The EU-project SMAS: Safety Monitoring and Assurance System for Chilled Meat Products

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International Workshop

Quality Management of the Chill Chain

Athens, GREECE, 16 December, 2005

National Technical University of Athens, School of Chemical Engineering
Laboratory of Food Chemistry and Technology

S M A S

QLK1-CT-2002-02545

Development and application of a TTI based Safety Monitoring and Assurance System for Chilled Meat Products

A European Commission Research and Technology Development Project

FIFTH FRAMEWORK PROGRAMME
Quality of life and management of living resources

http://smas.chemeng.ntua.gr

Meat Chill Chain- Need for better management

Meat products are perishable and unless processed, packaged, distributed and stored appropriately can spoil in relatively short time. Overgrowth of incidental pathogenic bacteria like *Listeria monocytogenes*, *Salmonella sp.* and *Escherichia coli* followed by undercooking or inadequate preparation may pause a potential hazard for the consumer. Despite the proliferation of food safety regulations and the application of safety management systems such as HACCP, risk assessment studies show that foodborne disease has remained a main concern in the last decade.

Why SMAS?

Meat Chill Chain-
Need for better management

It is generally recognized by the European industry, retailers, food authorities and even consumers that the weakest link that affects directly safety and quality of chilled products is the actual ***chill chain***. A big percentage of foodborne disease is due to temperature abuse.

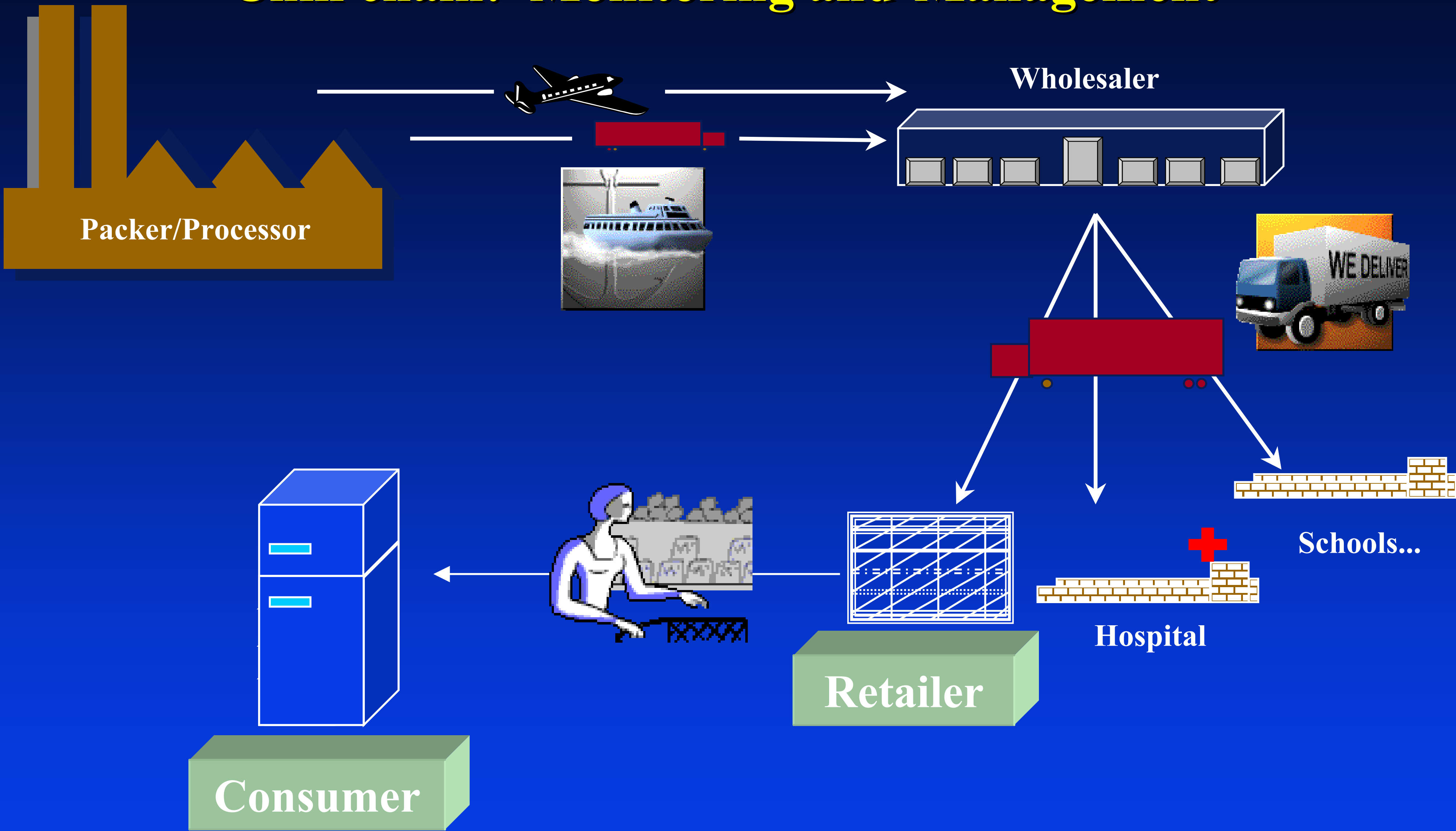
Why SMAS?

Meat Chill Chain- Need for better management

Application of an optimised quality and safety assurance system for chilled distribution of fresh meat and meat products requires continuous monitoring and control of storage conditions from production to consumption. The systematic management of the chill chain and the improved evaluation of safety, quality and shelf life of meat can lead to reduced safety risk and increased quality, with a significant health and economic impact to the European society and market.

Why SMAS?

Chill chain: Monitoring and Management



From packing to consumer

What is SMAS?

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

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

The SMAS project

The acronym *SMAS* summarizes the long title of the 3 year (2003-2006) action project "Development and application of a TTI based Safety Monitoring and Assurance System for Chilled Meat Products", co-ordinated by the National Technical University of Athens (NTUA). Funded by the EC, it is part of the key action of Food, Nutrition and Health. The project basis consists of validated predictive models of predominant meat pathogens growth and kinetics of the response of selected TTI, all applied in an expanded TTI application scheme that translates TTI response to meat microbiological and quality status.

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

OVERALL OBJECTIVE

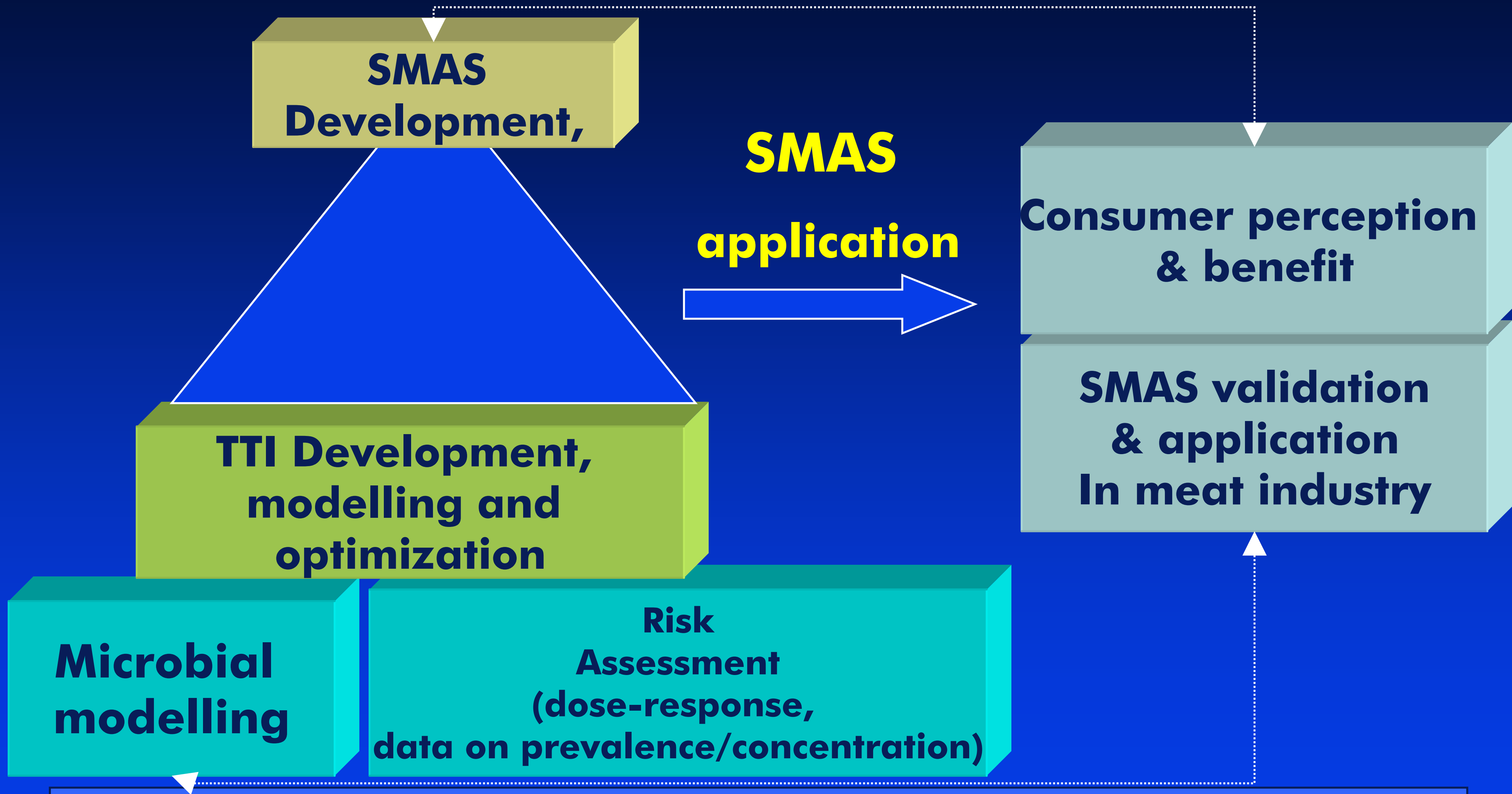
State of the art of

TTI technology + Quantitative risk assessment

⇓

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

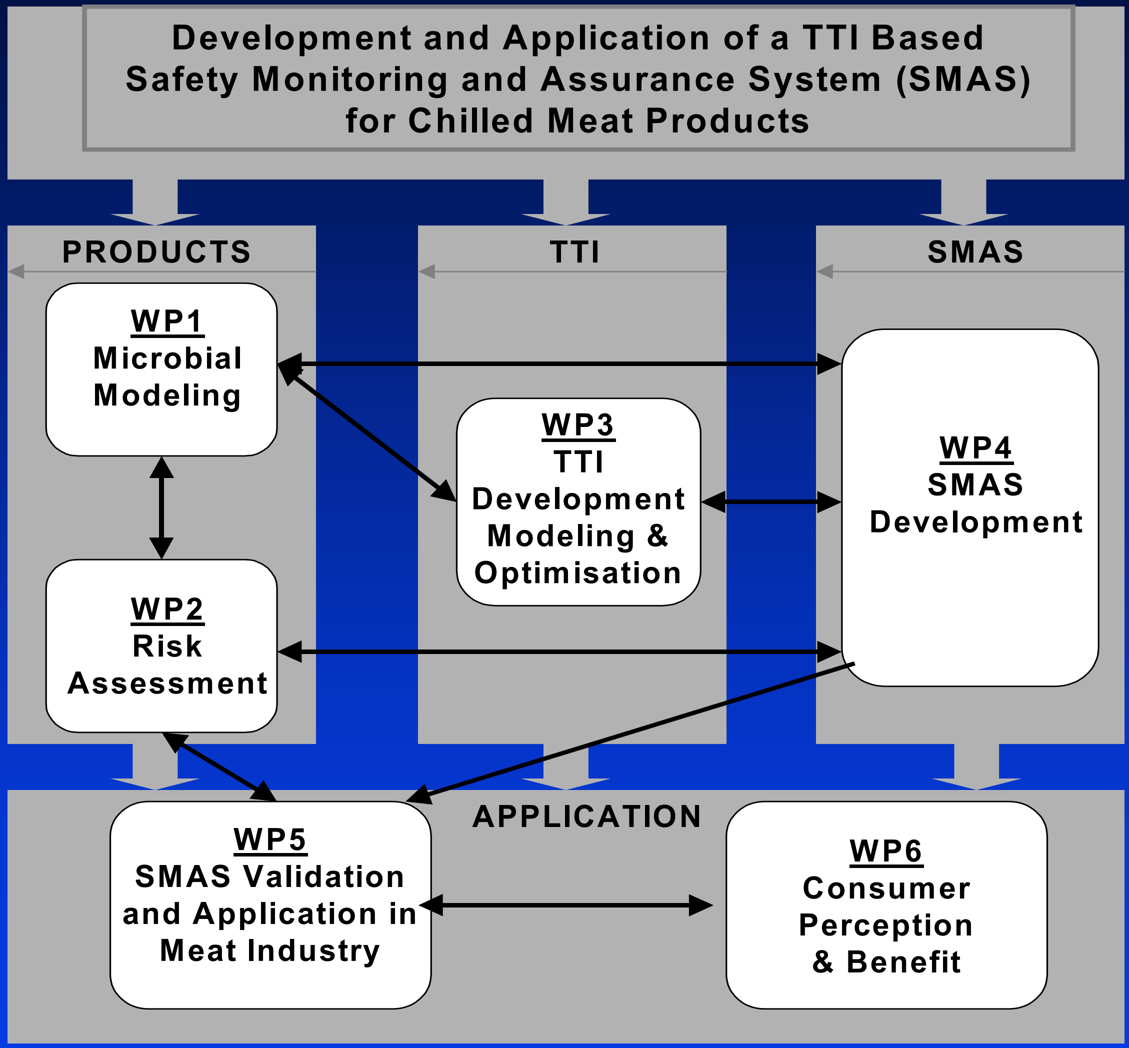
SMAS objectives



What is the structure of SMAS?

PROJECT WORKPLAN

Workpackages & their interrelation



Project QLK1-2002-02545

The 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

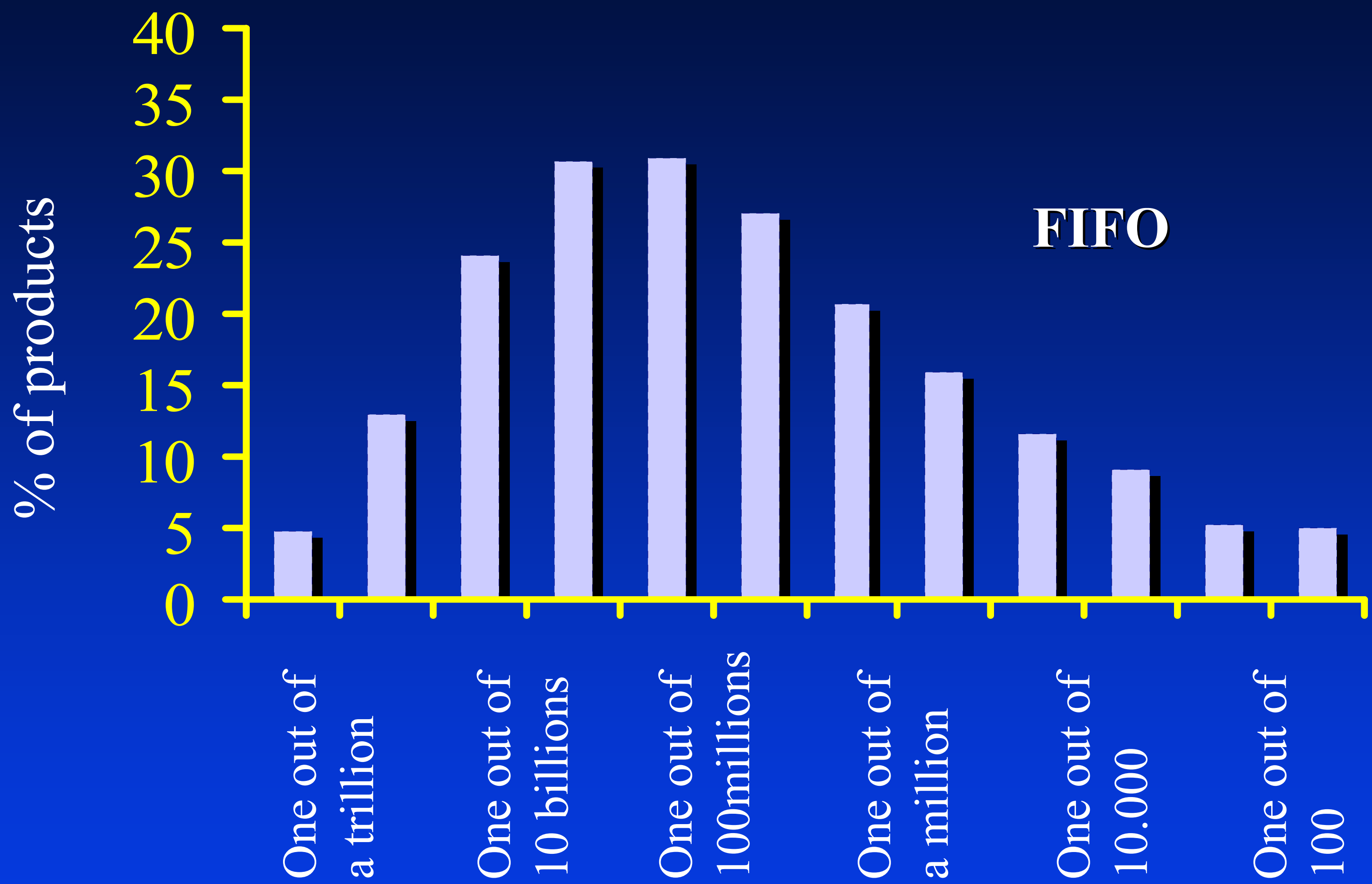
Main Advantages:

✓variations of product characteristics are considered

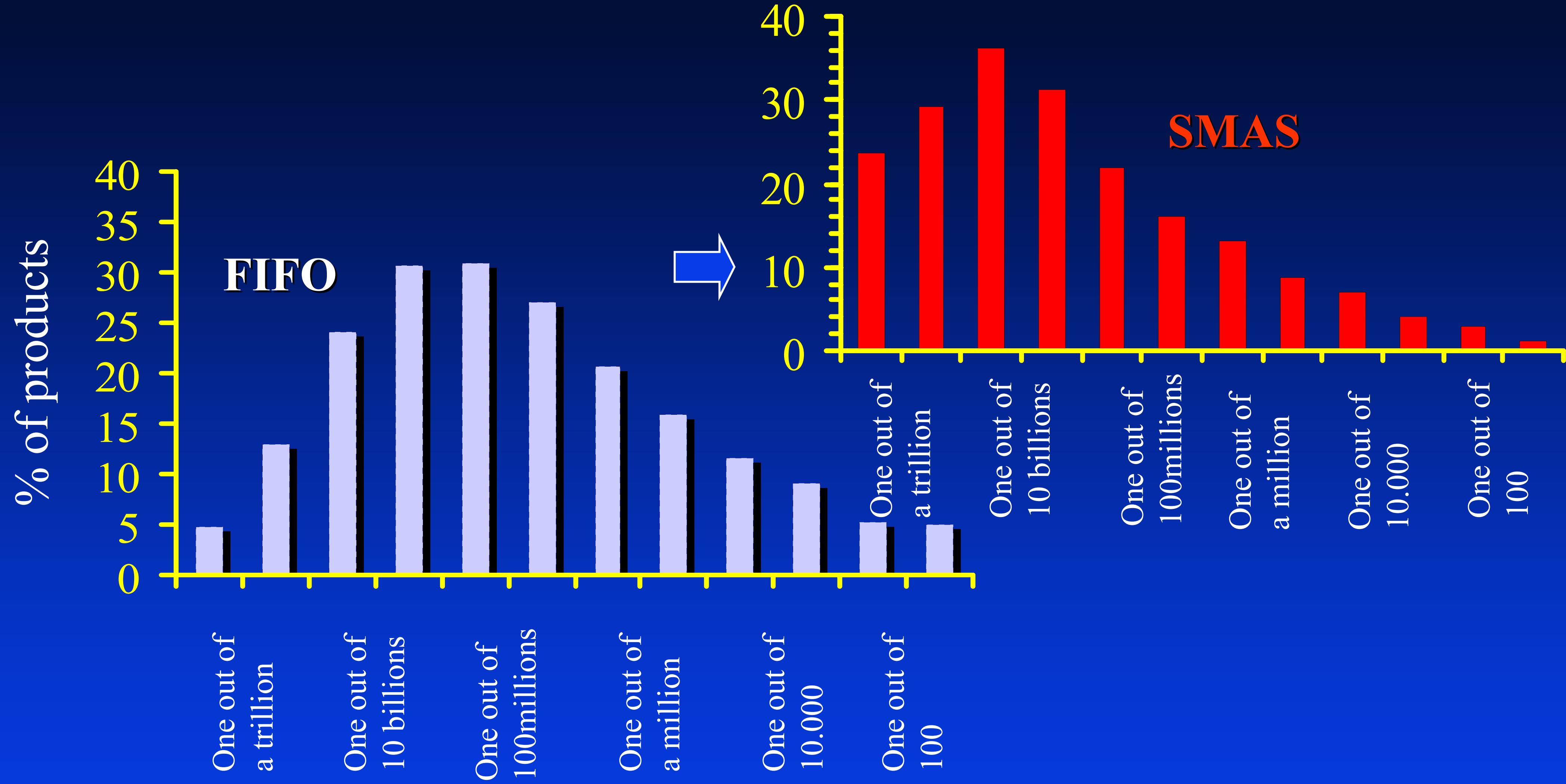
✓the REAL time-temperature history of the product is taken into account based on TTI response

SMAS vs FIFO

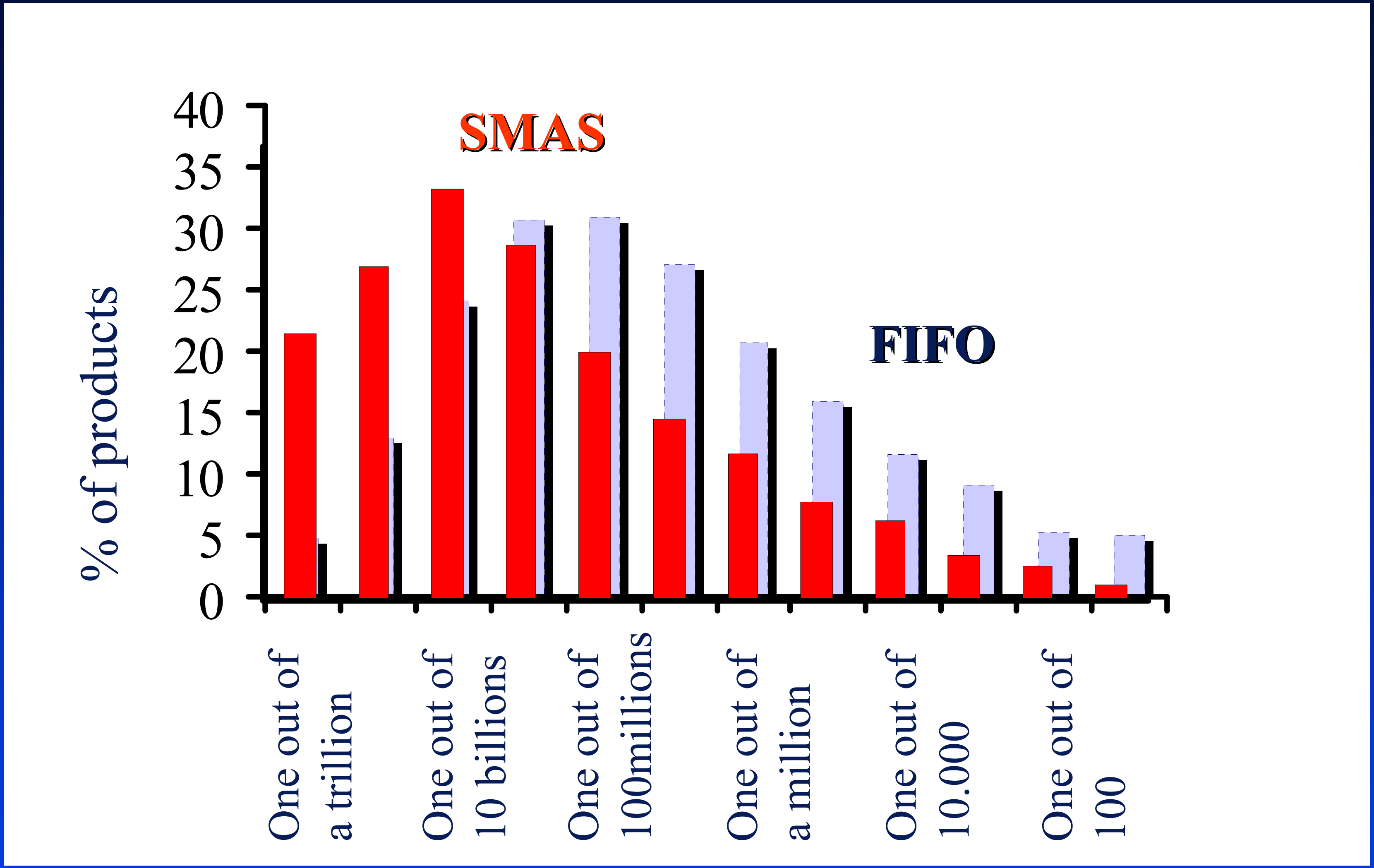
The contribution of SMAS in the chill chain management can be visualized as a minimization of risk for illness and optimisation of the meat product quality at the time of consumption



