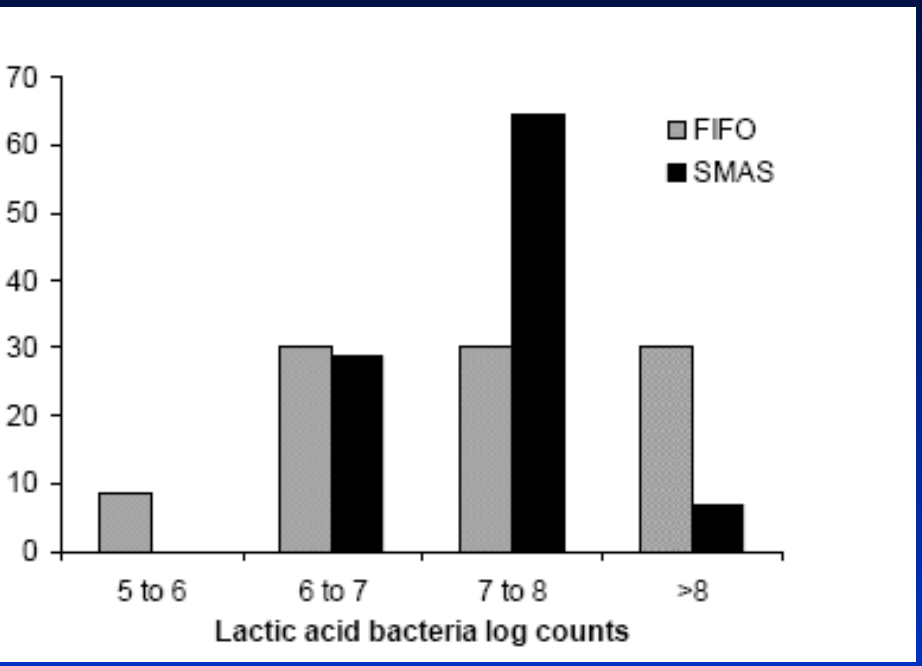
SMAS FIELD TEST 2 RESULTS



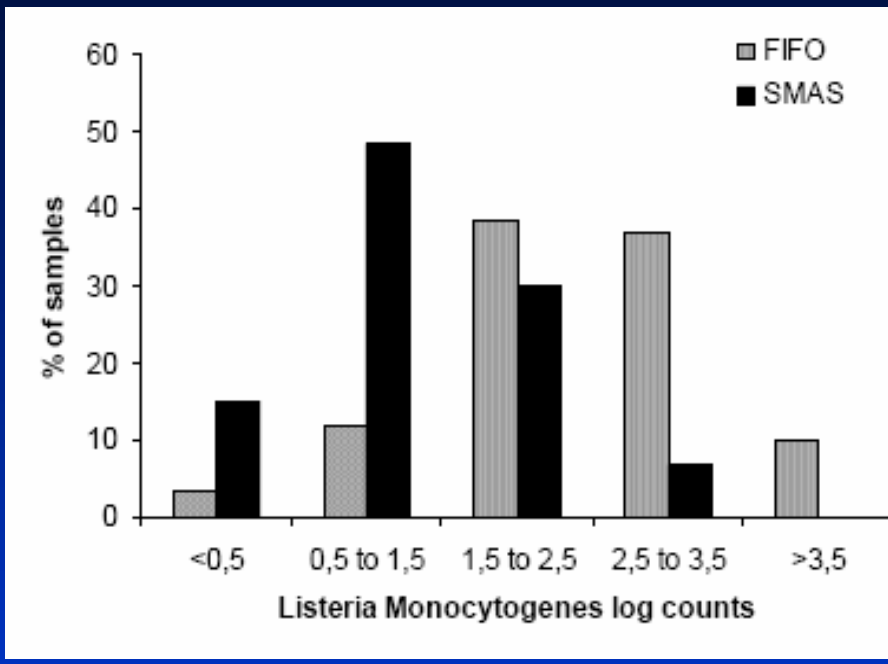
28% samples reach the level of log3 with FIFO approach 3% when SMAS split is applied

MAS Field Test - Ground lamb

SMAS FIELD TEST 2 RESULTS



tribution of Lactic acid bacteria growth for 120 samples at time of microbiological lysis - time of 'consumption'.



Distribution of *Listeria monocytogenes* gro all 120 samples at time of microbiological analysis - time of 'consumption'.

The **distribution** of microbiological growth (spoilage and pathogens **moves to the left i.e. to lower values**,

for the **SMAS** sorted samples.

MAS
alidation Tests

Participants

- NTUA, Greece
- SIK, Sweden
- TNO, The Netherlands
- Teagasc, Ireland
- AUA, Greece

Meat Product	Packaging	Microorganisms measured	TTI for product monitoring
Pork cuts	MAP	Lactic acid bacteria	L4-11t / M4-6t
Ground pork	Air	Pseudomonas	L4-11t / M4-10t
Ground pork	Air	Pseudomonas/*Listeria monocytogenes*	L4-11t / M4-10t
Ground pork	Air	Pseudomonas/ *Salmonella enteriditis*	L4-11t / M4-10t
Ground lamb	MAP	Lactic acid bacteria /*Listeria monocytogenes*	L4-11t / M4-6t
Beef	VP	Lactic acid bacteria /*E. coli O157:H7*	L4-54t / M4-29t
Cooked ham	MAP	Lactic acid bacteria /*Listeria monocytogenes*	L4-54t / M4-29t
Ground beef	Air	Pseudomonas	M4-6t / M4-10t

S M A S

QLK1-CT-2002-02545

elopment and application of a TTI based Safety Monitorin and Assurance System for Chilled Meat Products

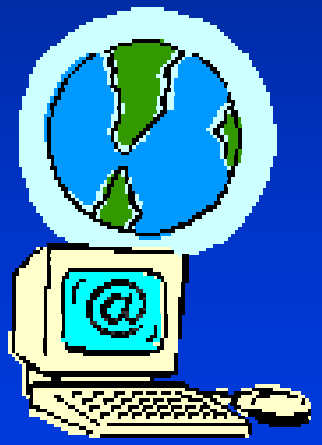
ropean Commission Research and Technology Development Projec

FIFTH FRAMEWORK PROGRAMME
Quality of life and management of living resources

http://smas.chemeng.ntua.gr

ICROBIAL RISK ASSESSMENT of meat produc
(MIRAM)

A SMAS Project Site



http://smas.chemeng.ntua.gr

Quality Management of the Chill Chain

International Workshop

16 December 2005

Athens, Greece

National Technical University of Athens

Agricultural University of Athens

http://smas.chemeng.ntua.gr

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