Probability of illness



Probability of illness



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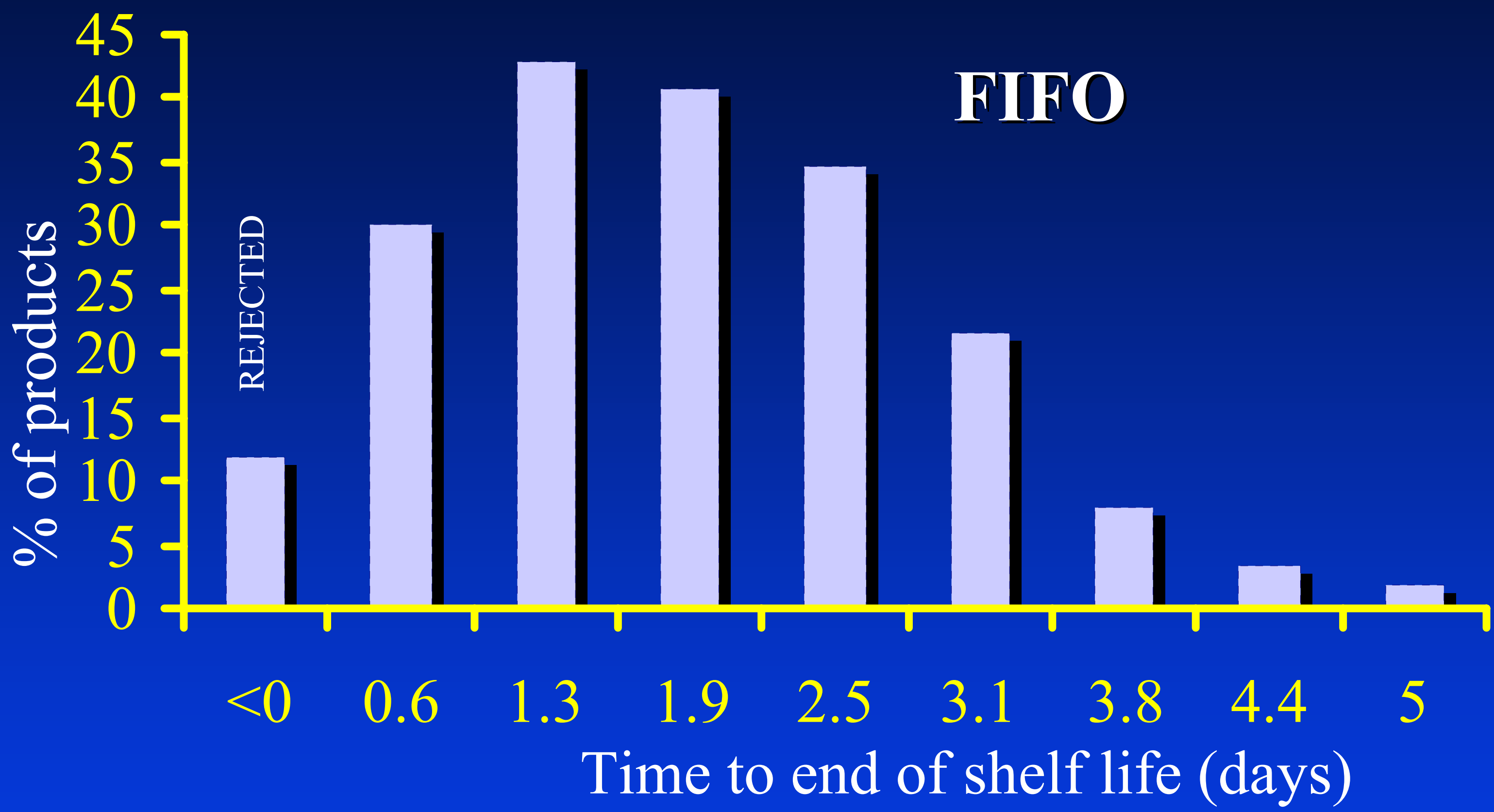
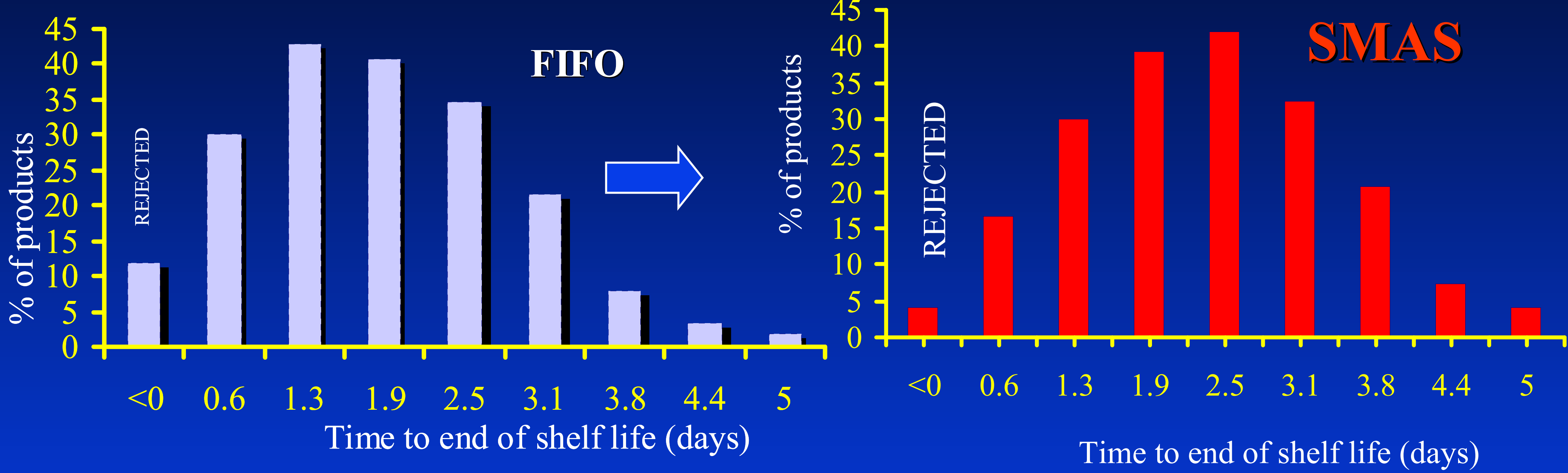
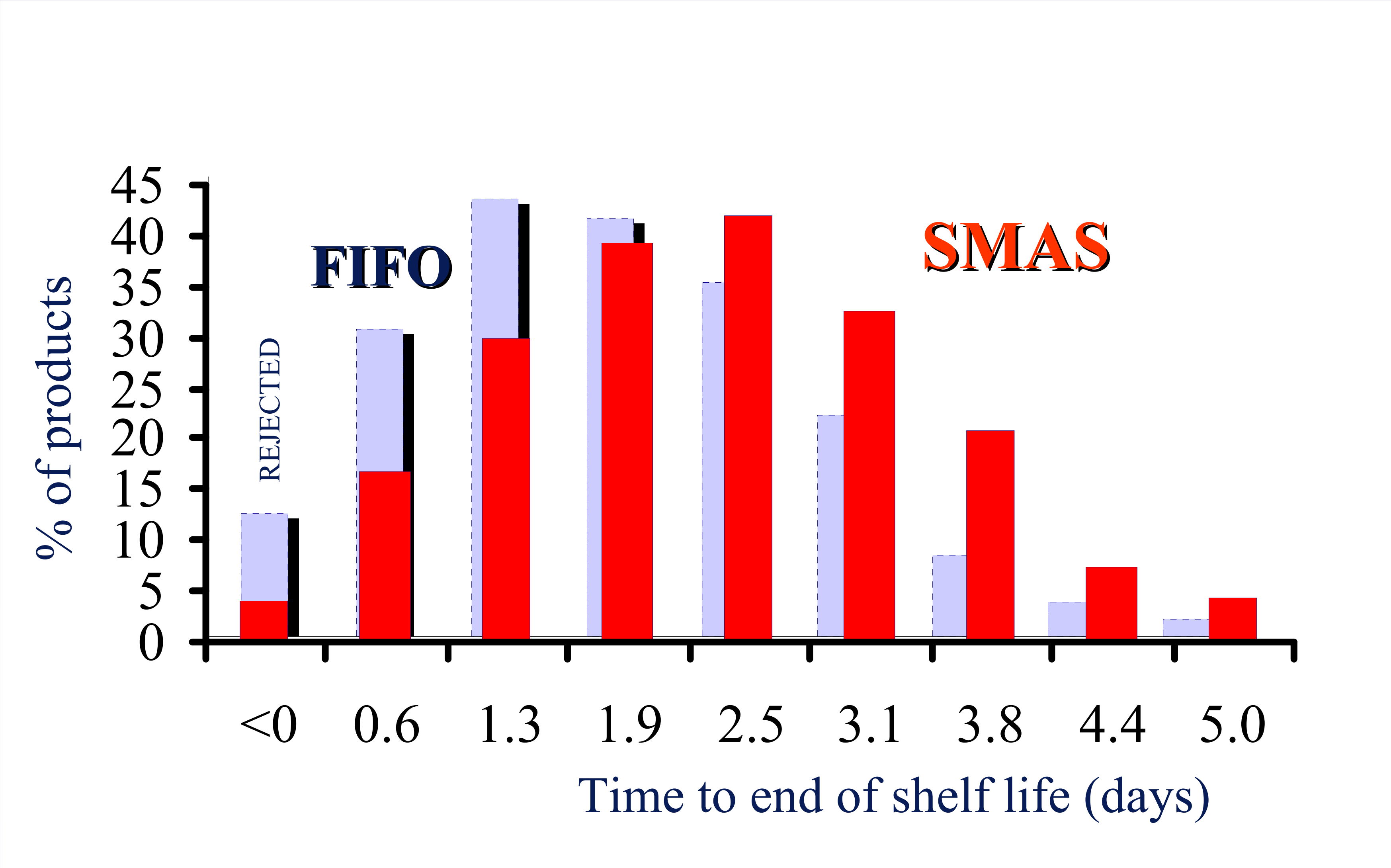


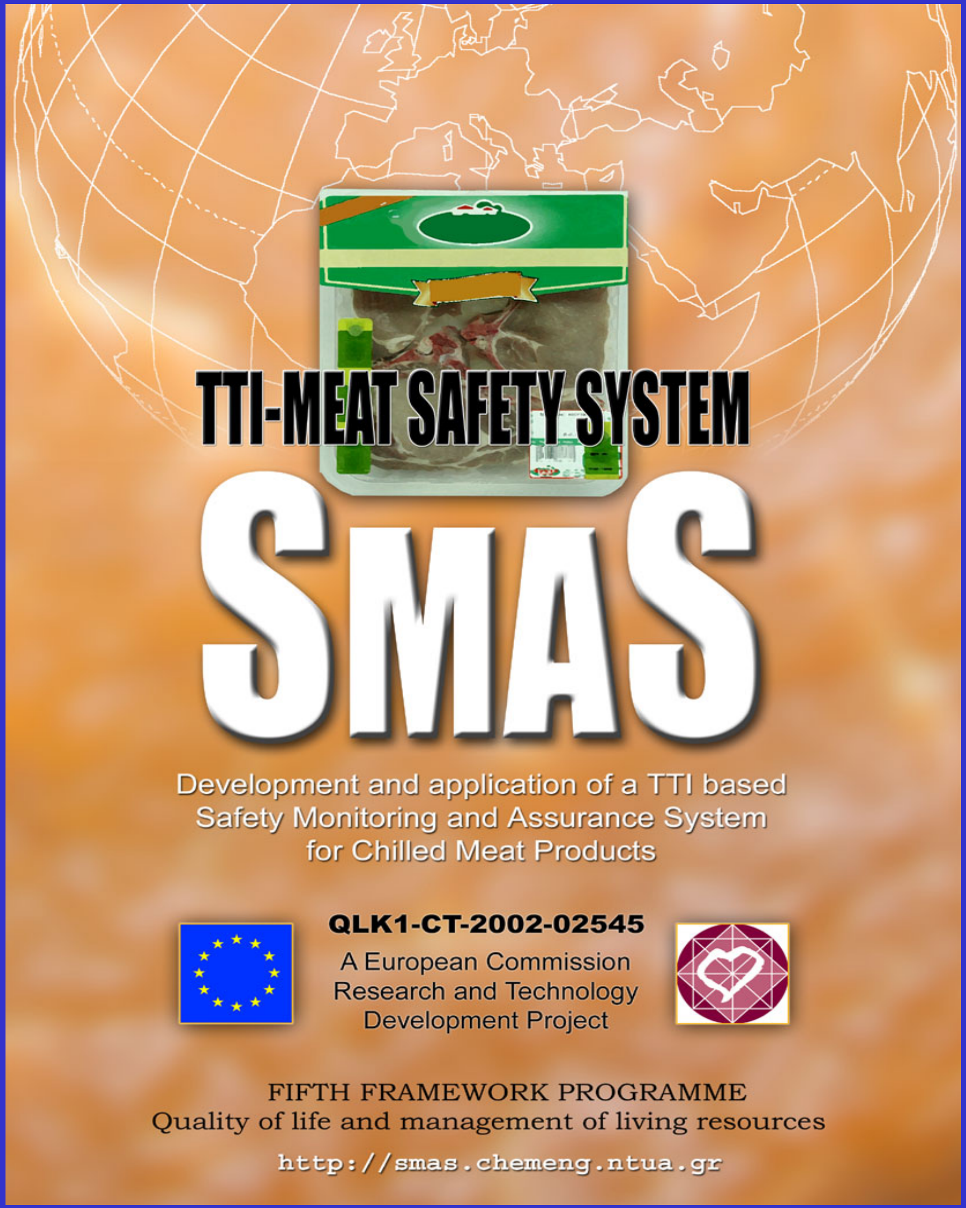
Product quality at consumption



Product quality at consumption



Product quality at consumption



Meat Chill Chain - Need for better management

It is generally recognized by the European industry, retailers, food authorities and even consumers that the weakest link that affects directly safety and quality of chilled products is the actual ***chill chain***. Over 44% of foodborne disease is due to temperature abuse.

Meat products are perishable and unless processed, packaged, distributed and stored appropriately can spoil in relatively short time. Overgrowth of incidental pathogenic bacteria like *Listeria monocytogenes*, *Salmonella sp.* and *Escherichia coli* followed by undercooking or inadequate preparation may pause a potential hazard for the consumer. Despite the proliferation of food safety regulations and the application of safety management systems such as HACCP, risk assessment studies show that foodborne disease has remained a main concern in the last decade.

Application of an optimised quality and safety assurance system for chilled distribution of fresh meat and meat products requires continuous monitoring and control of storage conditions from production to consumption. The systematic management of the chill chain and the improved evaluation of safety, quality and shelf life of meat can lead to reduced safety risk and increased quality, with a significant health and economic impact to the European society and market.

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7 Institutes/Companies are members of the SMAS project, working on its main interrelating workpackages with the ultimate purpose to deliver an effective chill chain decision and management tool.

The main tangible goal of the SMAS project
is to develop a reliable and practical decision and management tool
for an optimized handling of meat products in terms of both safety and quality

http://smas.chemeng.ntua.gr

SMAS BROCHURE

Tasks

- Study of the temperature conditions in the chill chain

  (fluctuations during transport/storage, variability within the domestic equipment)

- Correlation temperature handling to food quality with the use of Time Temperature Indicators

- Validation of the Safety Monitoring and Assurance System (SMAS) by simulation and experiment

CHARACTERISTICS OF THE ACTUAL CHILL CHAIN

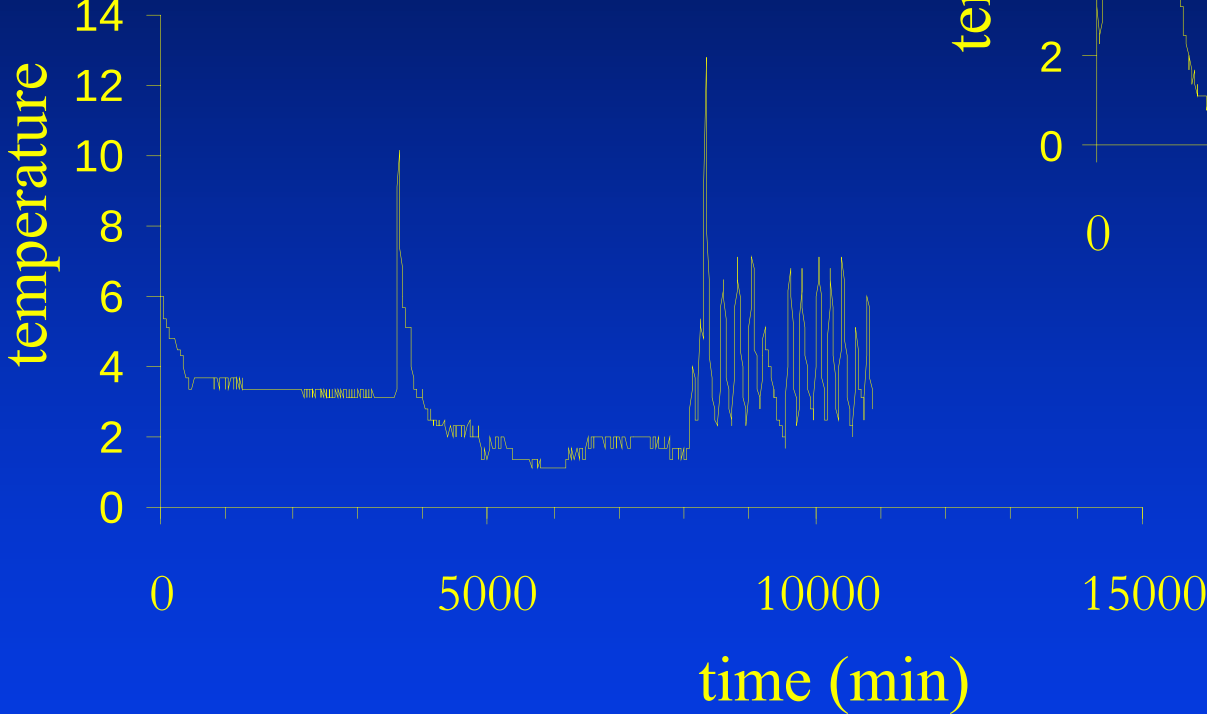
Weak links in the chill chain

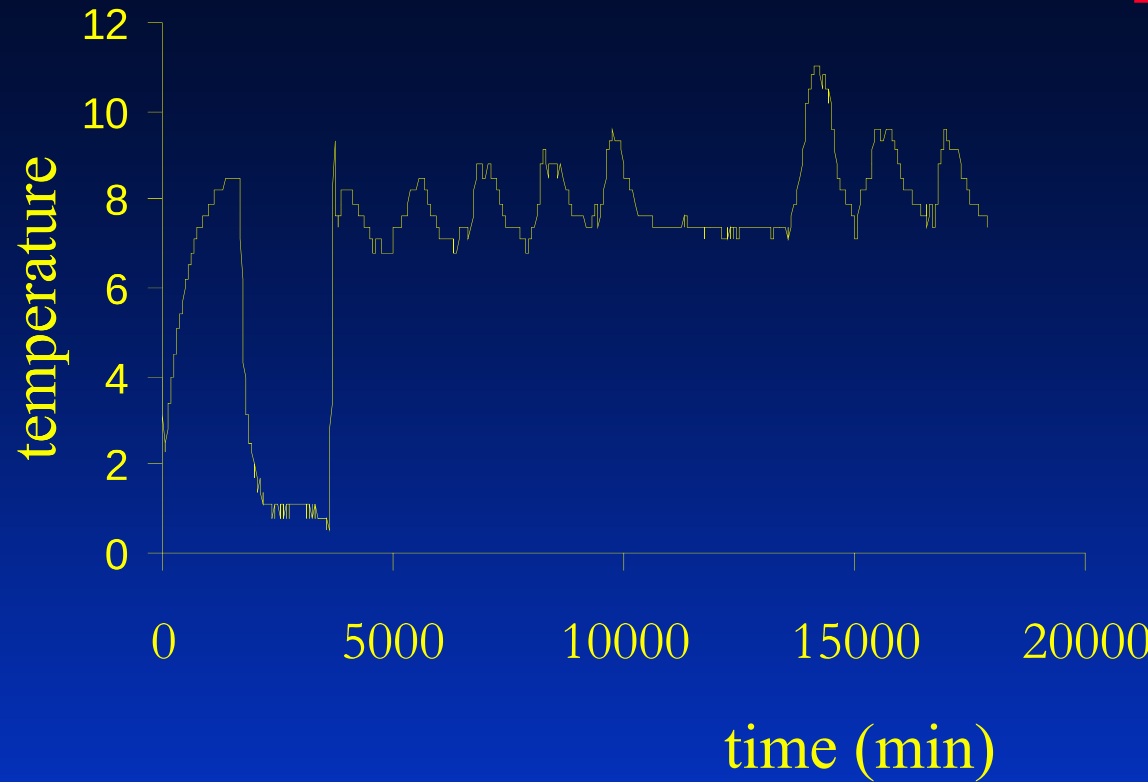
Electronic dataloggers

1st stage of the survey:

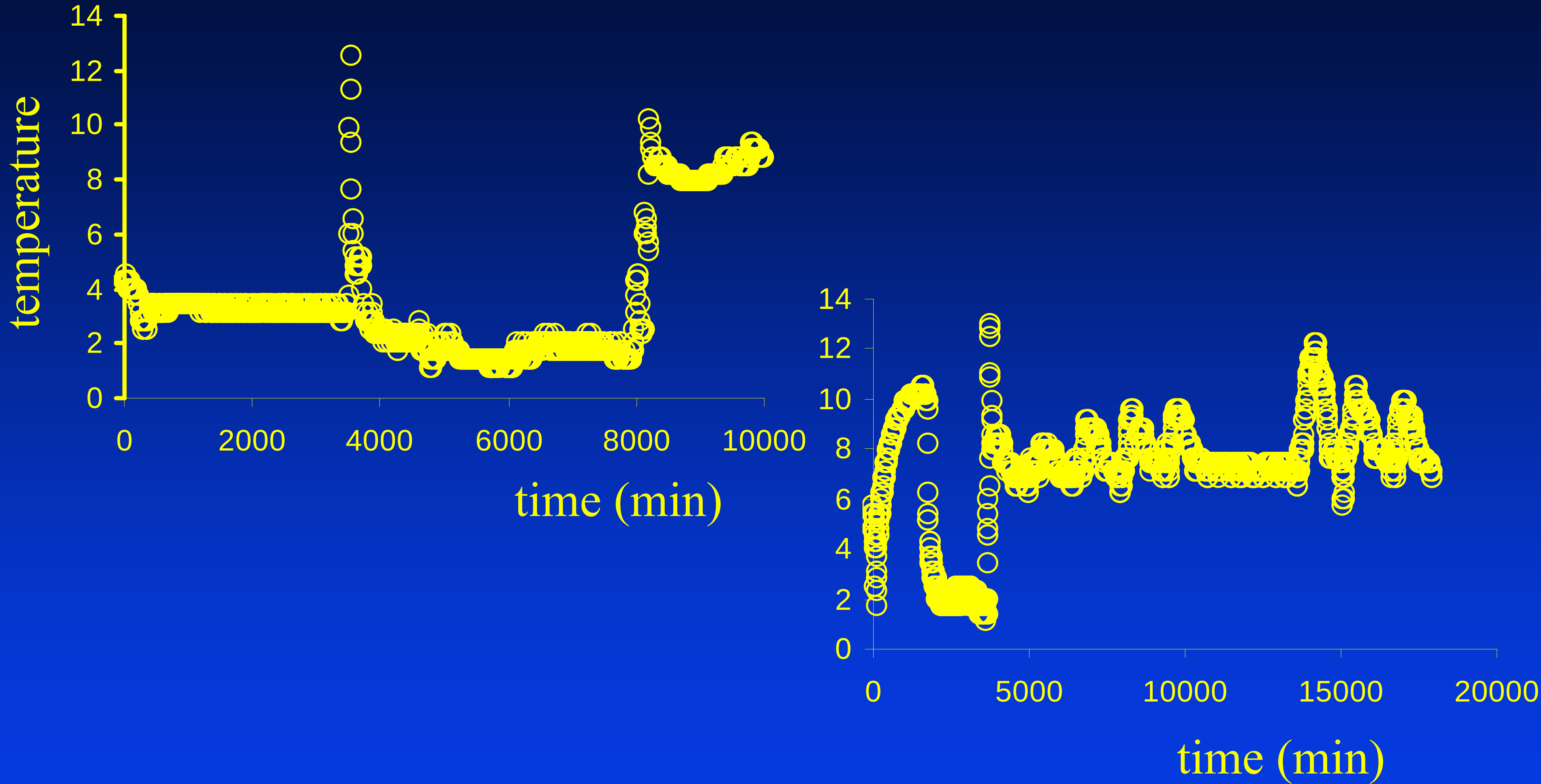
Data loggers were sealed in packages of ground beef and monitored from processing through distribution to delivery and storage in SuperMarkets all over Greece

Survey for temperature conditions (1)

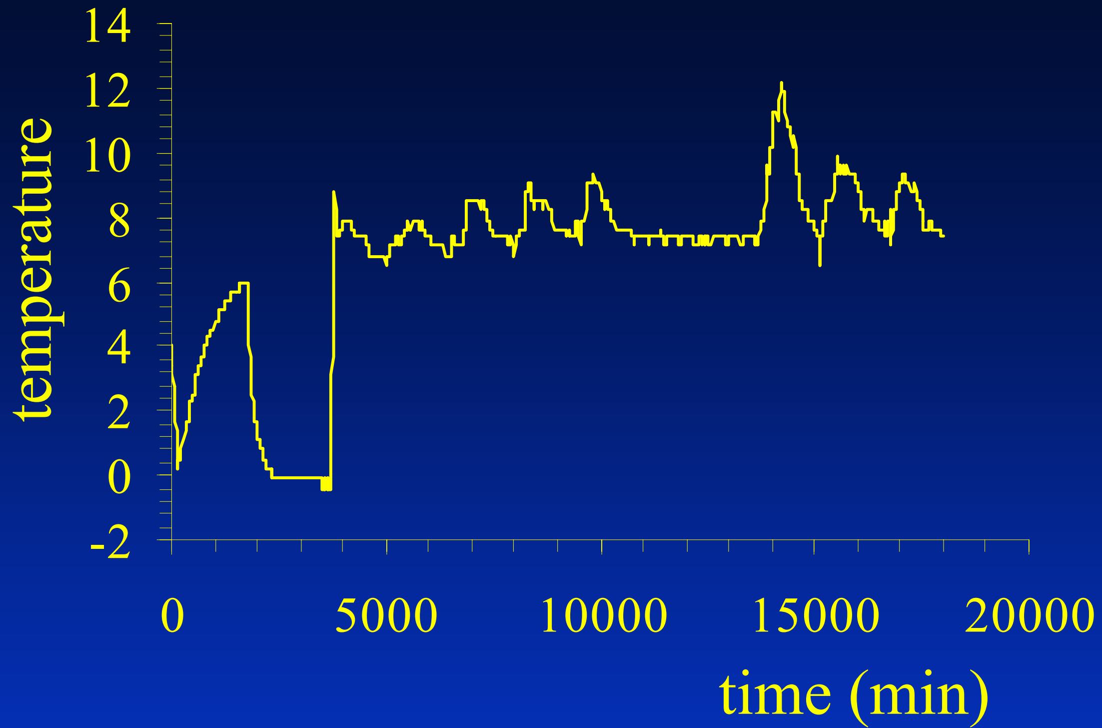


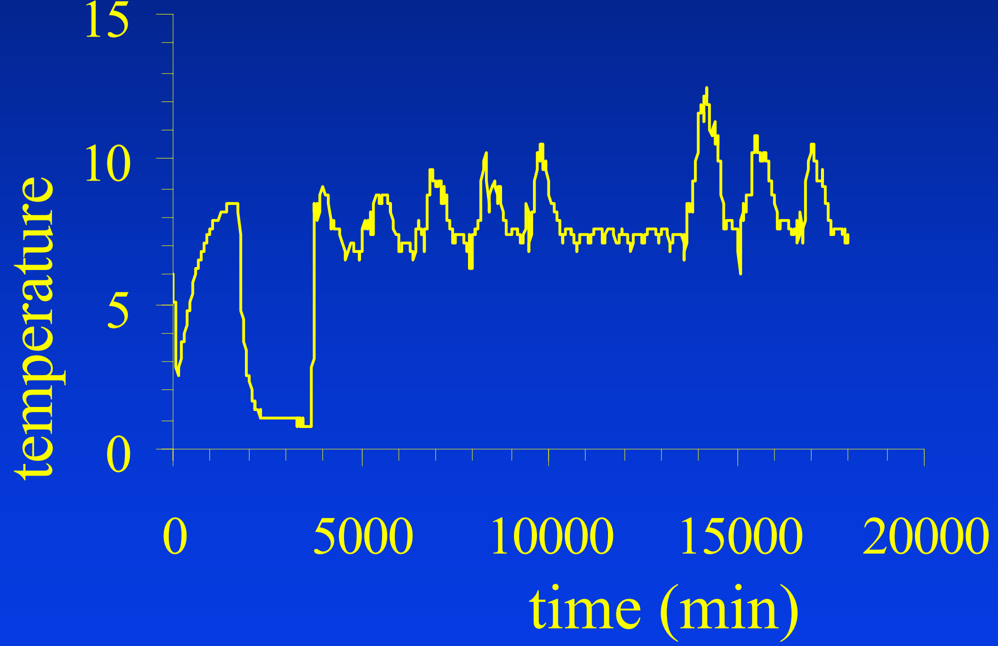


Temperature conditions FROM production TO the retail outlet



Temperature conditions FROM production TO the retail outlet





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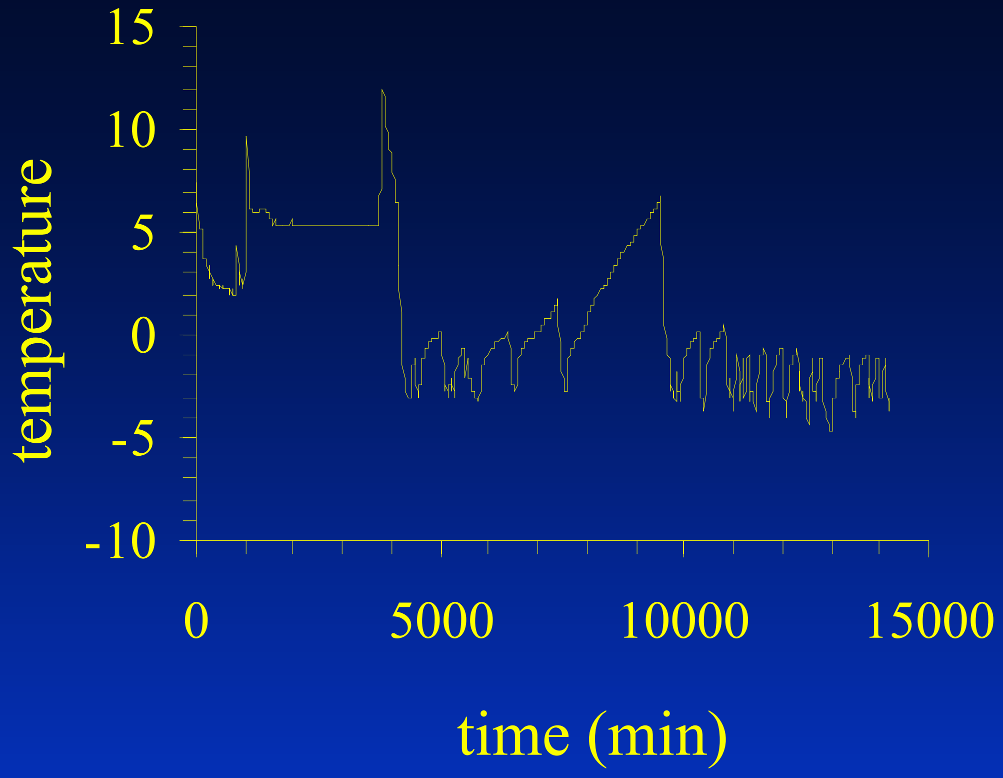
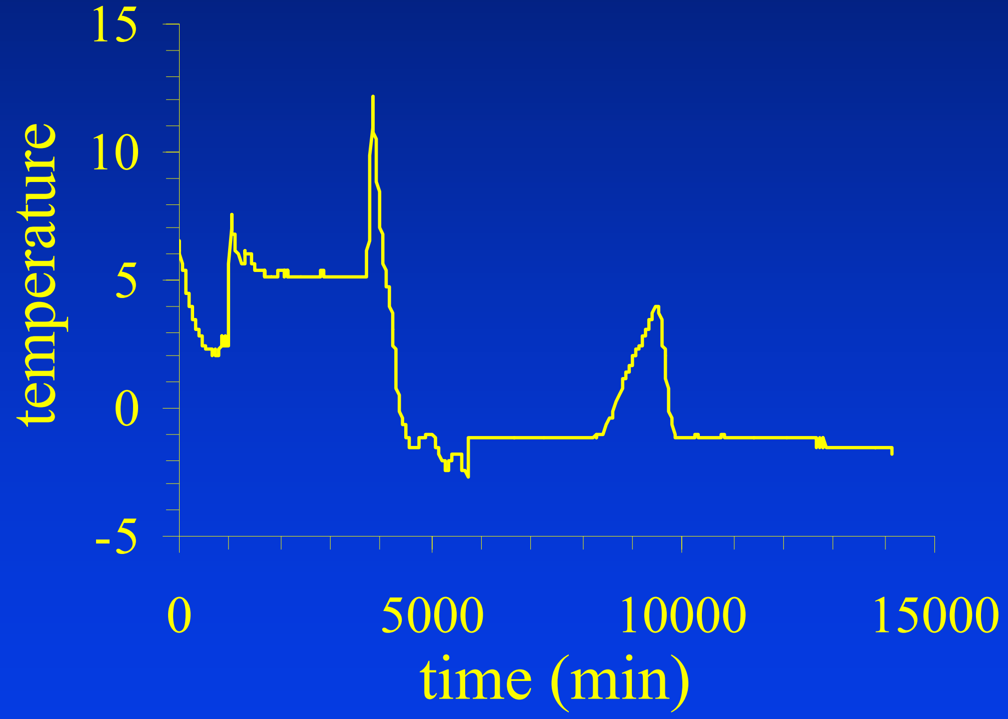
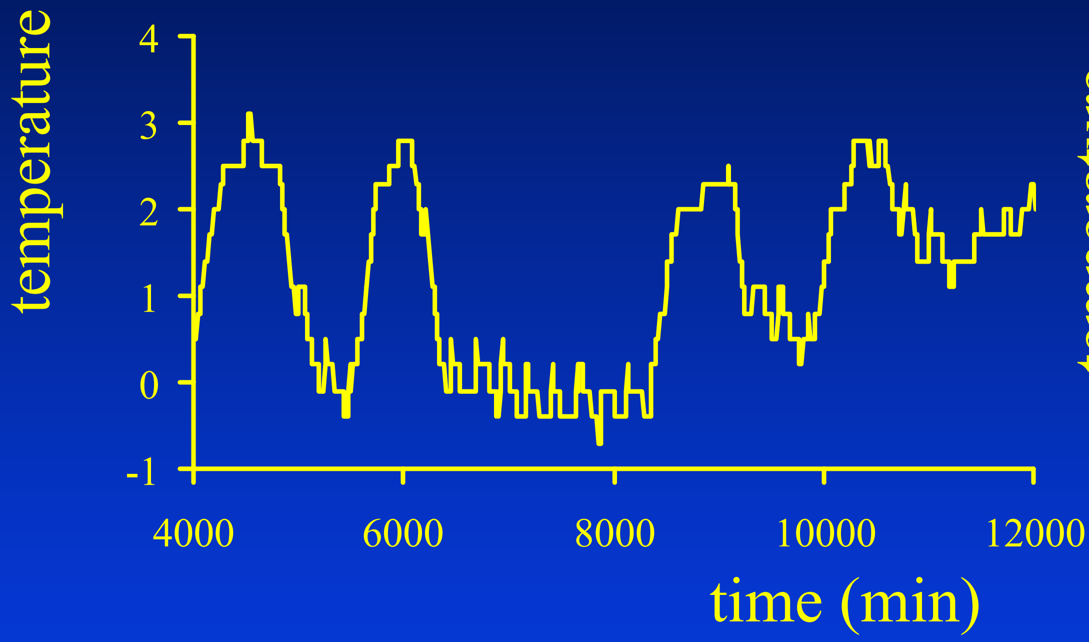
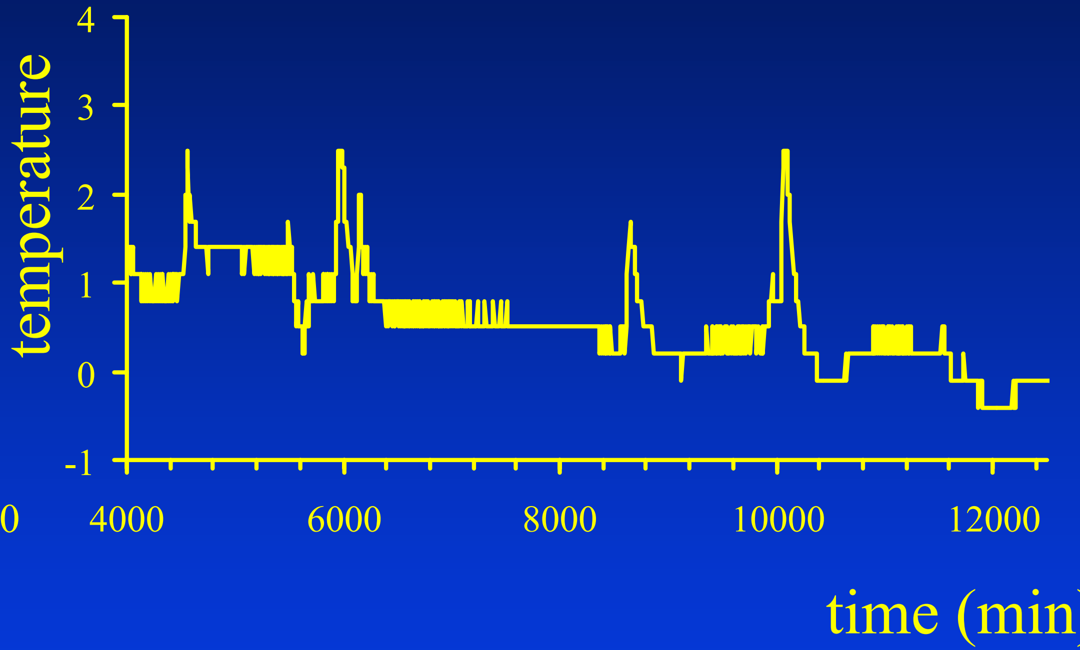




Temperature conditions FROM production TO the retail outlet





Temperature conditions FROM production TO the retail outlet

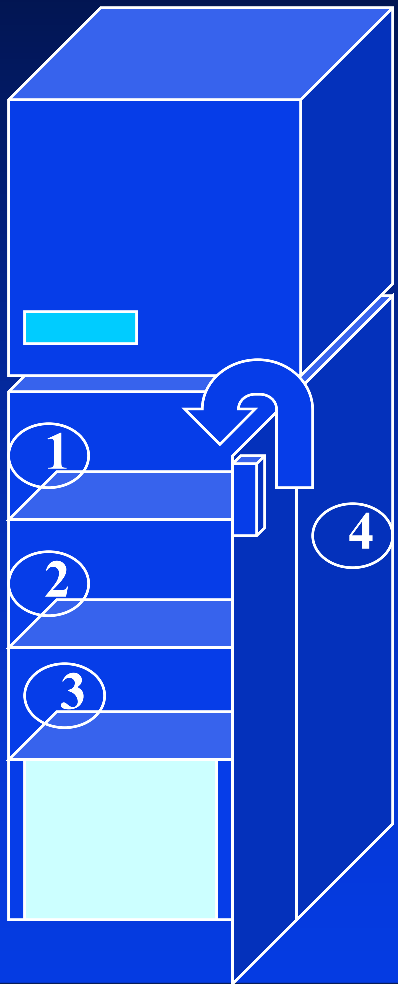
Conclusions from survey (1)

- Sharp (but short) increases of temperature (during transport)
- Cases of retail storage at temperatures > 7°C
- Significant temperature fluctuations

Temperature conditions FROM production TO the retail outlet

Variations WITHIN the domestic refrigerator

2st stage of the survey:

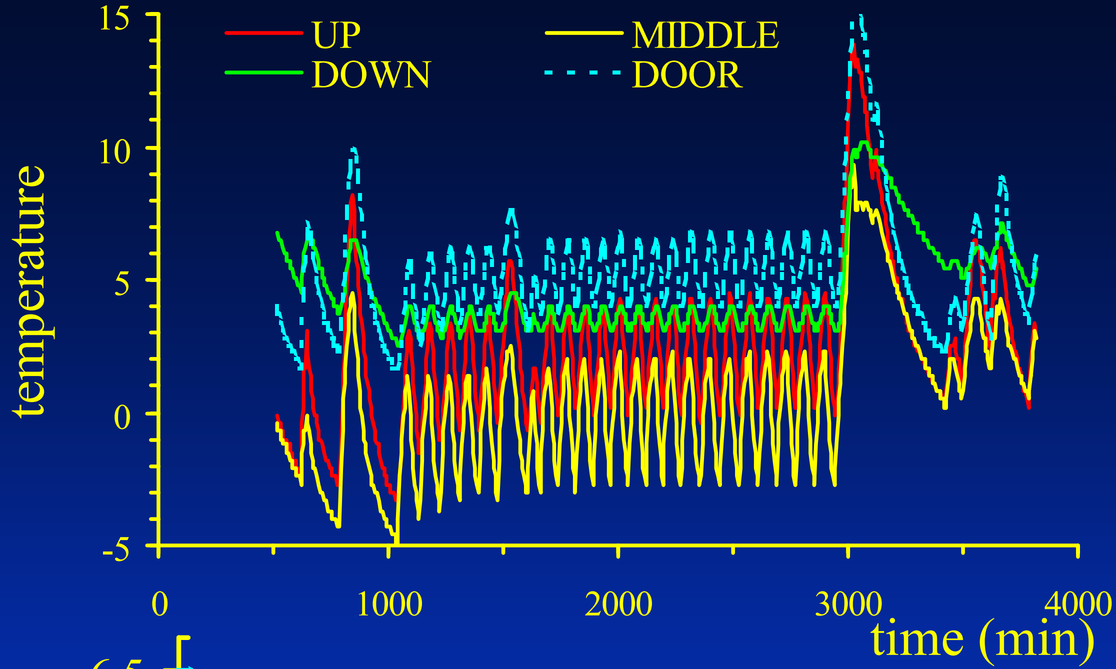


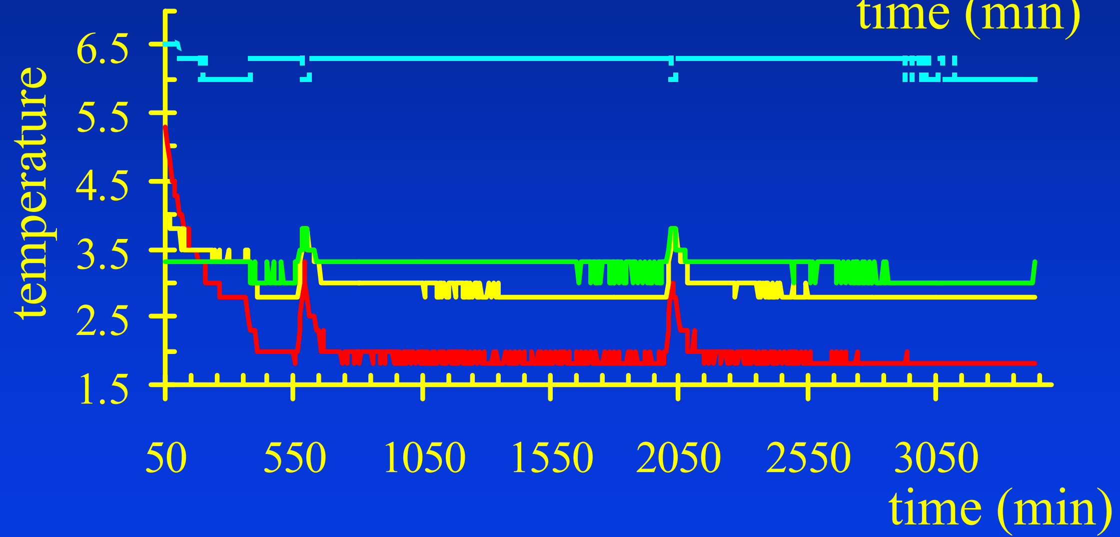
4 data loggers were distributed randomly to potential consumers to monitor variations INSIDE the refrigerator

Electronic dataloggers

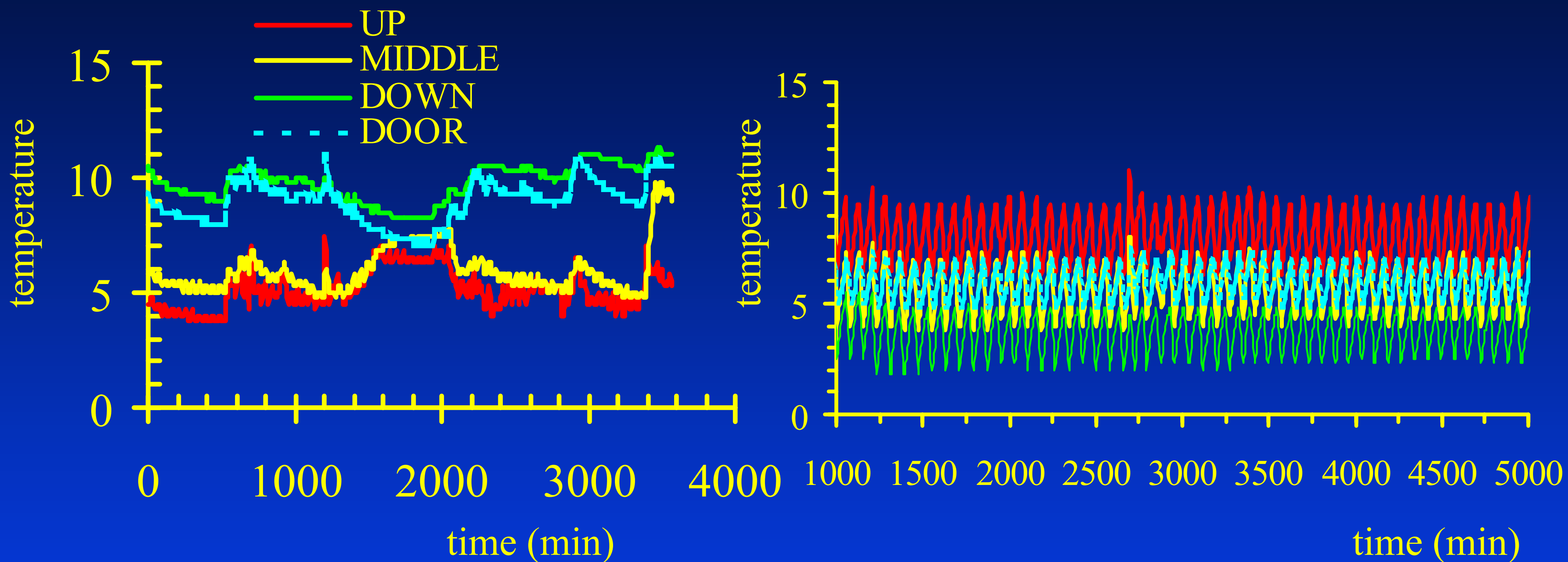
1: upper shelf
2: middle shelf
3: lower shelf
4: door

Survey for temperature conditions (2)

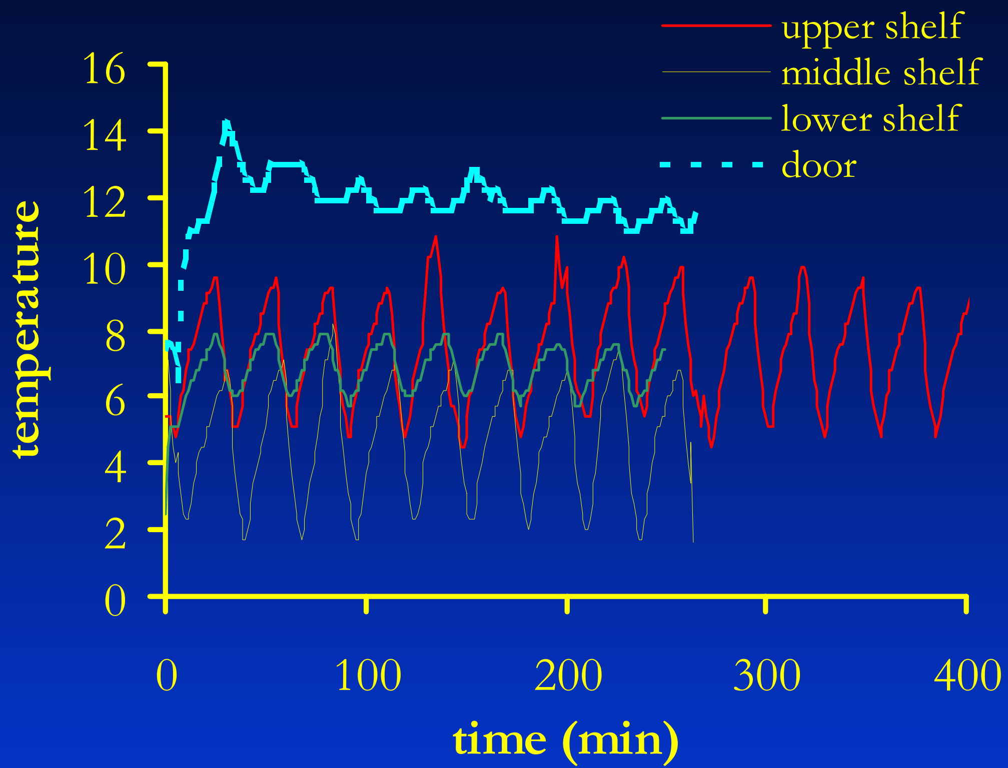


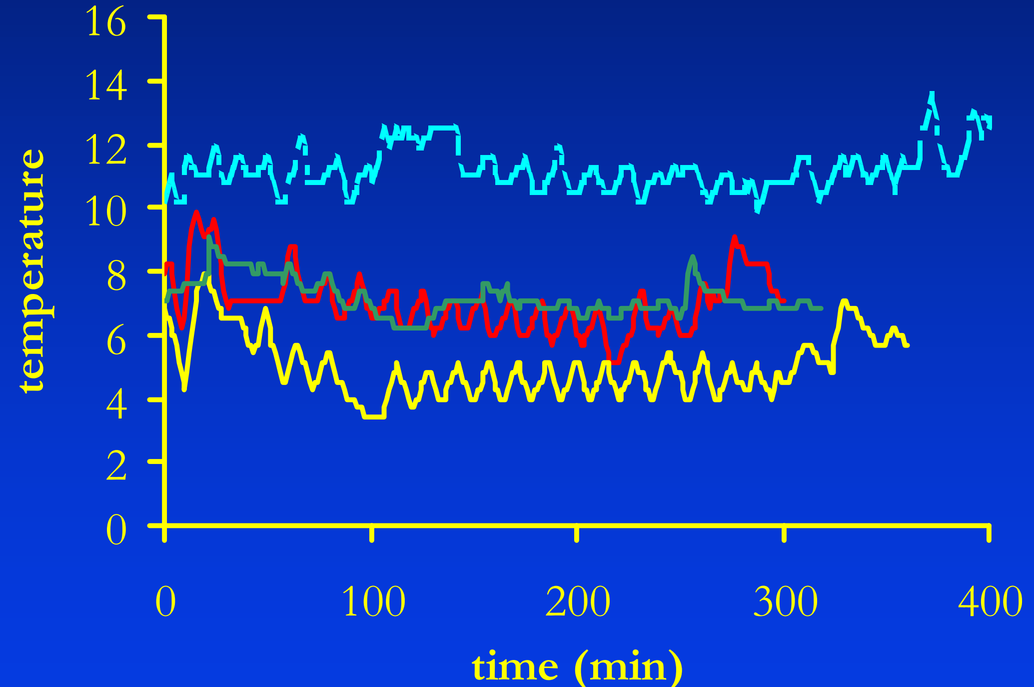


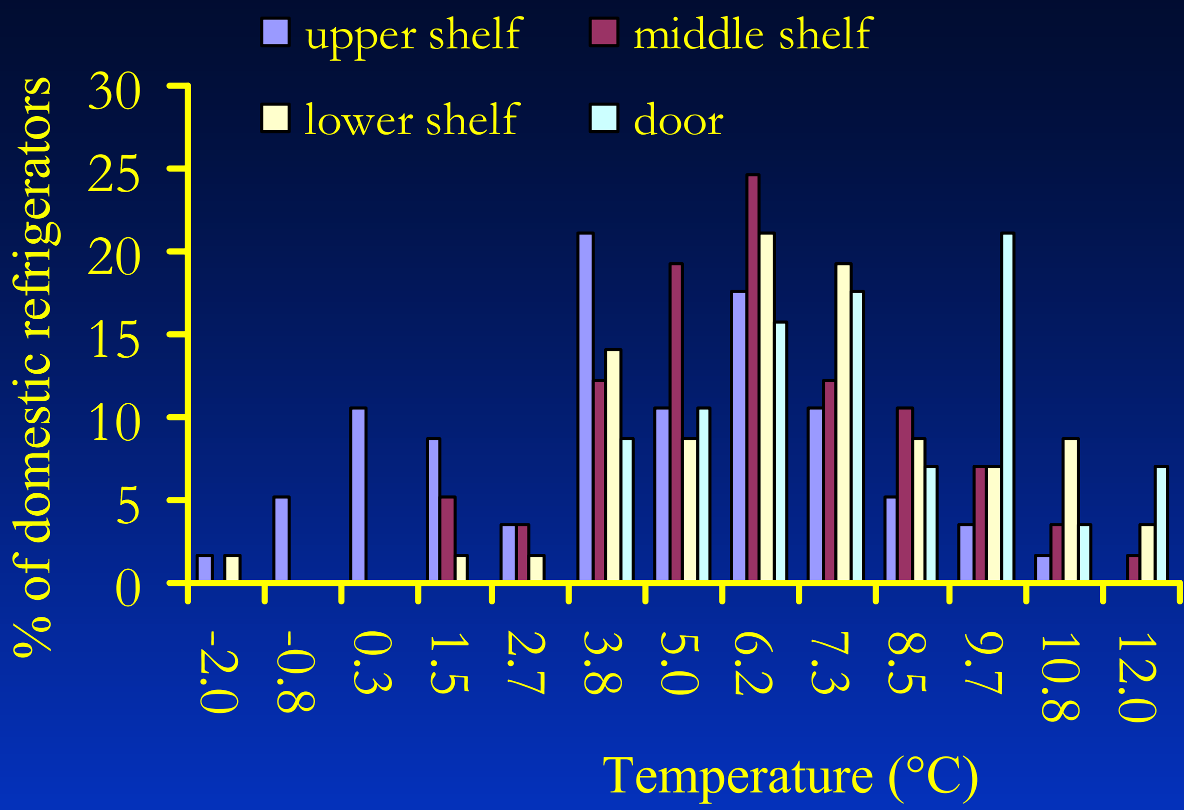
Temperature conditions IN the domestic refrigerator



Temperature conditions IN the domestic refrigerator

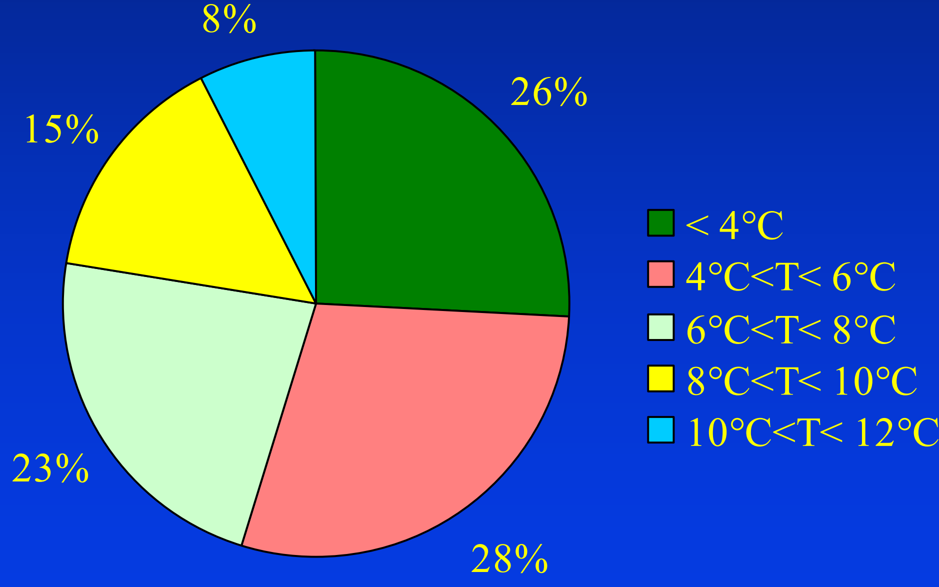

upper shelf
middle shelf
lower shelf
door
16
14
12
10
8
6
4
2
0
temperature
0
100
200
300
400
time (min)


16
14
12
10
8
6
4
2
0
temperature
0
100
200
300
400
time (min)



Temperature variation within domestic refrigerators

Average temperature of domestic refrigerators (~400 cases)



Temperature conditions WITHIN the domestic refrigerator

Temperature variations in distribution and storage conditions

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NEED for continuous monitoring TTI

TTI PRINCIPLES & APPLICATION

TTI: main principles

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

TYPES OF TTI

- **Diffusion based**
- **Microbial**
- **ENZYMATIC**
- **Polymer based**
- **Photochemical**

PRINCIPLES OF TTI

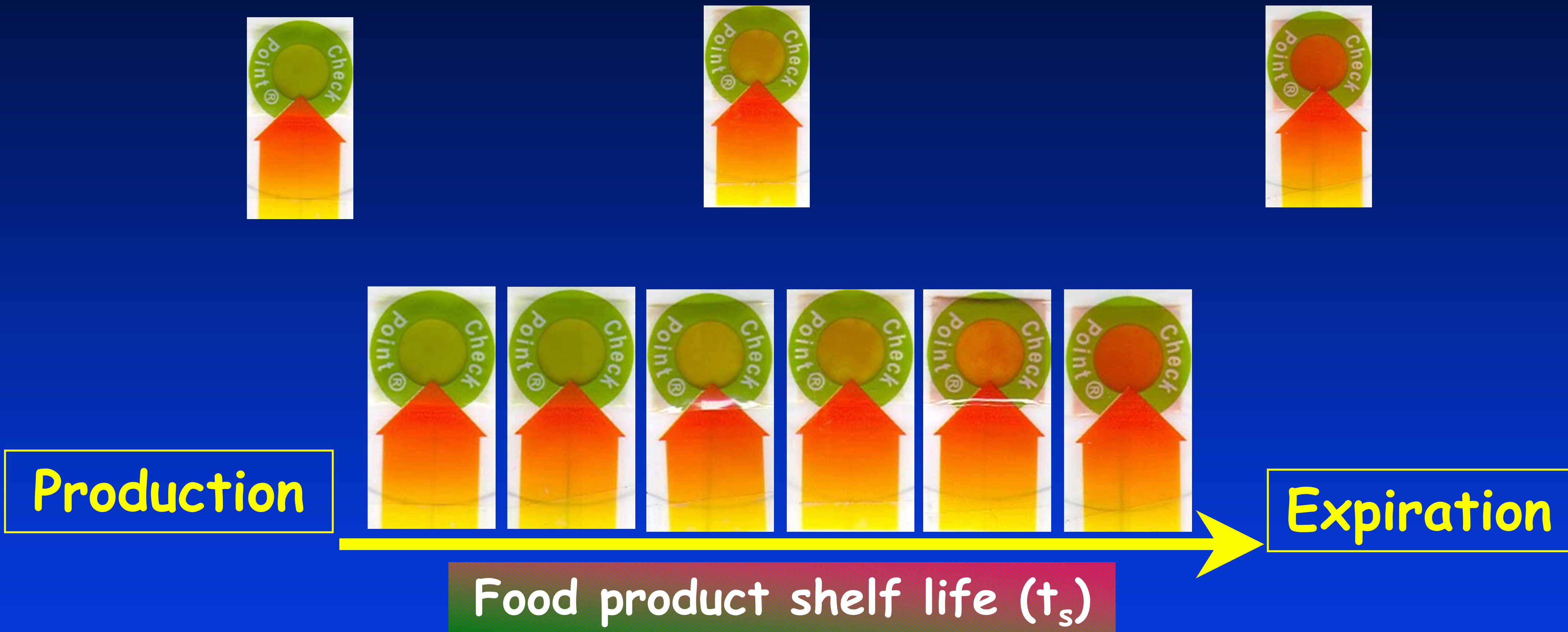
Time Temperature Indicators

The indicator starts with two liquid-filled pouches heat sealed into plastic

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

Tricolour response TTI

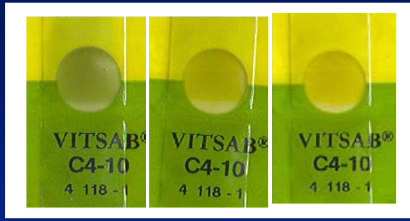


TTI

TTI Configurations

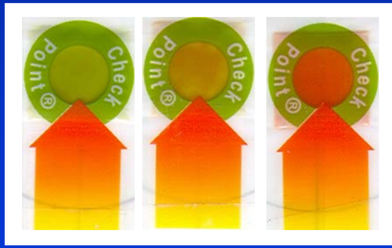
✓**Bicolor TTIs**

Color change from green to yellow



✓**Tricolor TTIs**

an initial green color changes into an amber or orange red and ends with a final pure red color, giving a much more clear perception especially to consumers, where the TTI mediates an alarm function in the form of a traffic light



Alternative methods measuring TTI response

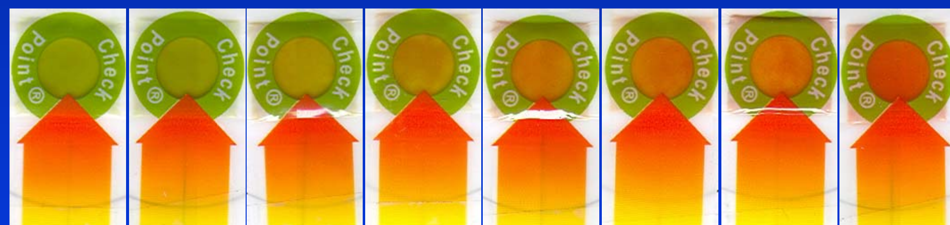
- **Instrumental measurement**

✓ Colormeter such as Minolta CR 200

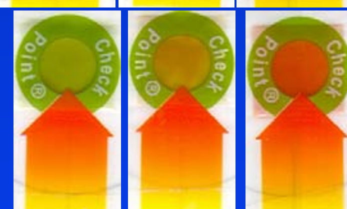
✓ Digital imagers such as a scanner

- **Visual measurement**

✓ 8 color scale



✓ A simple 3 color scale (consumer use)



Measuring devices for TTI response

TTI RESPONSE KINETICS

X: measurable change of TTI

Response function:

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

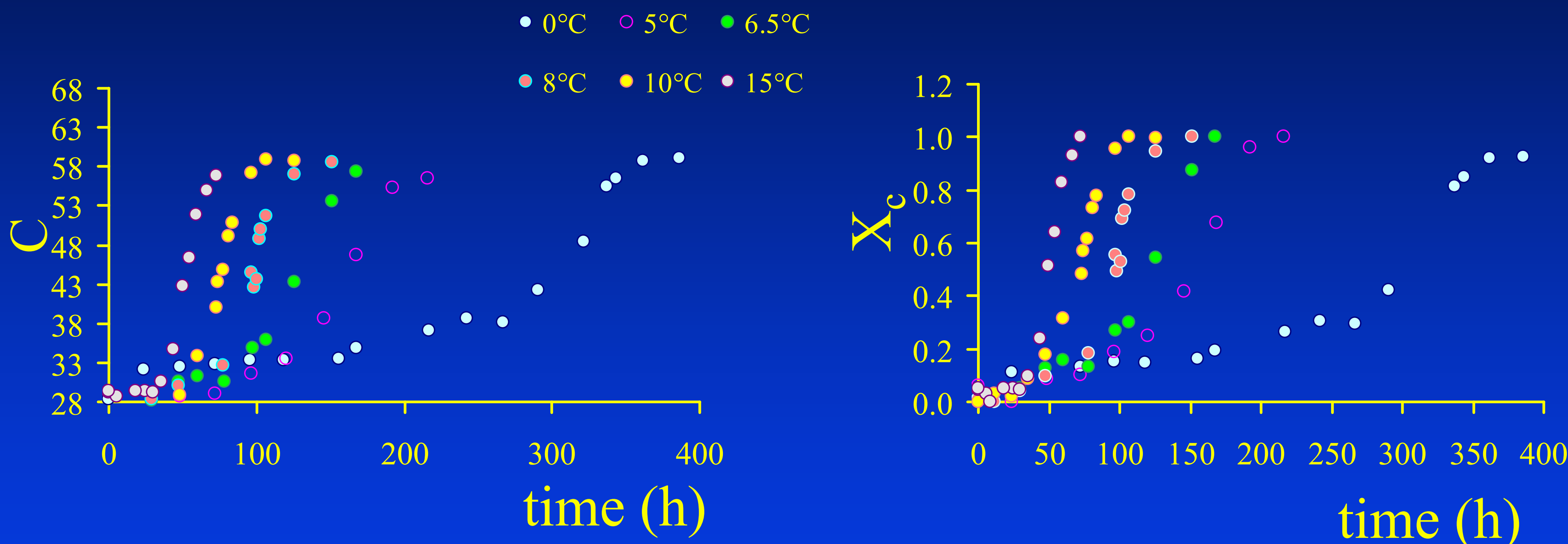
Temperature dependence - expressed by Ea

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

Kinetic study of enzymatic TTI

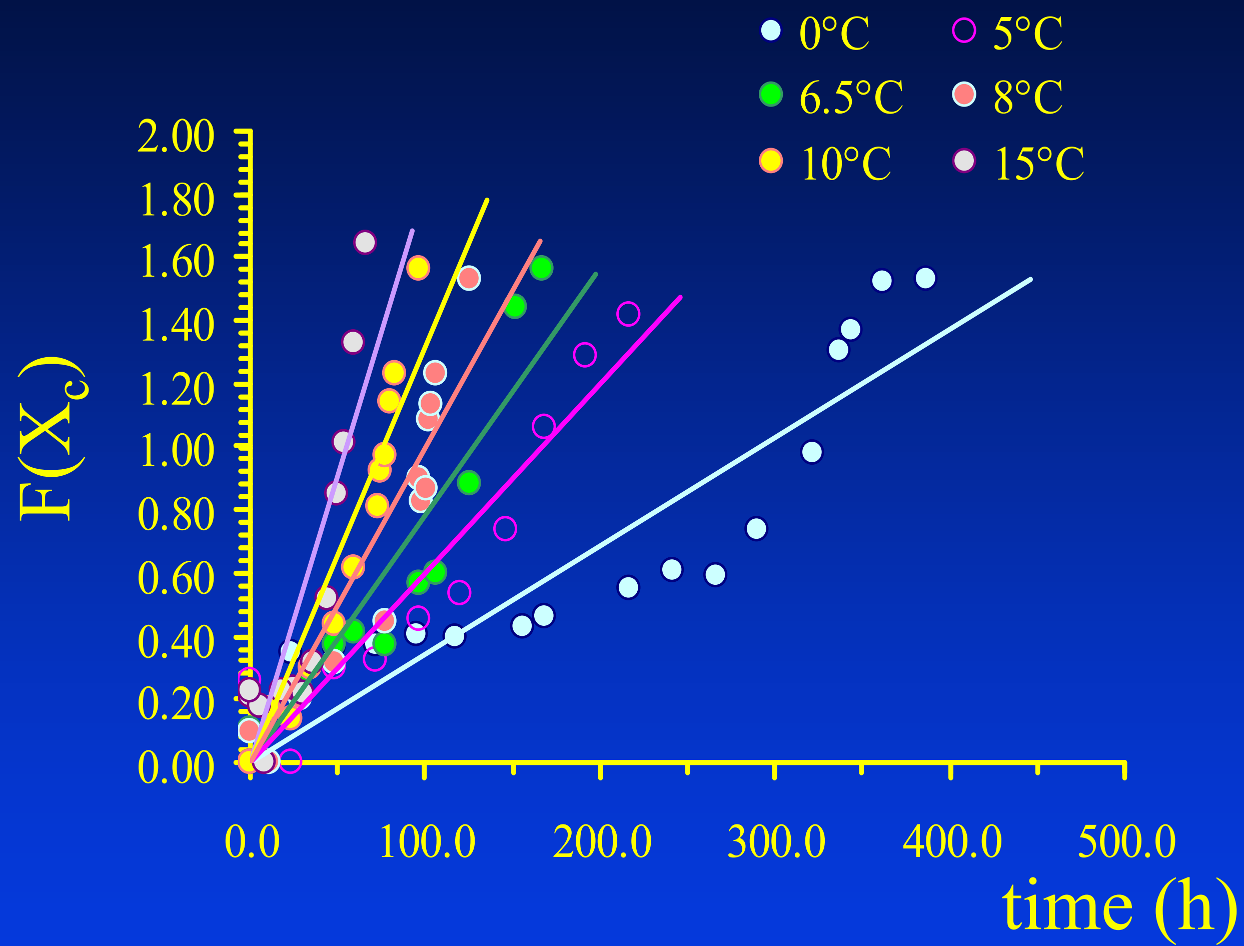
Kinetic study of TTI

isothermal experiments



M4-10

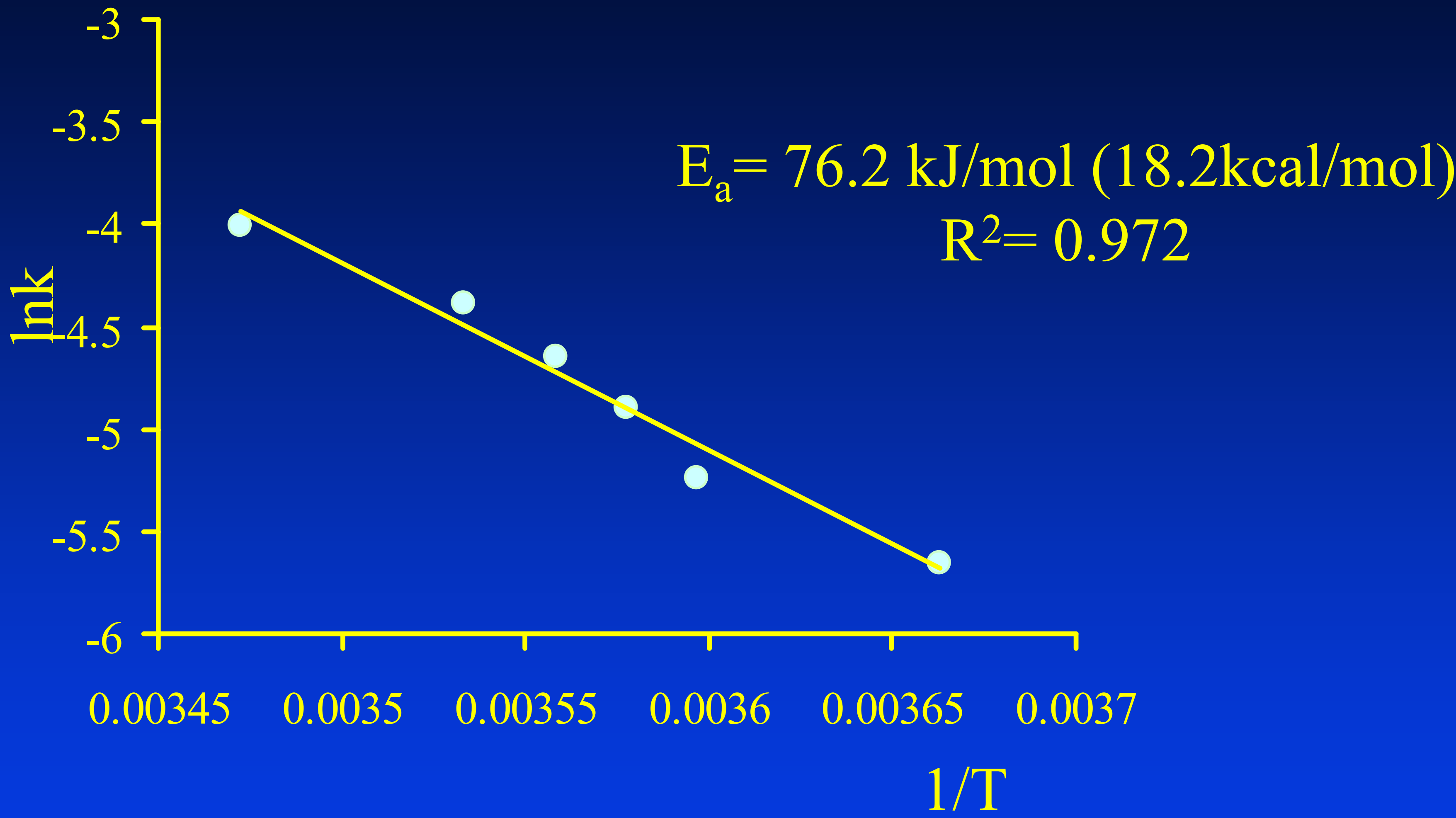
TTI



0°C
5°C
6.5°C
8°C
10°C
15°C
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
F(Xc)
0.0
100.0
200.0
300.0
400.0
500.0
time (h)

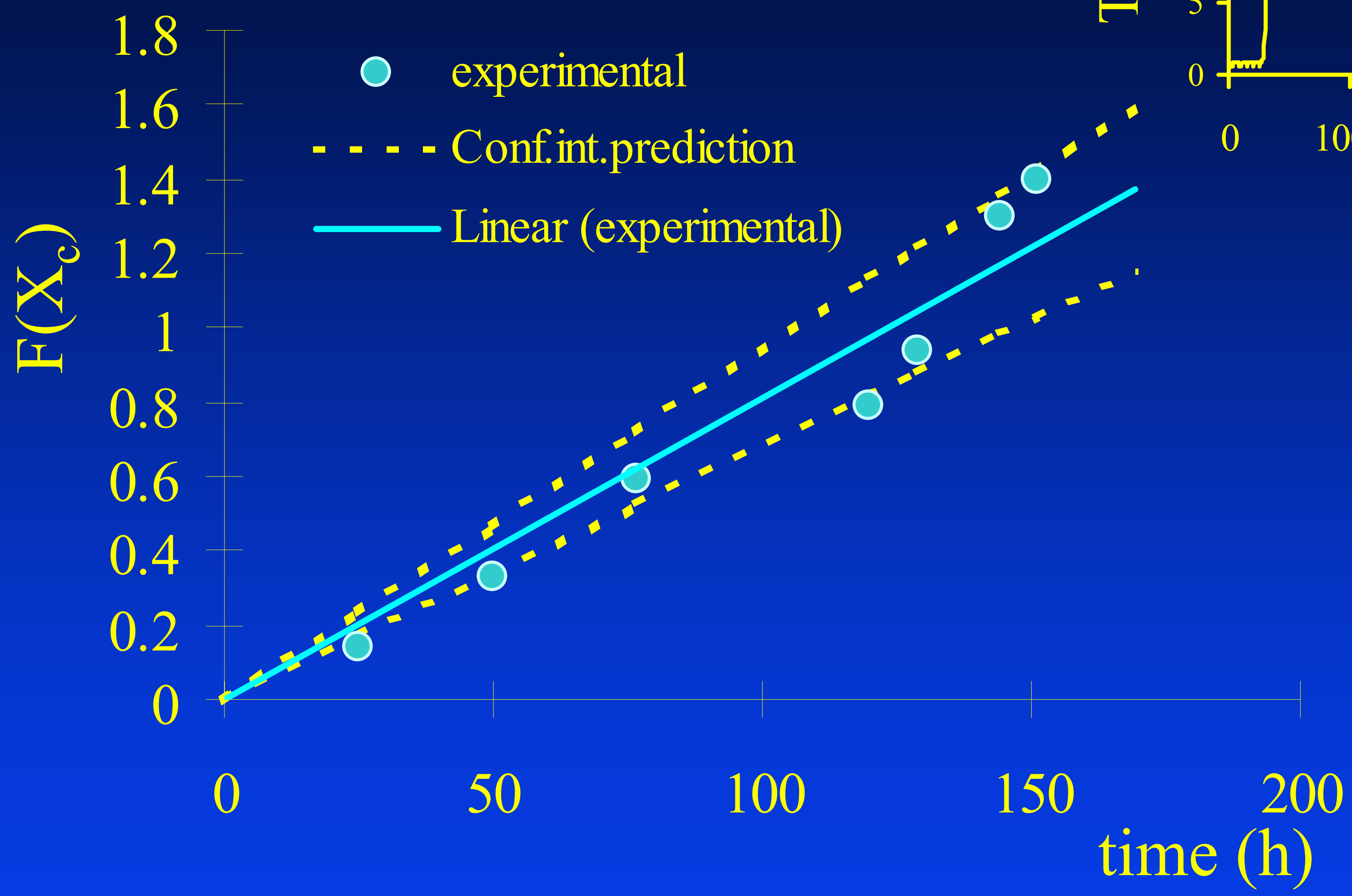
M4-10

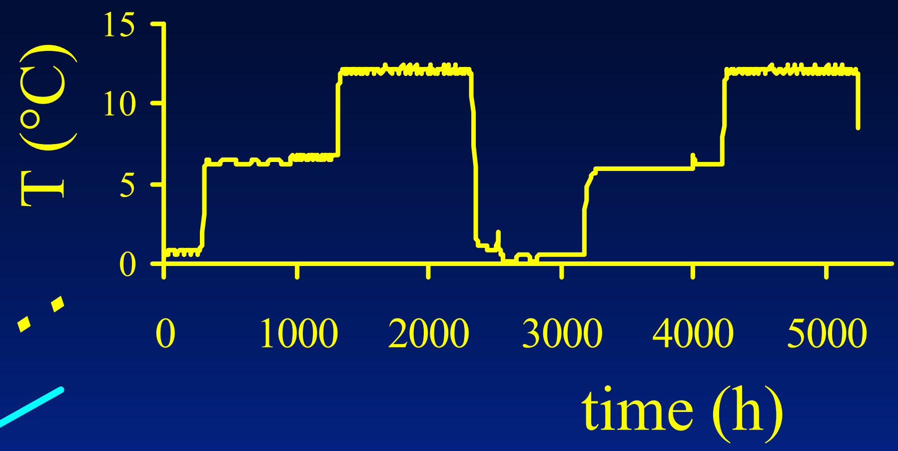
Arrhenius plot for TTI



M4-10

Validation under nonisothermal conditions





T_{eff} = 8.2°C

M4-10

TTI Study & Development

- ✓ A wide range of TTIs have been developed, kinetically studied & validated under variable temperature conditions
- ✓ 2 TTI configurations:
  - Bicolor (green to yellow)
  - Tricolor (green to yellow to red)
- ✓ Alternative methods of measuring TTI response
- ✓ Different color scales to allow accurate visual TTI readings

Wide range of TTIs

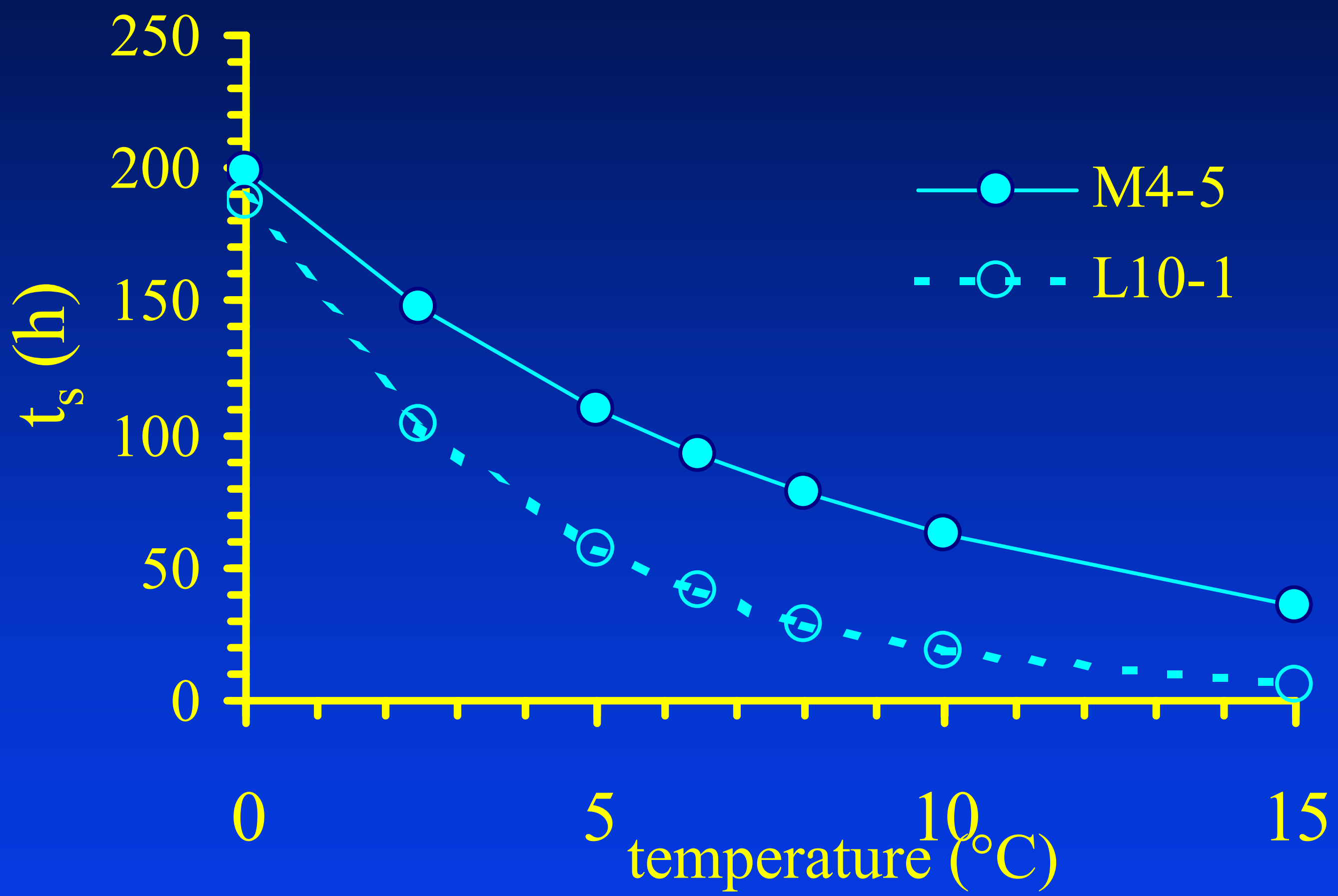
- ✓ Different TTI designs of various response characteristics response from hours to several weeks at refrigeration temperatures

- ✓ The TTIs temperature sensitivity ranged from 50 to 200KJ/mol covering the respective range of bacteria growth in meat products

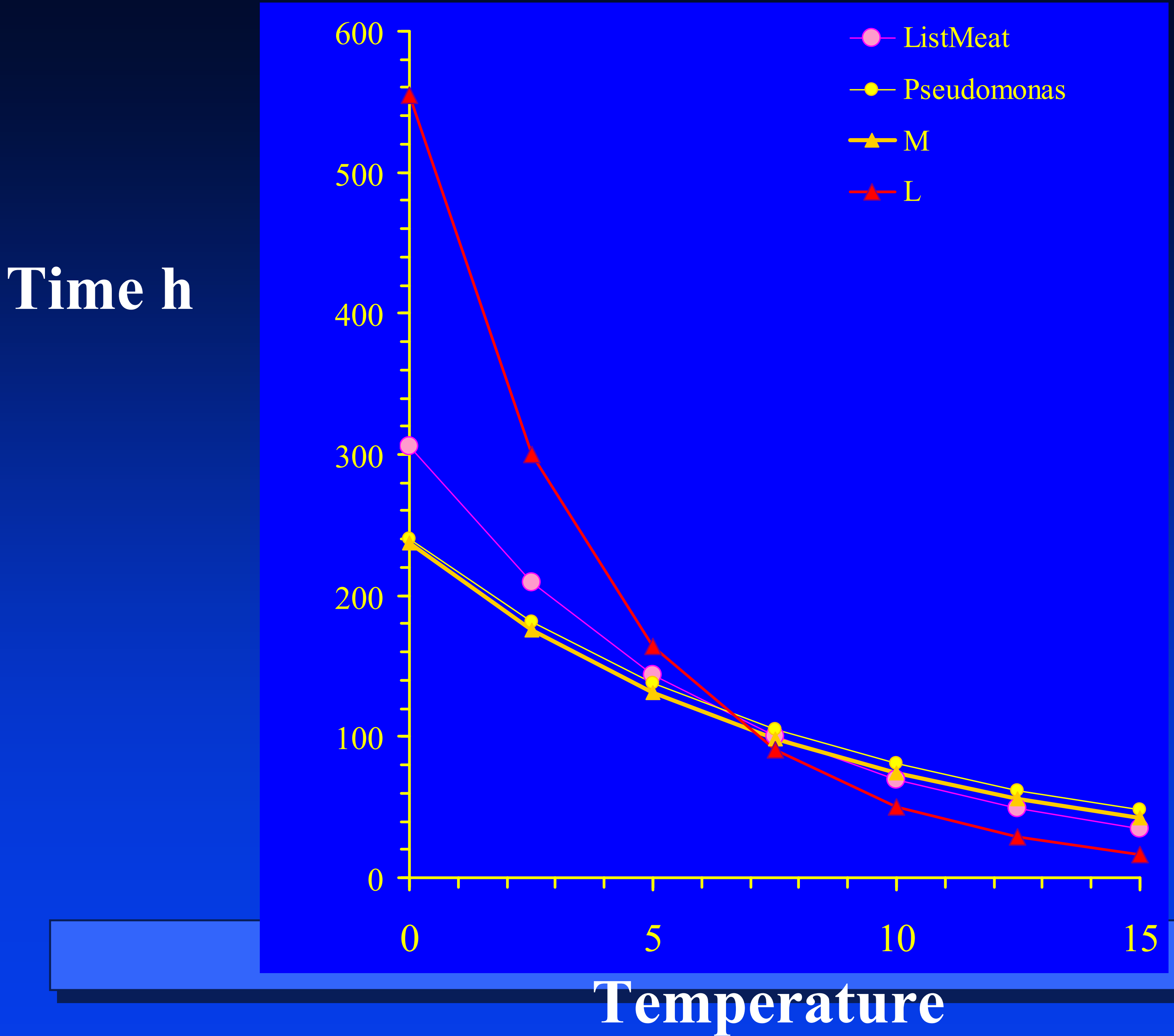
Wide range of TTIs

TTI Type	E_A (kcal/mol)–(kJ/mol)	Time to endpoint of Indicator (h)			
		0°C	5°C	10°C	15°C
M4-6	16.9-70.7	210	120	60	35
M4-7	19.0-79.5	250	150	70	50
M4-8	17.0-71.2	280	190	85	50
M4-9	21.4-89.6	415	190	74	57
M4-10	18.5-77.4	410	250	120	80
M4-23	16.3-18.2	917	630	300	16
M4-29	24.0-100.5	1000	670	280	170
L4-4	35.8-149.9	264	85	20	8
L4-11	47.9-200.5	880	197	52	11
L4-16	36.4-152.4	940	300	70	25
L4-42	35.5-148.6	2500	800	257	85
L4-54	40.0-167.4	3000	980	300	80
L4-58	22.0-92.1	2500	1300	700	220
LM4-8	20-83.7	310	155	80	50
B4-2	15.8-66.1	67	42	20	10
C4-8	10.2-42.7	200	165	122	67
C4-13	11.1-46.5	400	260	200	150
C4-20	12.6-52.7	570	470	300	210

TTI Study



TTI kinetic results – Comparison Type L vs M


Time h
600
500
400
300
200
100
0
ListMeat
Pseudomonas
M
L
0
5
10
15
Temperature

KINETICS OF MICROBIAL GROWTH

- Growth for **variable** temperature distribution

$$f(N)_t = \int_0^t \mu_{max}[T(t)]dt = \mu_{ref} \int_0^t \exp\left(\frac{-E_A}{R}\left(\frac{1}{T}\right)\right)dt$$

$$= \mu_{ref} \exp\left(\frac{-E_A}{RT_{eff}}\right)t$$

T_{eff} : constant temperature that results in the same quality change as the variable temperature distribution over the same time period

TTI RESPONSE KINETICS

X: measurable change of TTI

Response function:

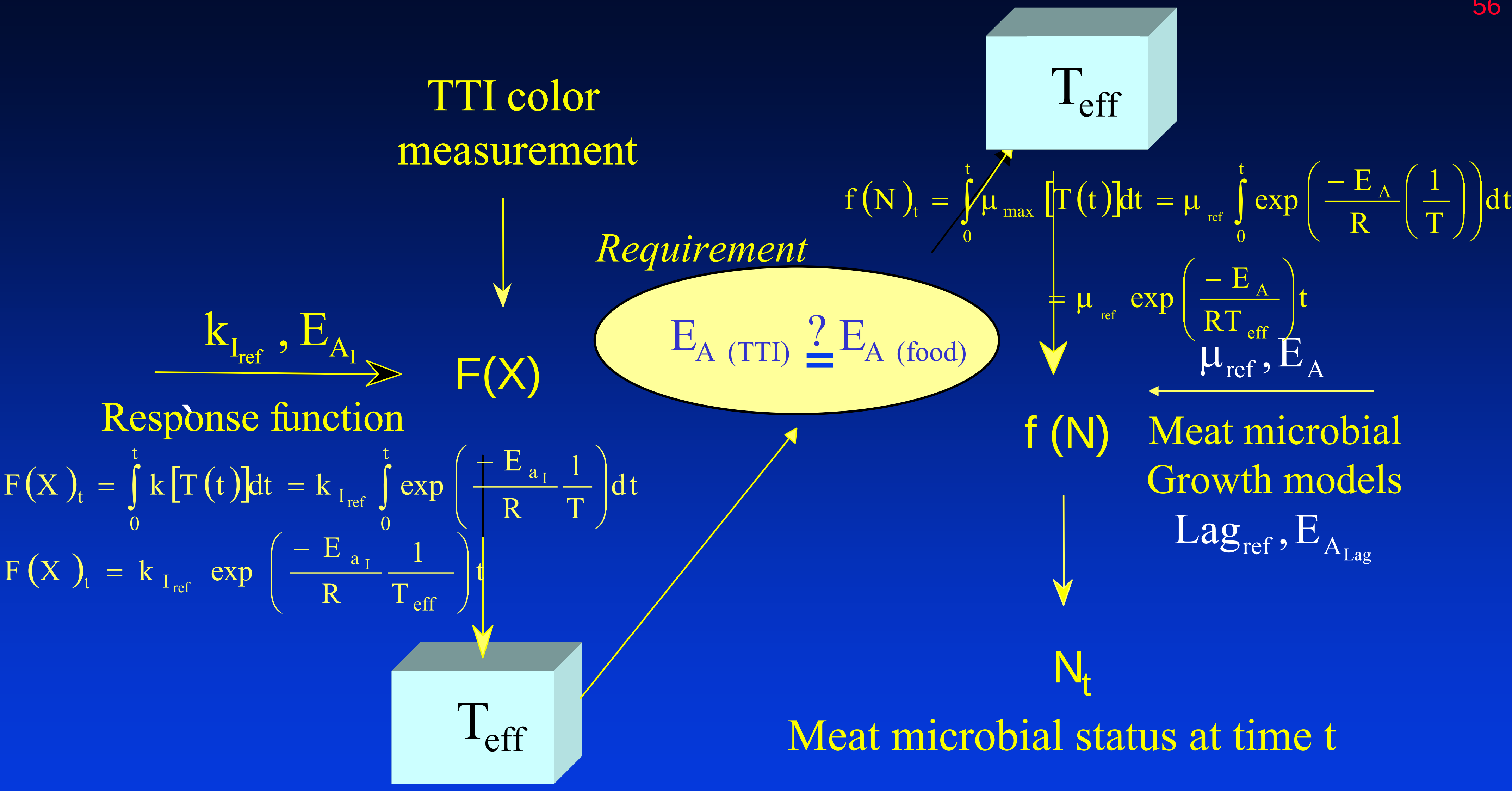
$$F(X) = kt = k_{I_{ref}}\ exp\left(\frac{-E_{a_I}}{R}\left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right)t$$

- *For variable temperature distribution:*

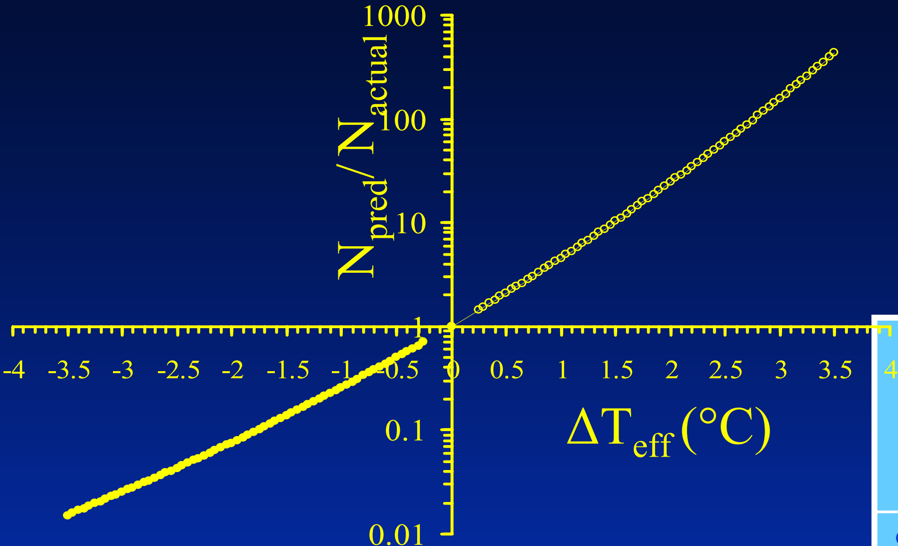
$$F(X)_t = \int_0^t k[T(t)]dt = k_{I_{ref}} \int_0^t exp\left(\frac{-E_{a_I}}{R}\left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right)dt$$

- *Using effective temperature:*

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



TTI application scheme



$logN_o$=2.5, $logN_{final}$=8
($E_a \simeq$ 70.3 kJ/mol, Shelf life@4°C=305h)

	E_A (TTI) (kJ/mol)	T_{eff} (°C) (predicted)	ΔT_{eff} (°C) T_{eff} (TTI)- T_{eff} (actual)	N_{pred}/N_{actual}
Single TTI	46 (Type C)	8.04	-0.570	0.43
	76 (Type M)	8.75	0.140	1.03
	150 (Type L)	10.76	2.150	34.52
Double TTI	(46-150) (Type C-Type L)	8.67	0.062	0.90
Double TTI	(46-76) (Type C-Type M)	8.61	0.005	0.82

CORRECTION of the error in the T_{eff} estimation

INPUT

$\mu_{ref}, E_A, Lag_{ref}, E_{A_{Lag}}$

Food Characteristics

T(t) data

TTI response models

OR

Datalogger profile

TTI response

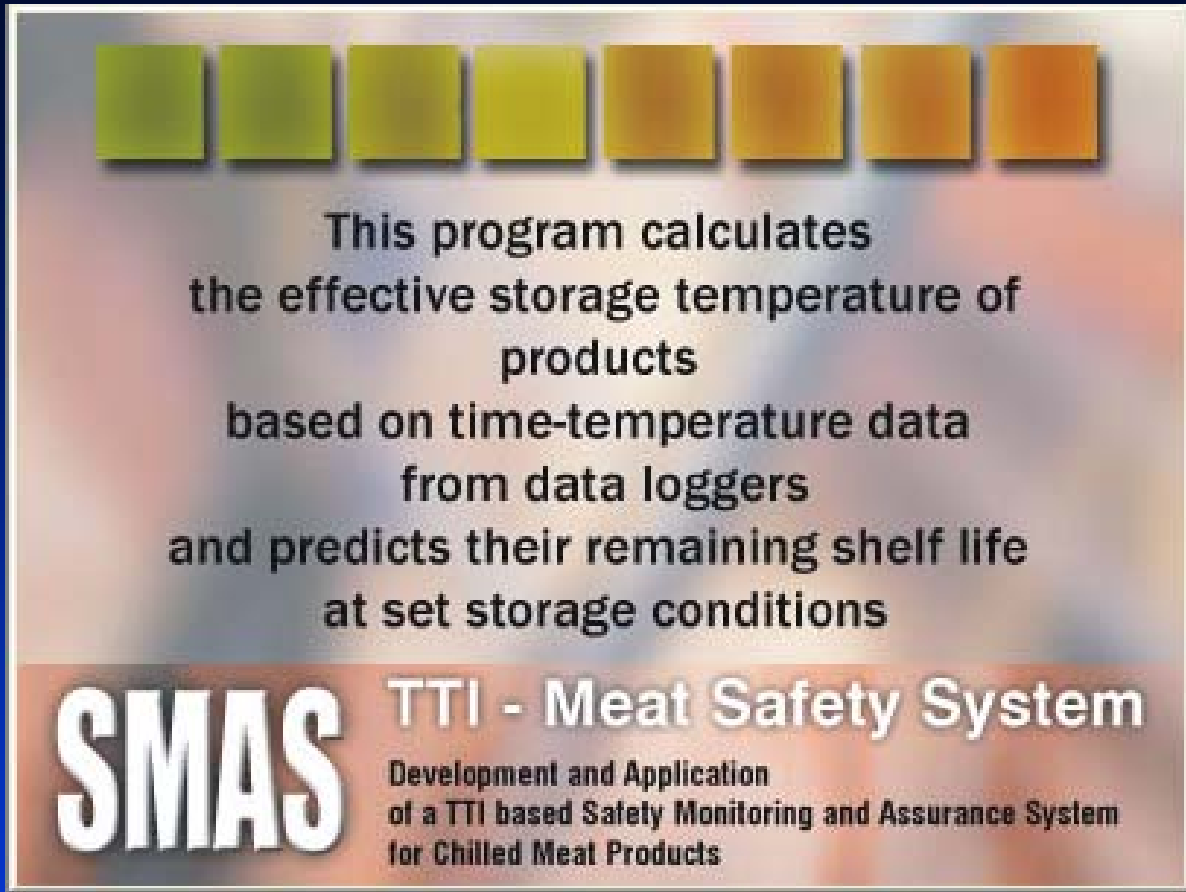
- **Lab scale**
- **Visual scale**

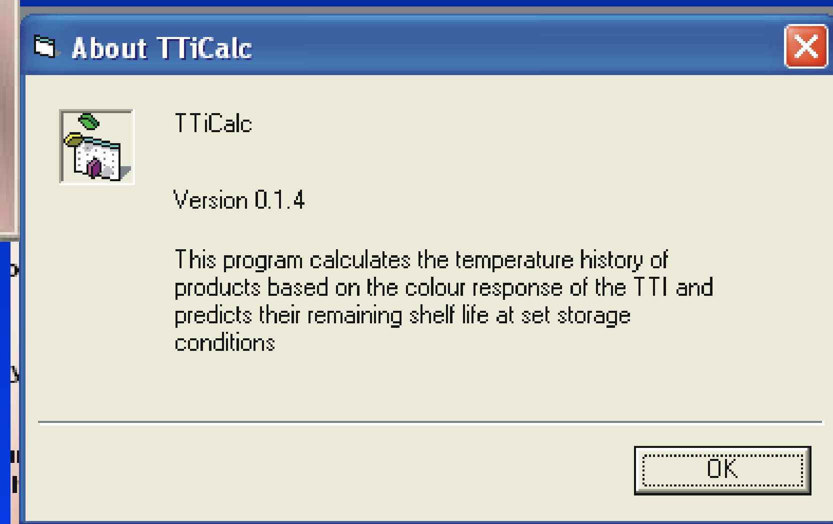
OUTPUT

T_{eff} calculation

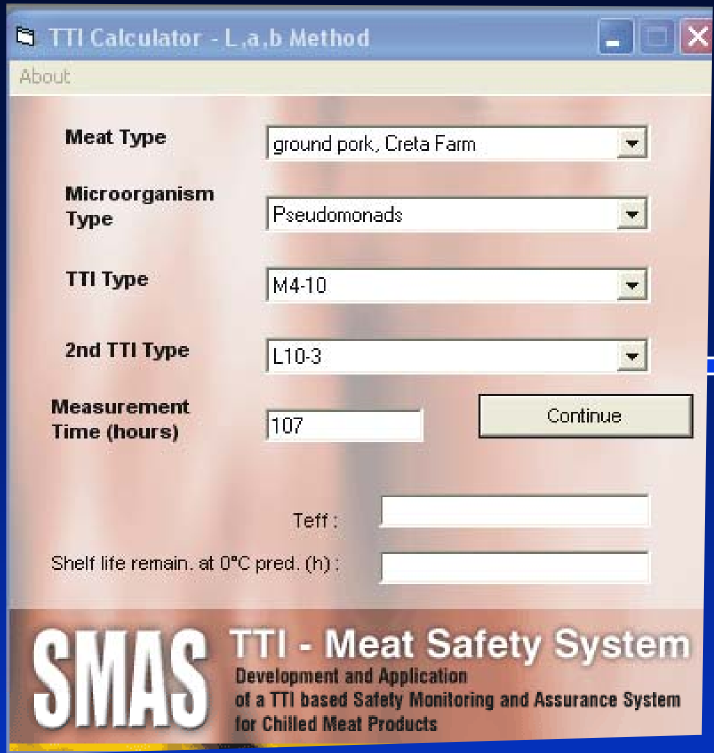
Acceptability limit
(e.g. N_s for microbial growth),
Initial status (N_o),
Food spoilage model

Remaining Shelf Life


This program calculates
the effective storage temperature of
products
based on time-temperature data
from data loggers
and predicts their remaining shelf life
at set storage conditions
SMAS
TTI - Meat Safety System
Development and Application
of a TTI based Safety Monitoring and Assurance System
for Chilled Meat Products

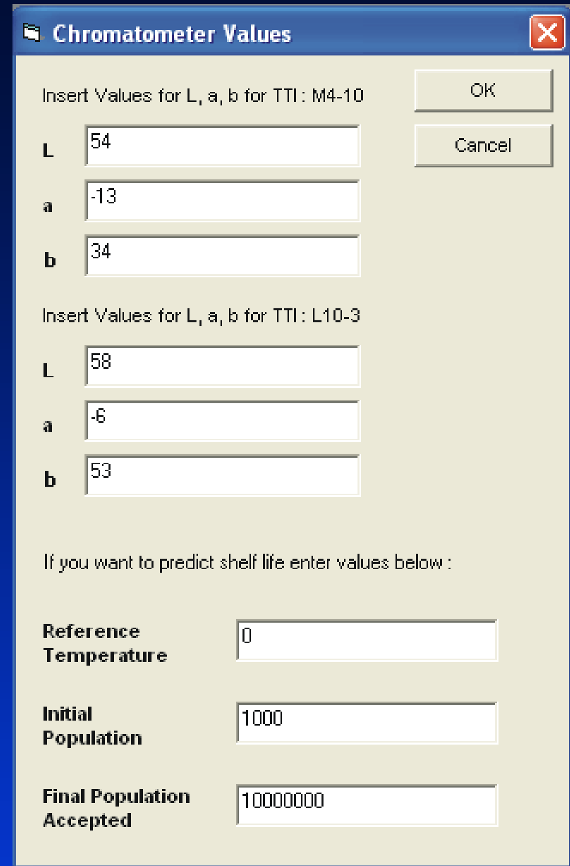

About TTiCalc
TTiCalc
Version 0.1.4
This program calculates the temperature history of products based on the colour response of the TTI and predicts their remaining shelf life at set storage conditions
OK

(2)



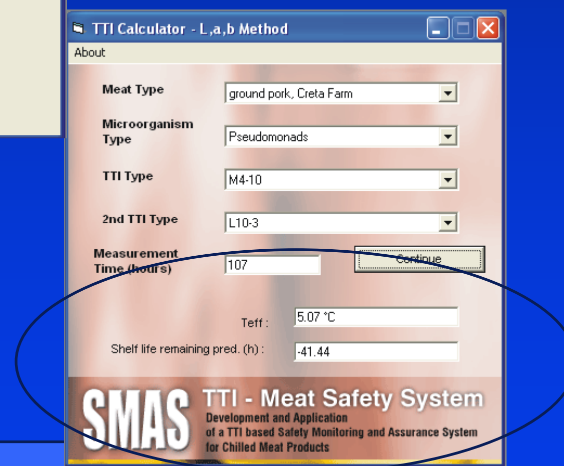
(TTI 1)

(TTI 2)



(3)

(1)



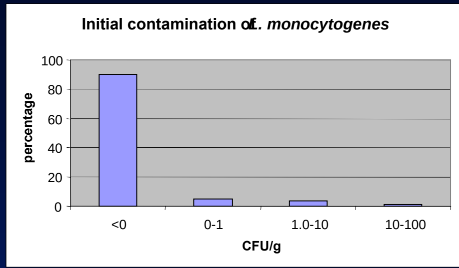
(RESULTS)

T_{eff}, Shelf life

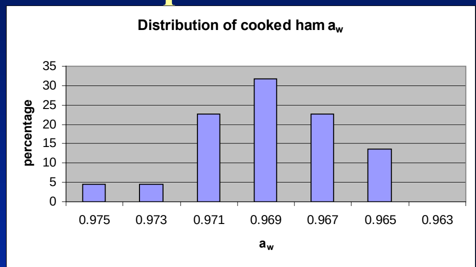
(a) Values for TTI color (Chromameter – Scanner- … Lab scale)

SMAS PRINCIPLES & APPLICATION

chill chain scenario



Final product → **Storage** (12h at 4 ^oC) → **Transport** (8h at 6 ^oC) → **Distribution Center** (24h at 4 ^oC)

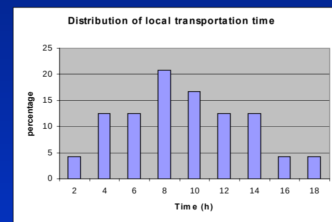


Product promotion

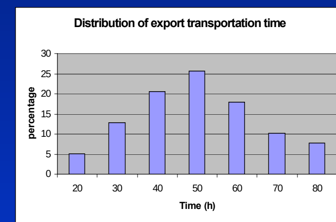
1st Decision point

(4 ^oC)

Local market



Export market

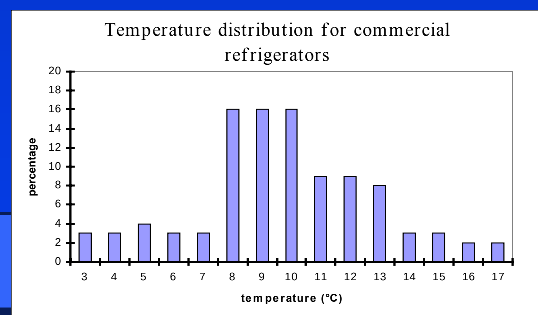


Retail Storage
(Super Market)

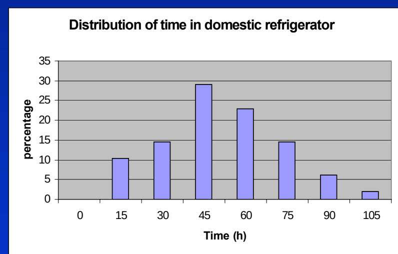
Stock Display

2nd Decision point

Display Cabinet
(6, 18, 30h)



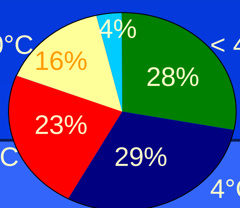
Domestic Fridge

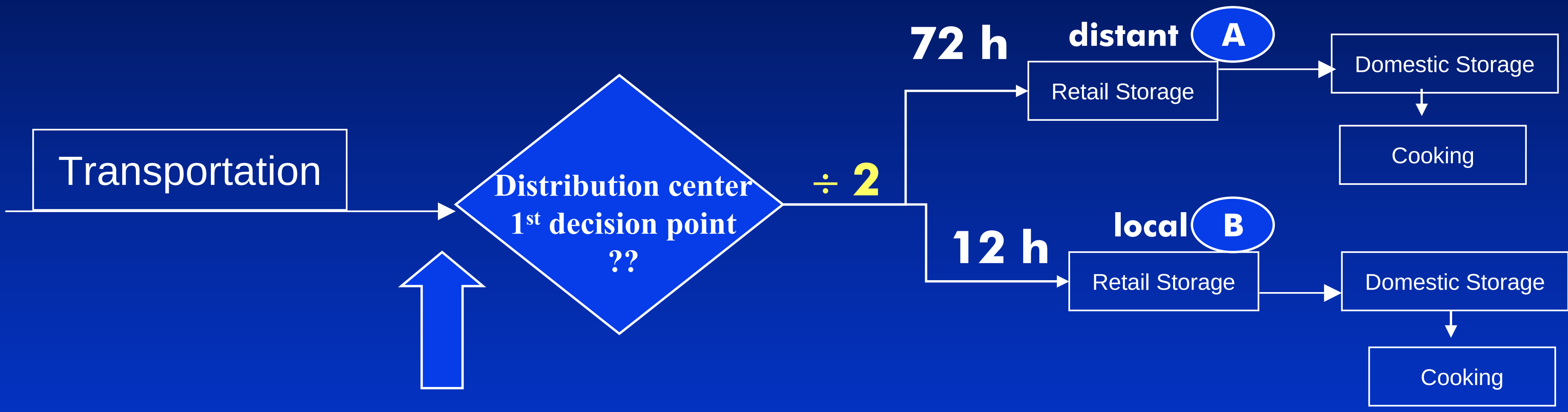


Consumption

Temperature distribution for domestic refrigerators

10°C<T< 12°C
8°C<T< 10°C
< 4°C
6°C<T< 8°C
4°C<T< 6°C



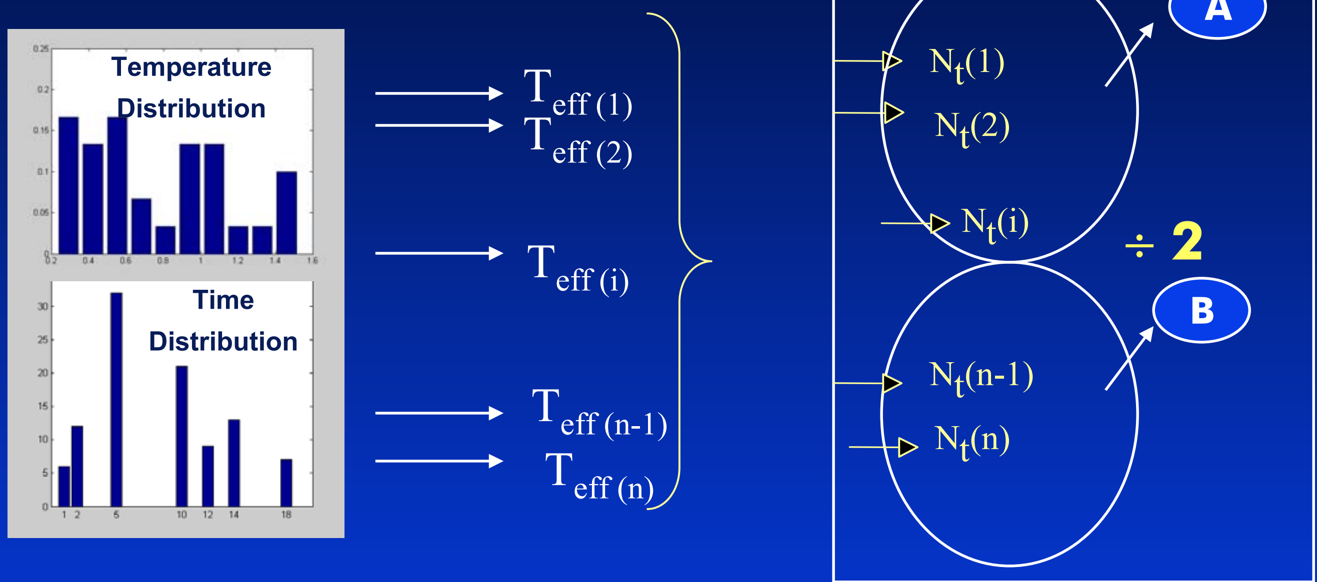


1. **Random Split**

OR

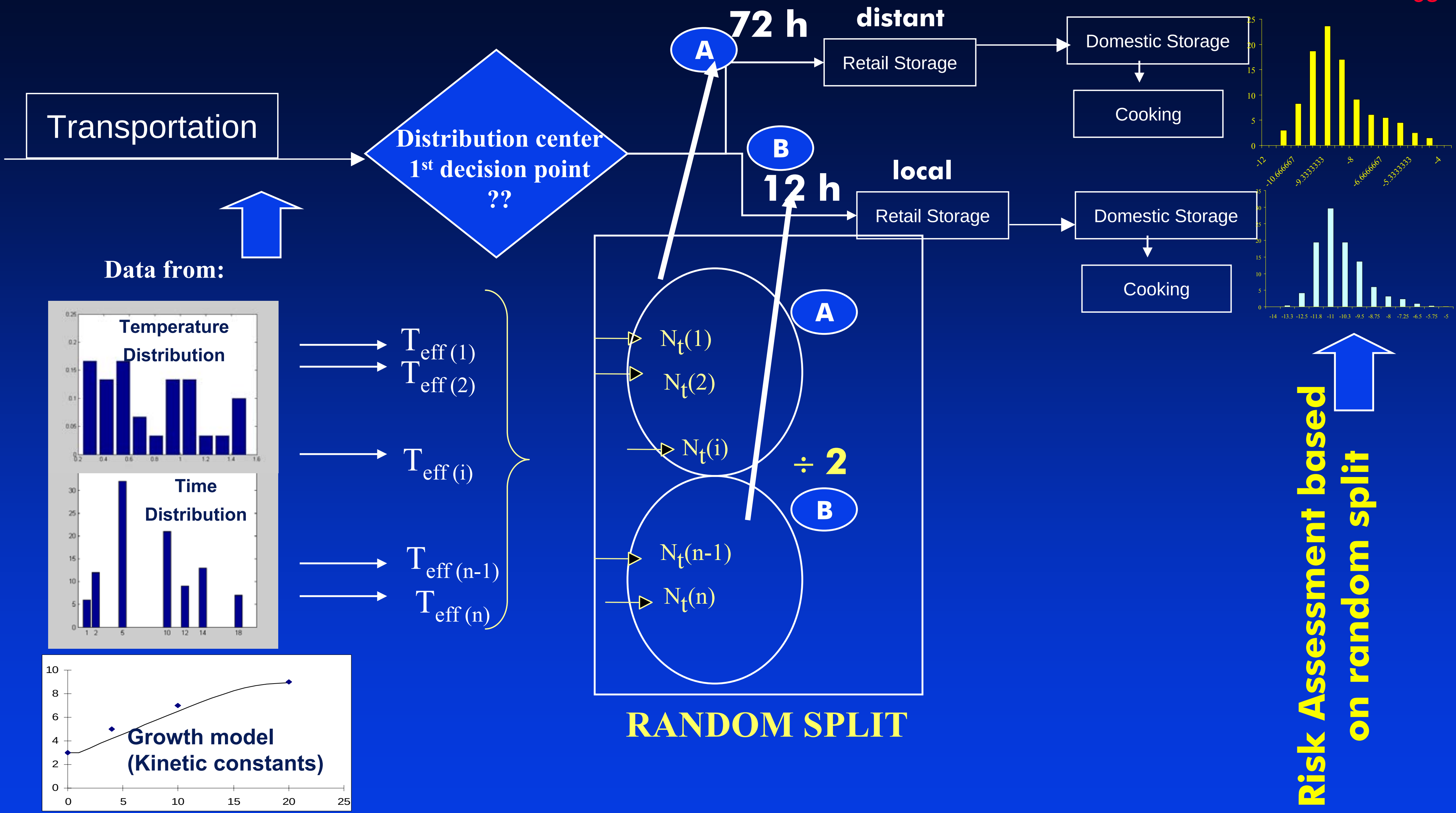
2. **SMAS based split**

Data from:

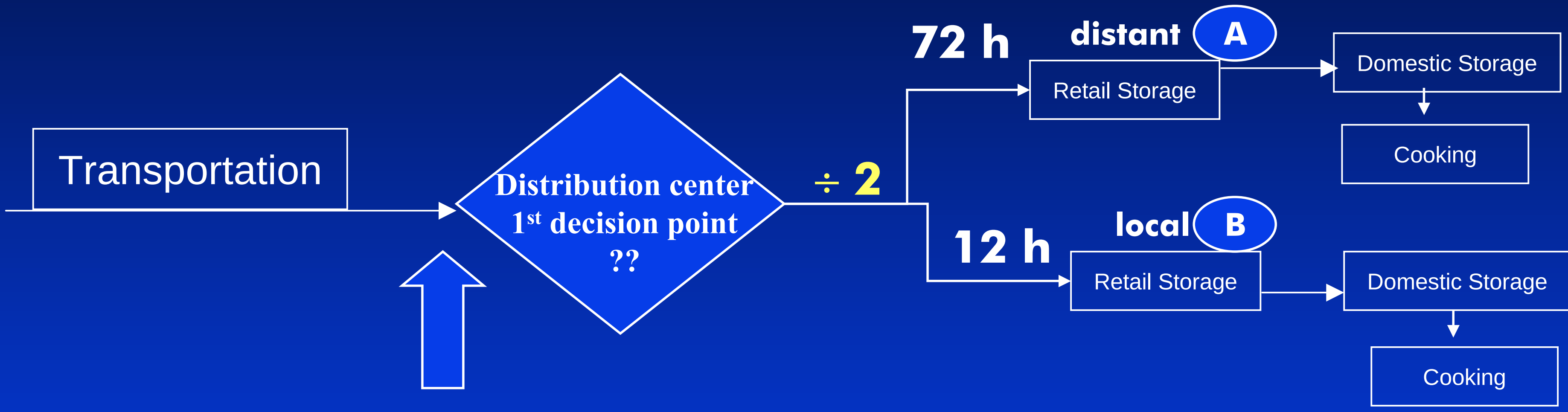


RANDOM SPLIT

1. Random Split



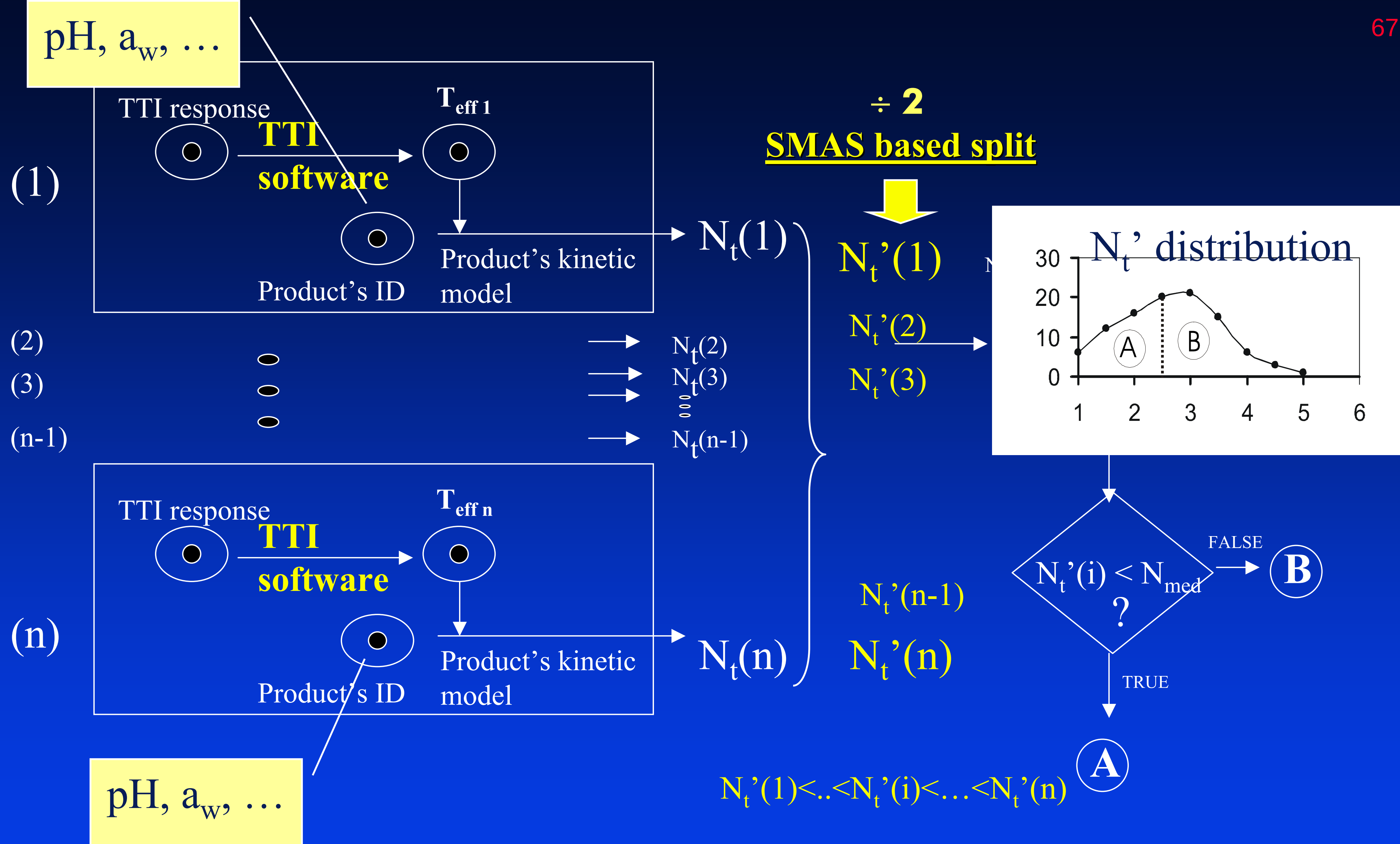
1. Random Split



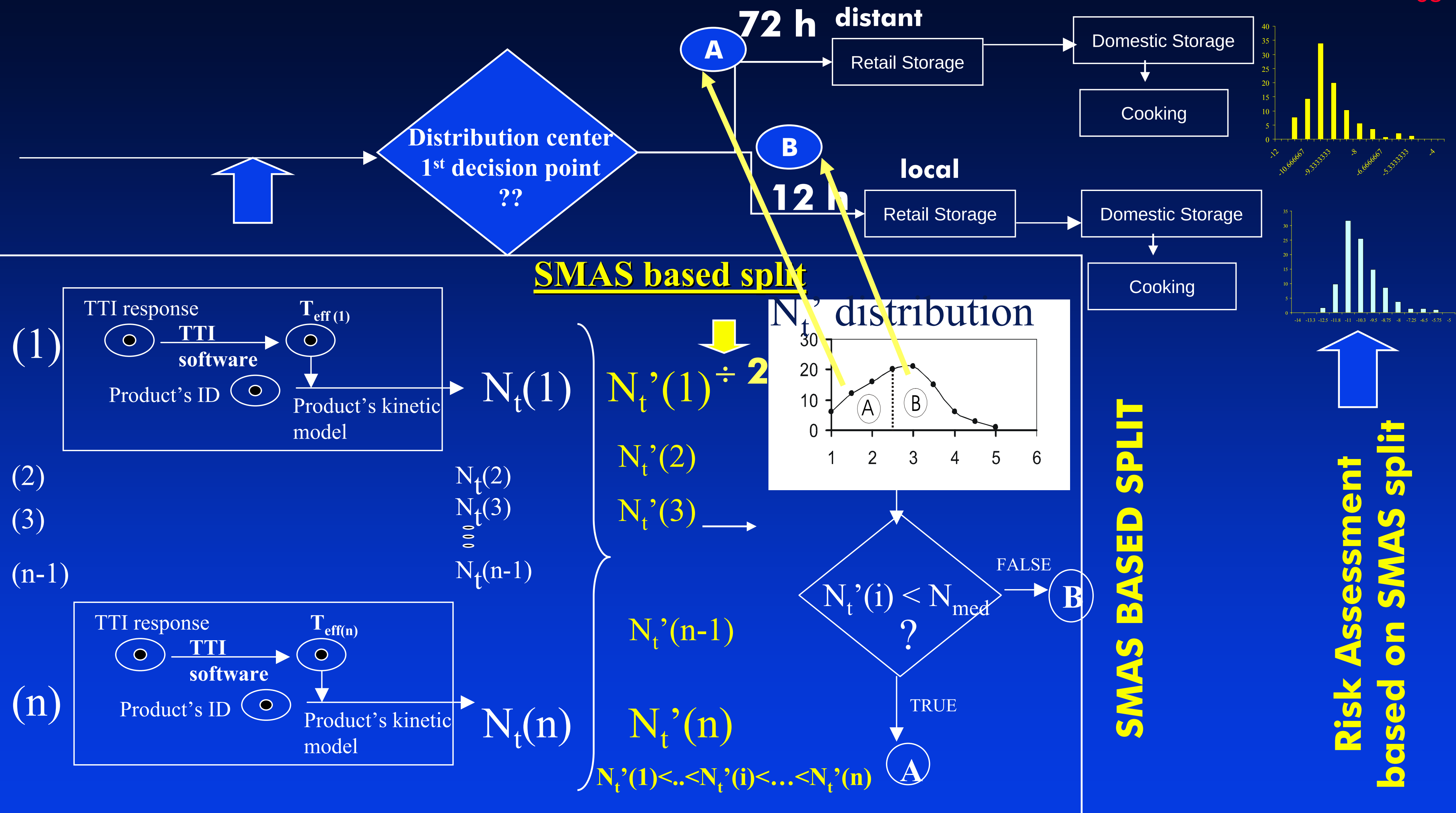
1. Random Split

OR

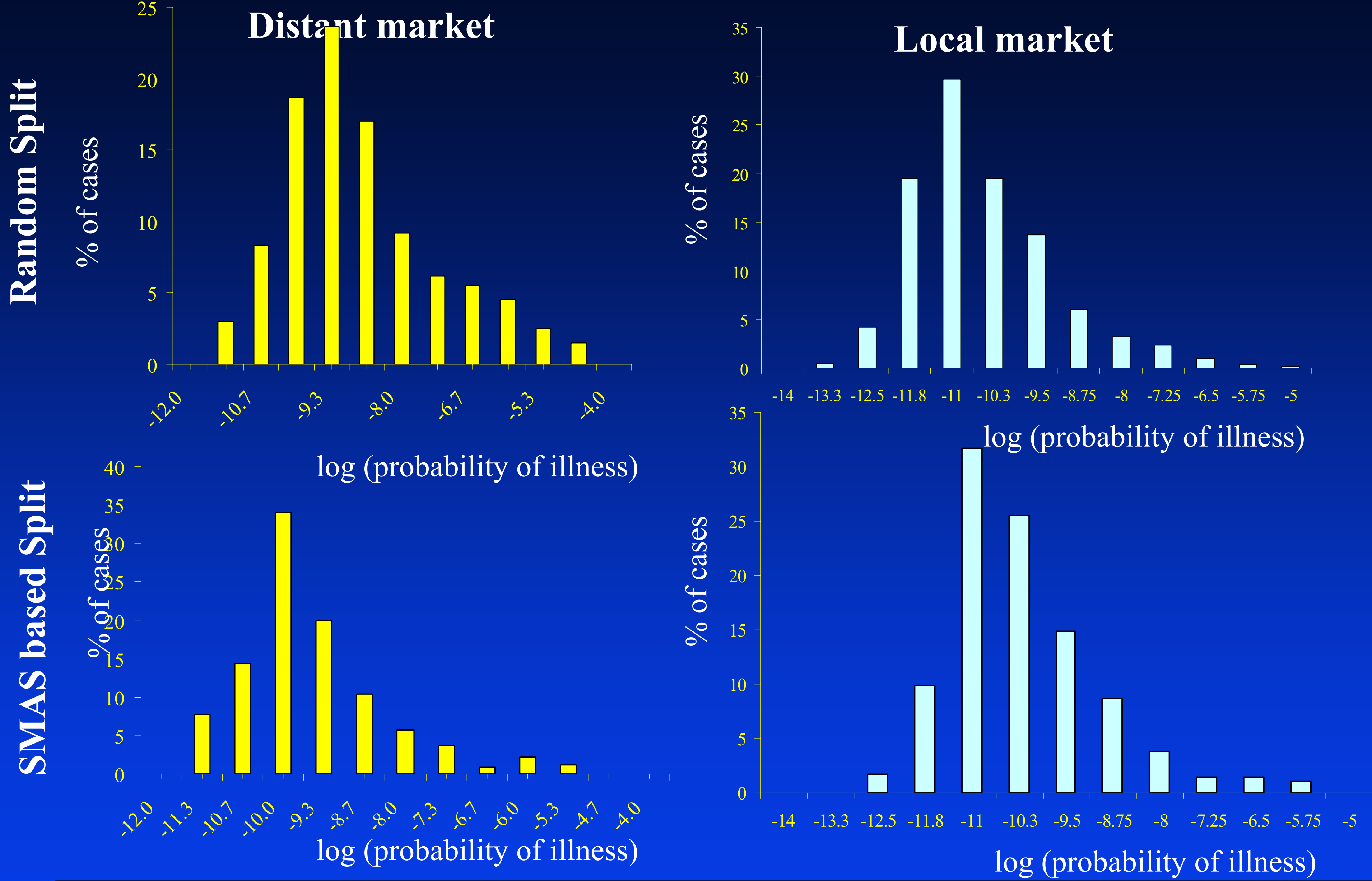
2. SMAS based split



2. SMAS based split



2. SMAS based split



Typical results

Microbial growth kinetic models for:

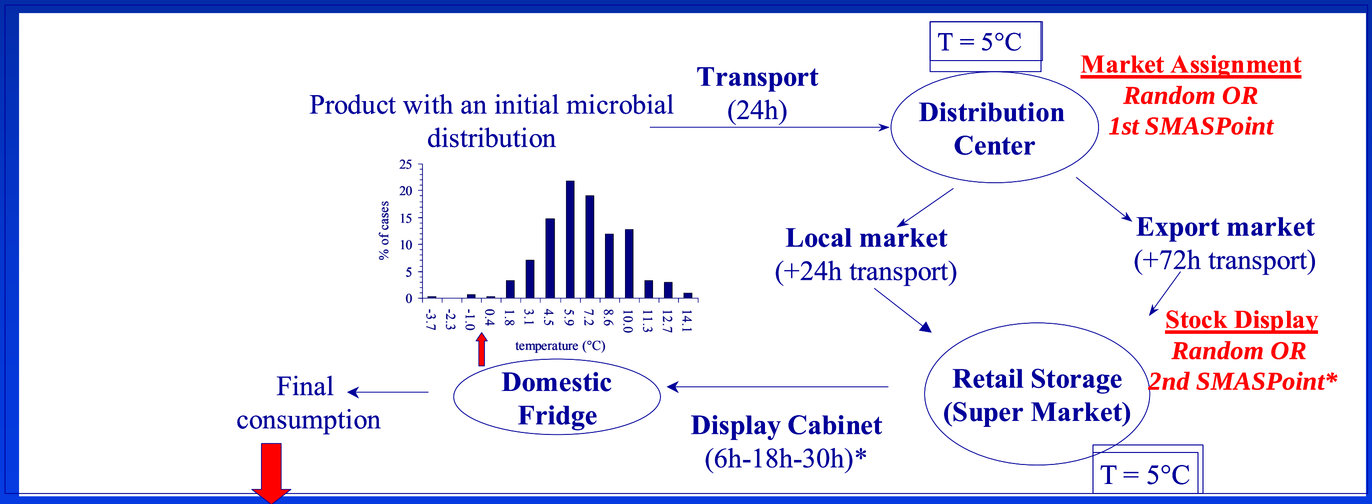
- ***Listeria monocytogenes*** ($E_A \cong$ 94.5 kJ/mol and μ_{ref}@10°C≅0.058h^{-1}) and **spoilage microorganisms, *Pseudomonas*** ($E_A \cong$ 73.1kJ/mol and shelflife$_f$@0°C≅190h).

For product monitoring and management at the SMAS points:

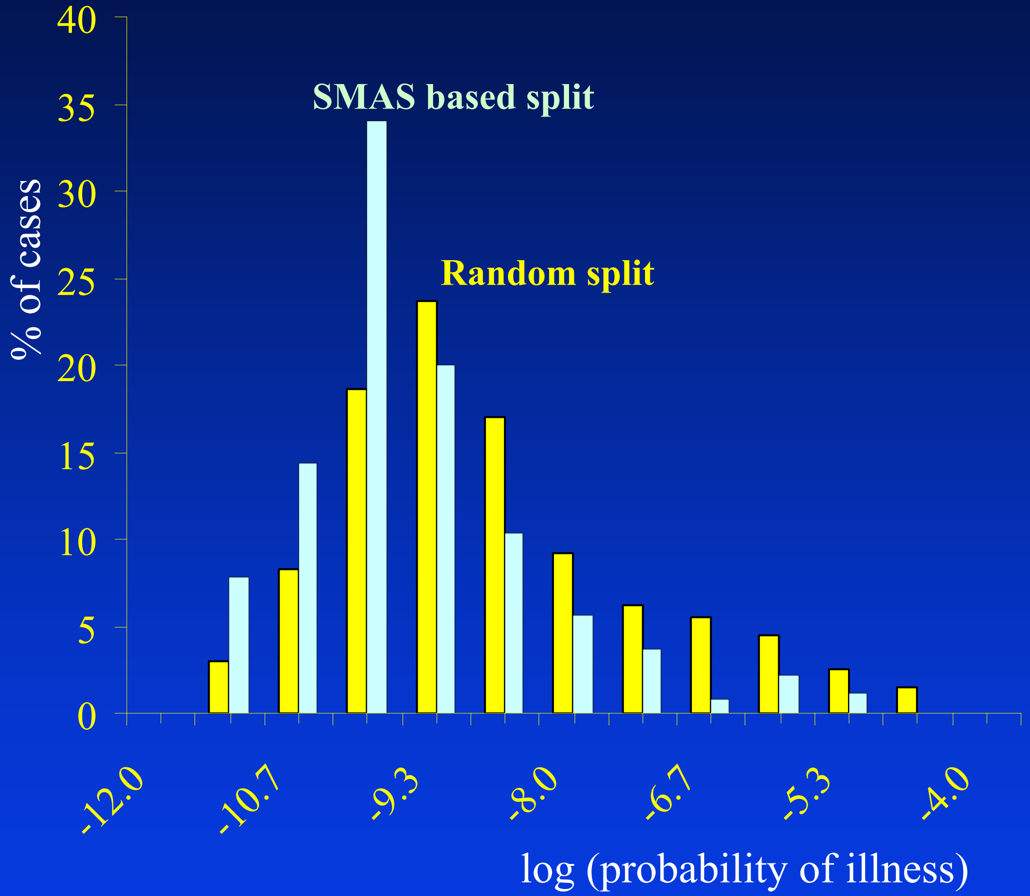
- an enzymatic TTI (**VITSAB® Type L10-3**) ($E_A \cong$ 158.5 kJ/mol and max response time$_f$@5°C≅150h)

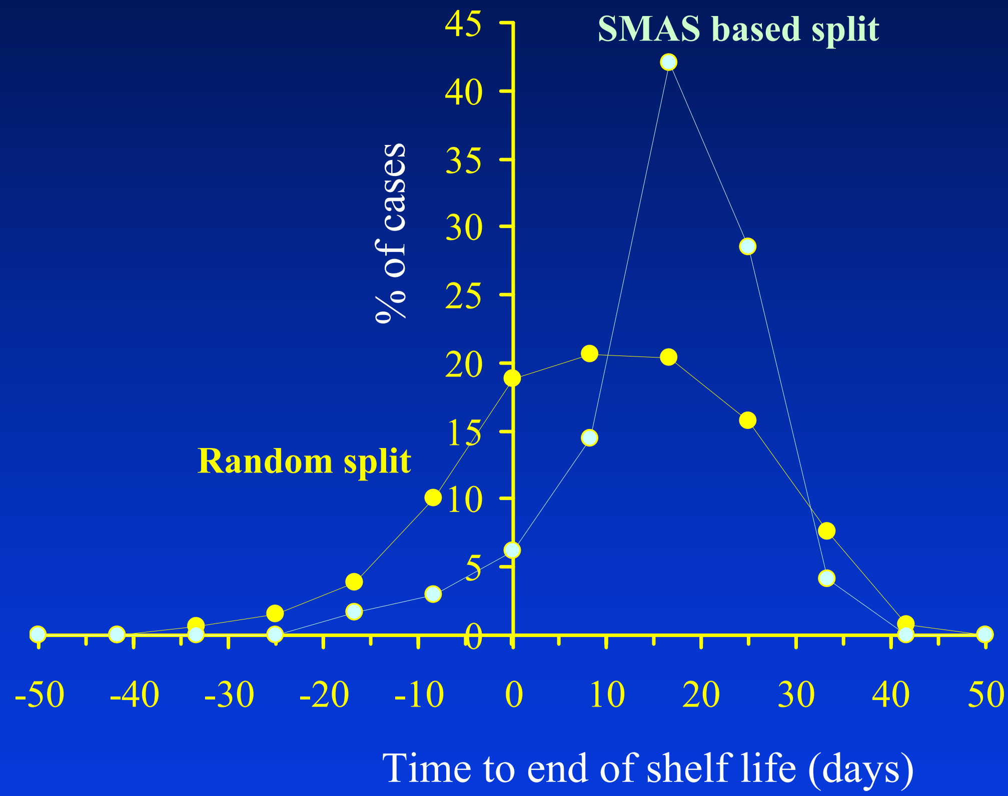
- Real data from surveys, for the stages of **transportation to the distribution center**, the **supermarket storage** and **stocking of the retail fridge cabinets**, and the domestic fridge.

- After domestic storage, a **cooking step** was assumed (logreduction ≅3.0±1.5CFU/g) and **a dose-response model** (Farber et al 1996) was applied for the estimation of the probability of illness.

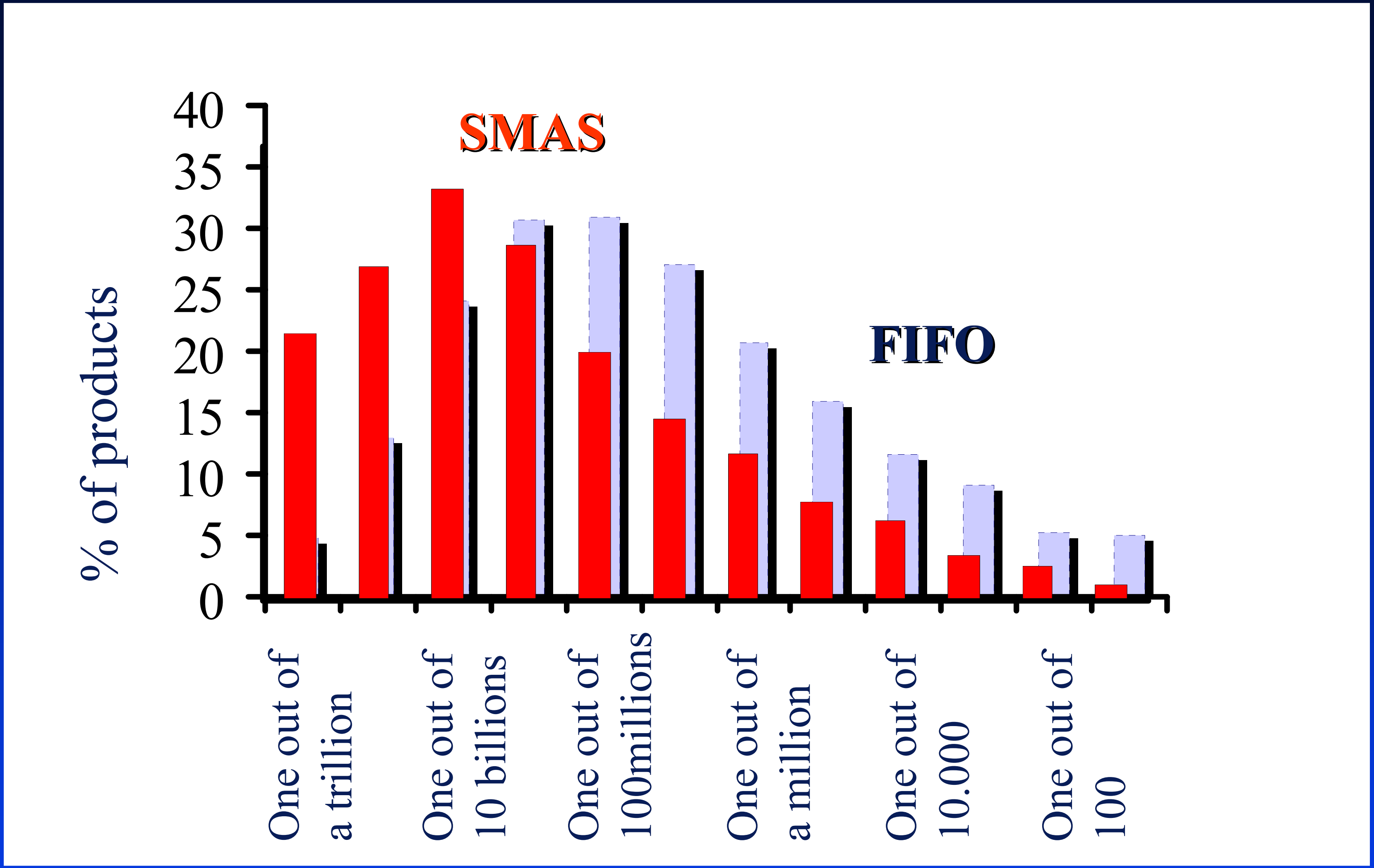


1st Example of SMAS application

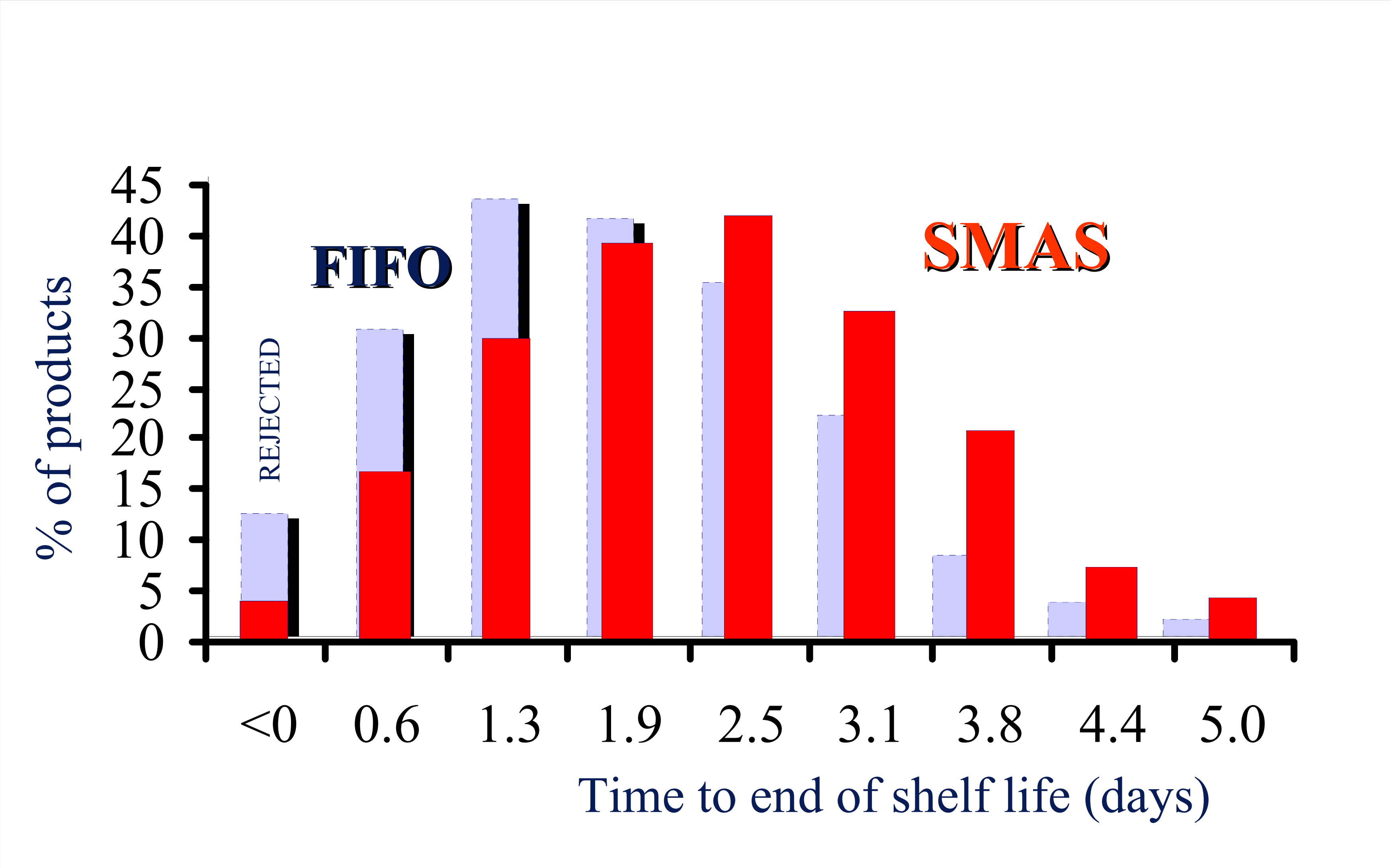




Distant market



Probability of illness



Product quality at consumption

Safety and quality assessment

- **Product:** Cooked meat (ham)

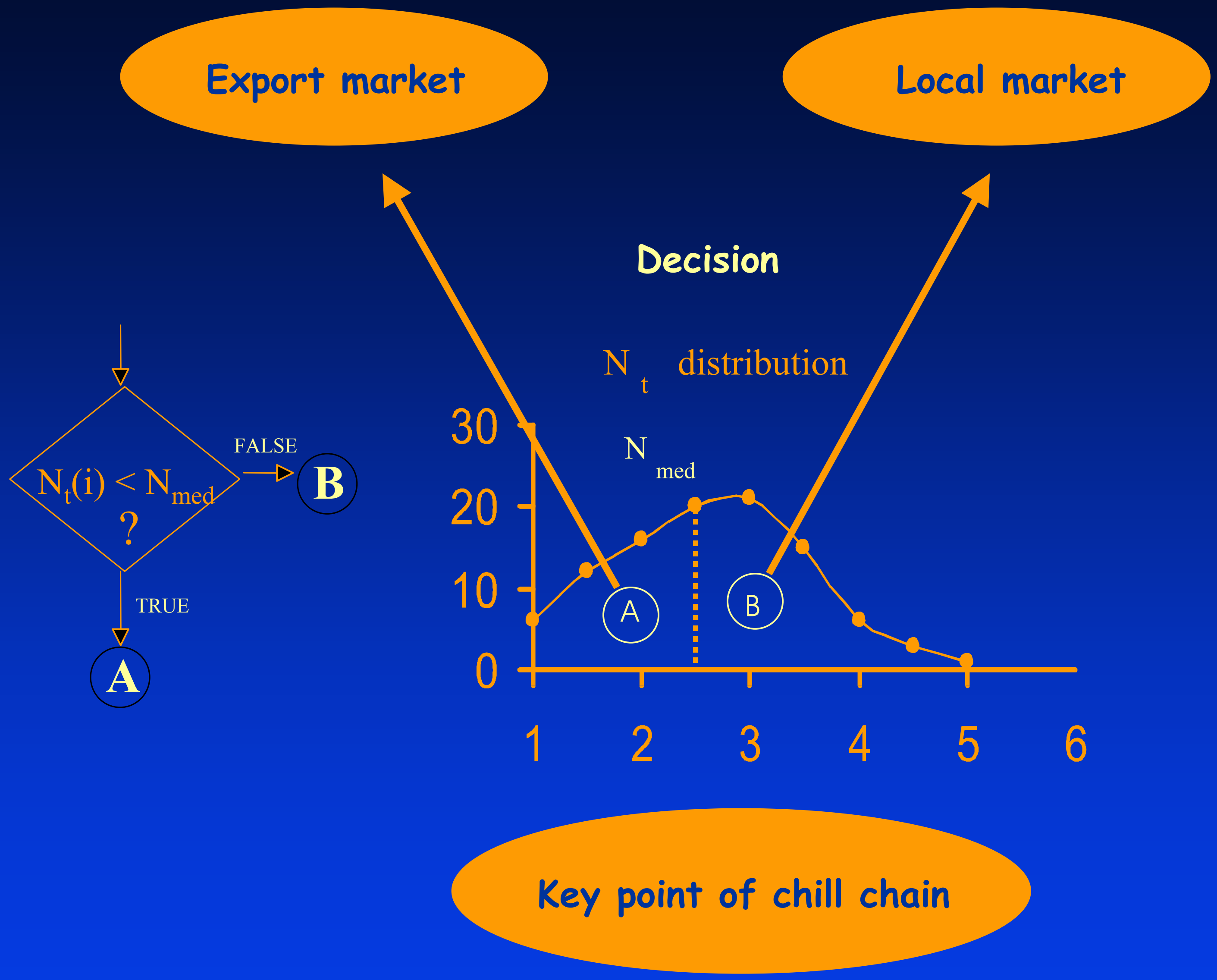
- **Method:** Comparison of listeriosis risk and remaining shelf life at the time of consumption in products managed with FIFO and SMAS system using Monte Carlo simulation

- **Tools:**
  - Microbiological data from literature
  - Temperature data collected in the chill chain
  - validated kinetic models of microbial growth
  - validated kinetic models of TTI response

Decision points in the chill chain:

1. Distribution Center
2. Stock display (retail level)

2nd Example of SMAS application



SMAS principles

Development of a Safety Monitoring and Assurance System (SMAS) for chilled food products

Evaluation of SMAS effectiveness
Risk estimation

- **Serving:** 50 g
- **Dose response relationship:** *Farber et al., 1996* →
- **Population:** Normal

152 *J.M. Farber et al. / Int. J. Food Microbiology 30 (1996) 145–156*

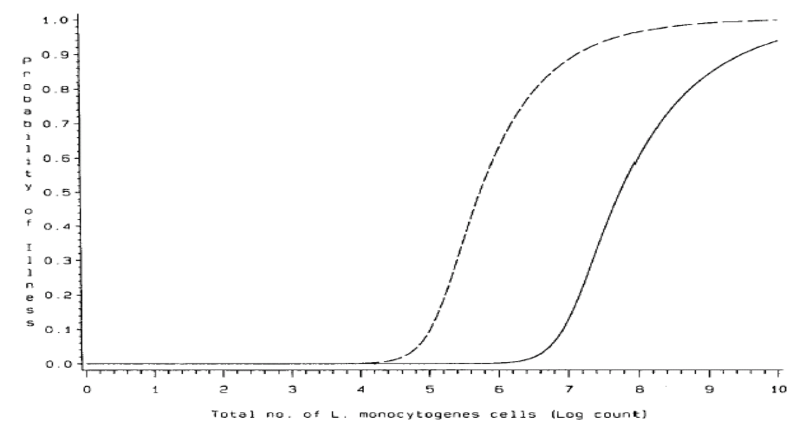
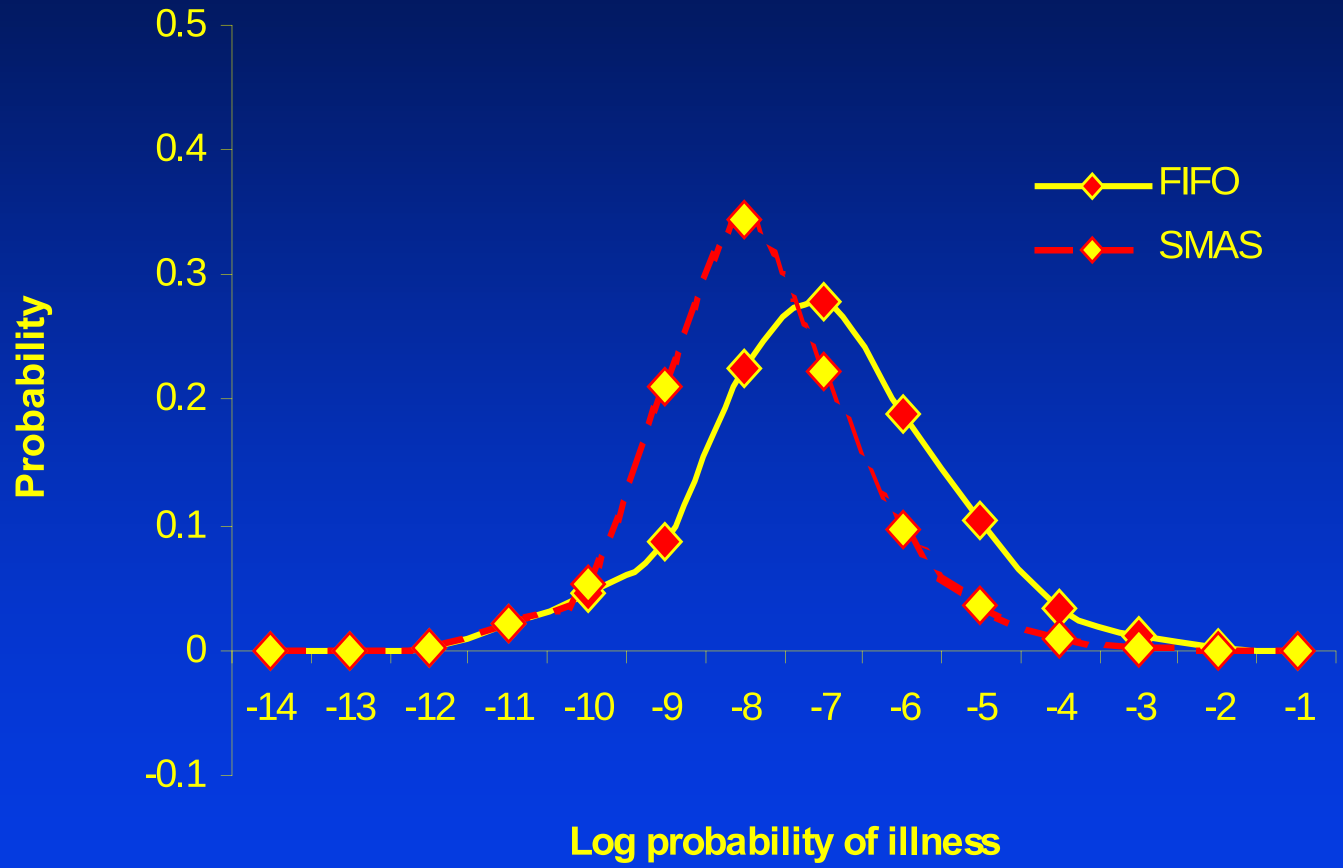


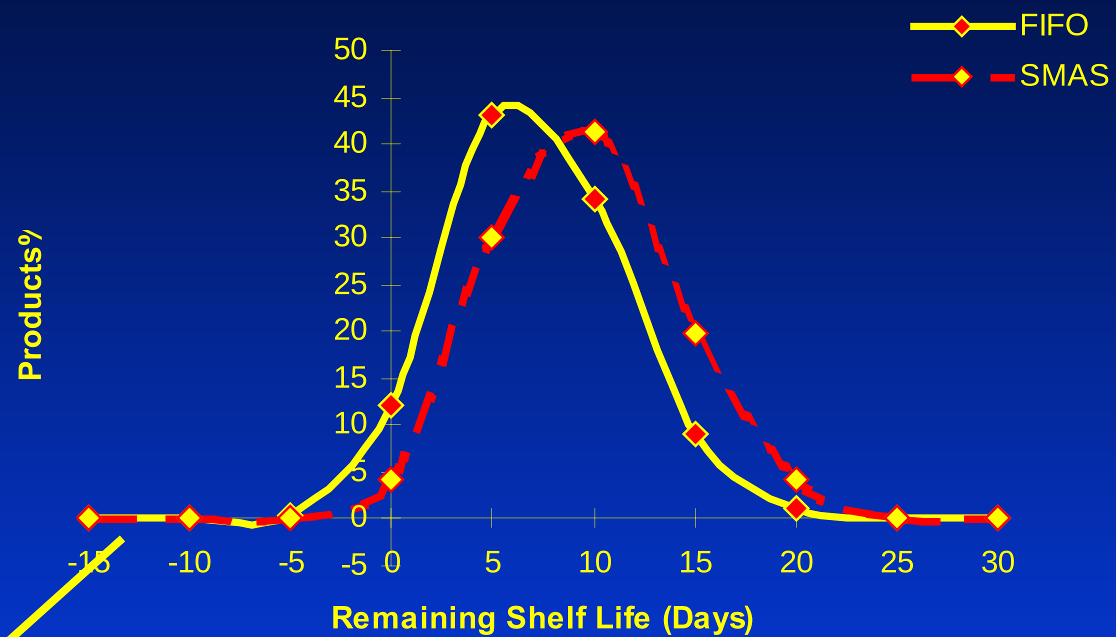
Fig. 1. Dose response curve for *Listeria monocytogenes* infections derived using the Weibull-Gamma model. Solid line, normal population; broken line, high risk population.

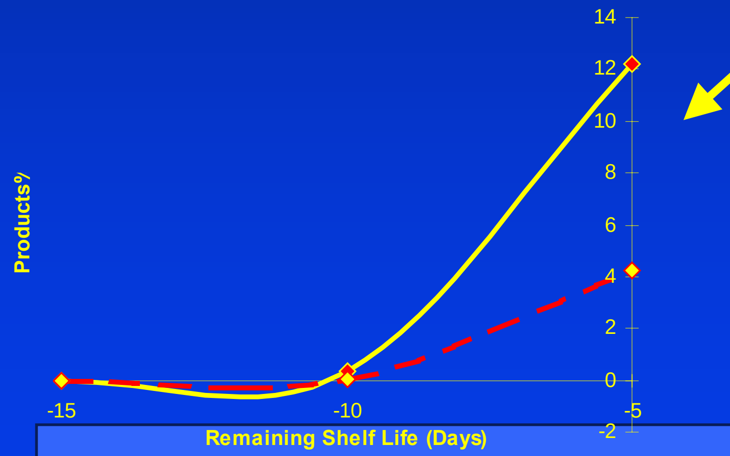
Evaluation of SMAS effectiveness

Results



Evaluation of SMAS effectiveness
Product Quality (shelf life)
Results





Spoiled products at the time of consumption

FIFO: 14.9%

SMAS: 4.3%

EXPERIMENTAL VALIDATION OF SMAS

Product: Cooked Ham (Air)

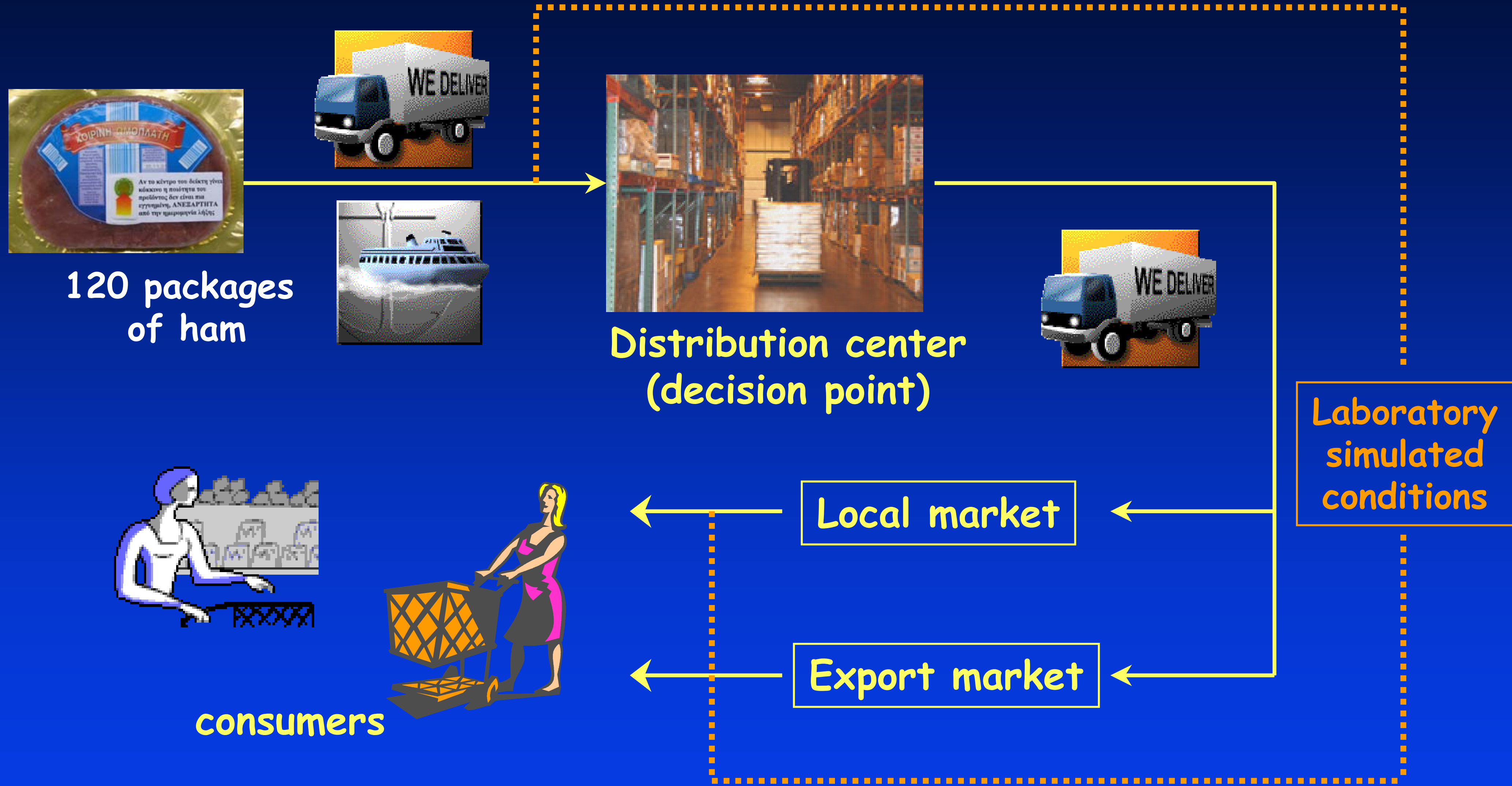
TTIs: L5-8 & M4-30

Temperature Conditions: ranging from 4 to 12°C

Bacteria measured: Lactic Acid Bacteria, *Listeria Monocytogenes*

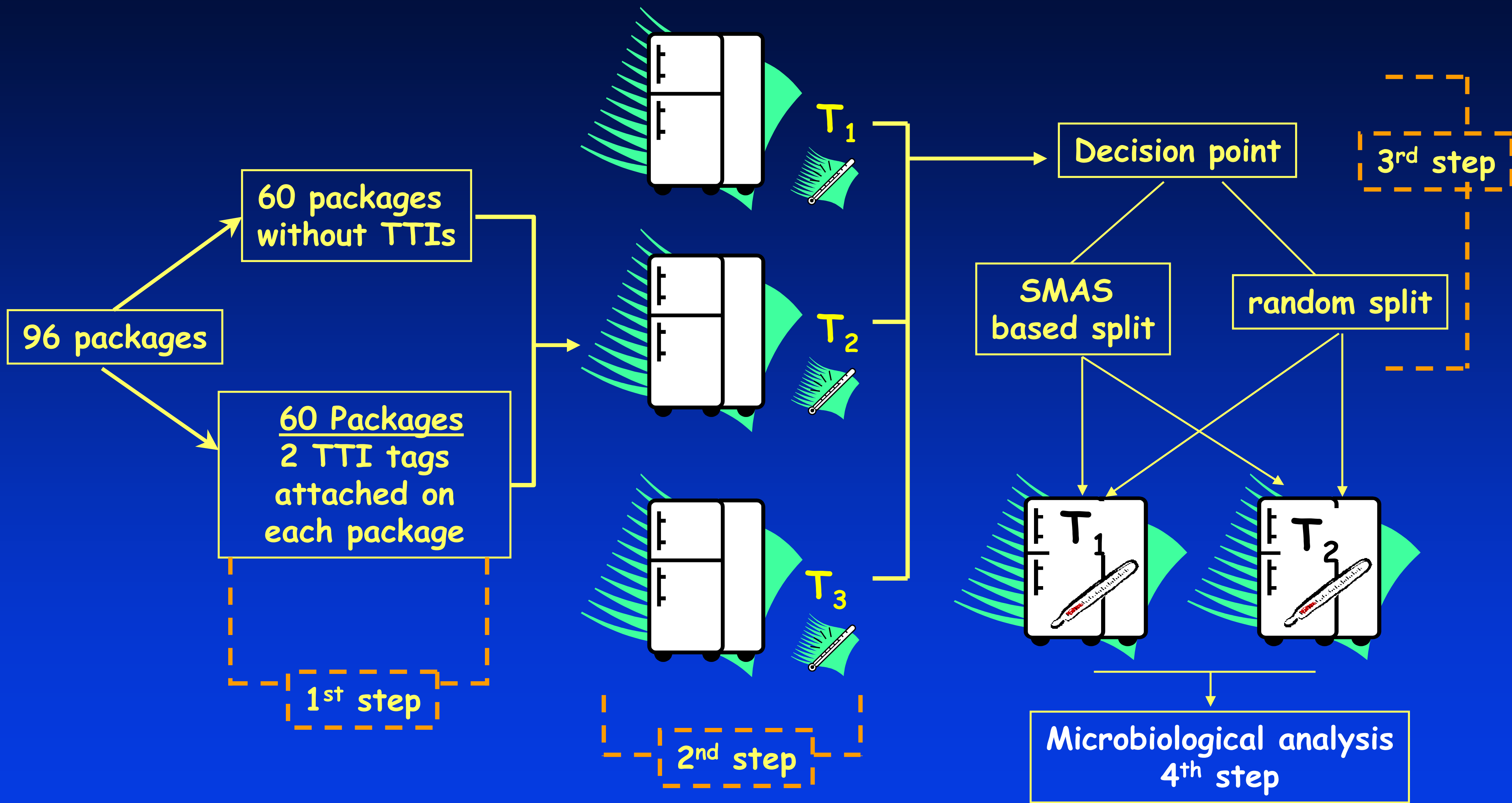
SMAS decsion time: 144hours

Design of the Field Test



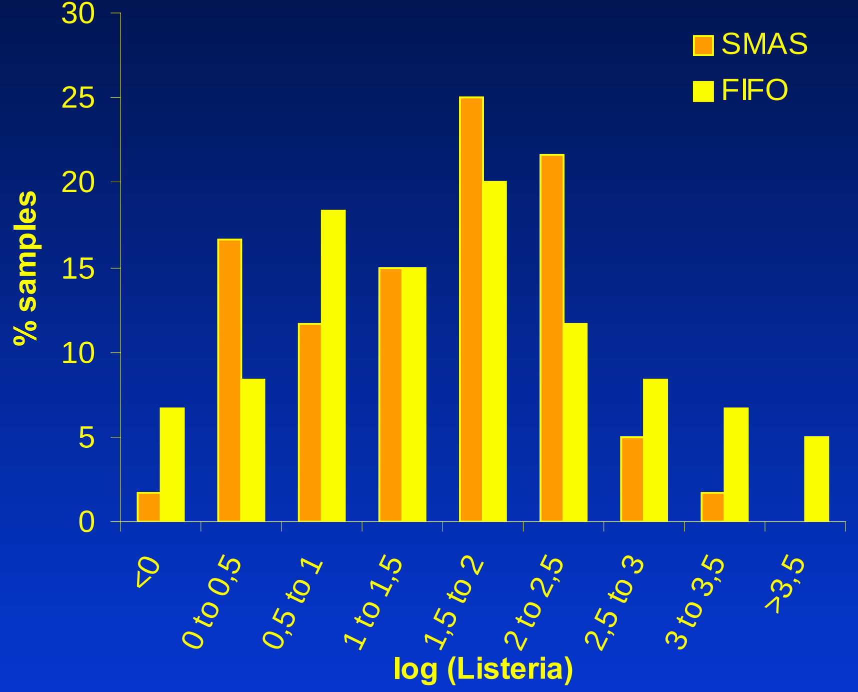
SMAS validation

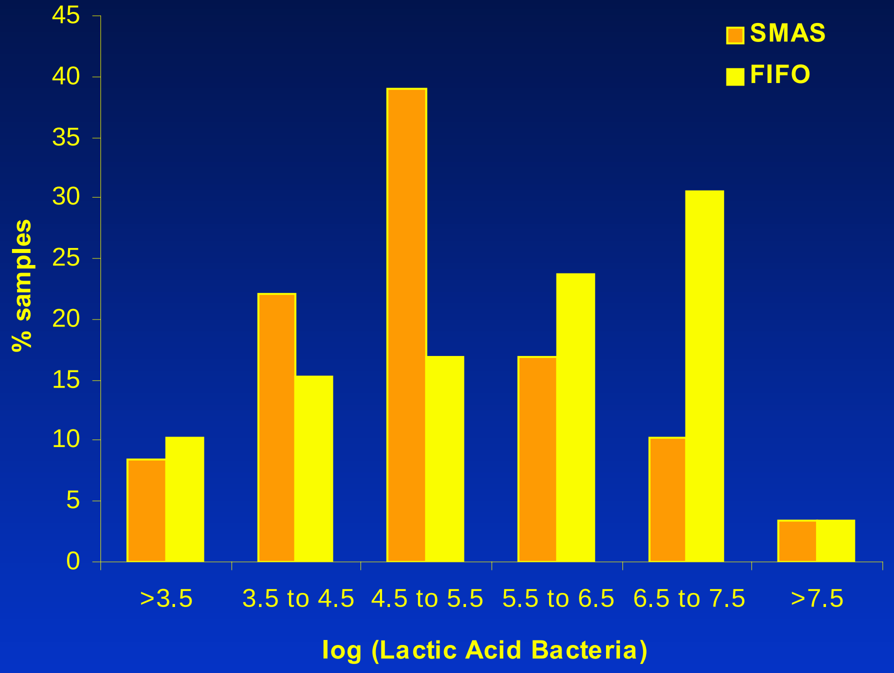
Laboratory simulated conditions



SMAS validation

Distribution of microbiological growth





Moving the distribution of both pathogens and spoilage to the left

SMAS validation

Development of a Safety Monitoring and Assurance System (SMAS) for chilled food products

Spoilage/risk based Management System

↓

Decision is based on growth prediction of risk posing (or spoilage) organisms

↙ ↘

Optimization of quality

Minimization of safety risk

Koutsoumanis, Taoukis and Nychas (2005) *Int. Journal of Food Microbiol.*

S M A S

QLK1-CT-2002-02545

Development and application of a TTI based Safety Monitoring and Assurance System for Chilled Meat Products

A European Commission Research and Technology Development Project

FIFTH FRAMEWORK PROGRAMME
Quality of life and management of living resources

http://smas.chemeng.ntua.gr