

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

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International Symposium

Safety and shelf life assessment of meat products in Europe

Ede, The Netherlands, 18 February, 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 pose 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.

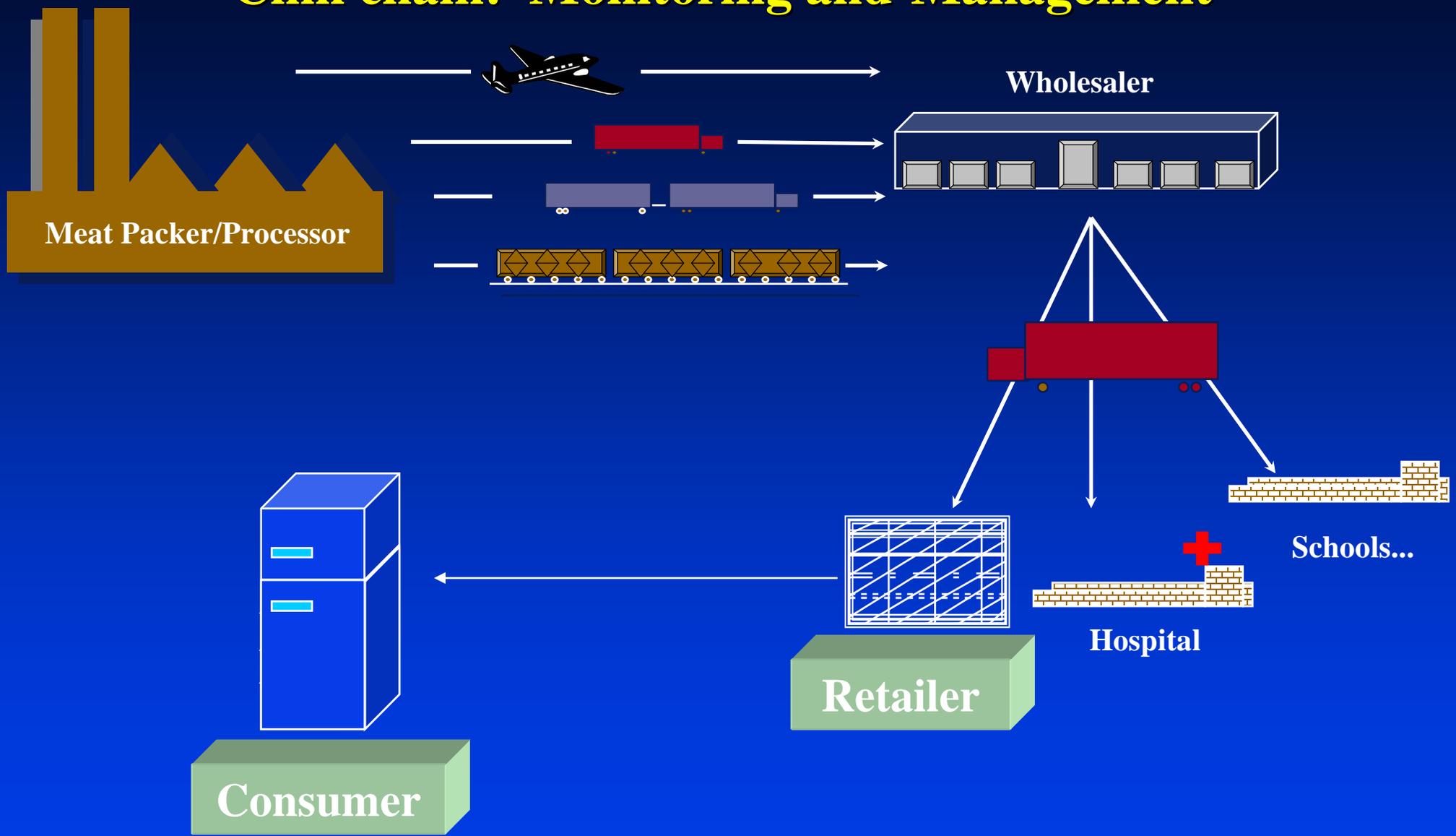
Why SMAS?

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?

Chill chain: Monitoring and Management



From packing to consumer

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?

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.

Project QLK1-2002-02545

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.



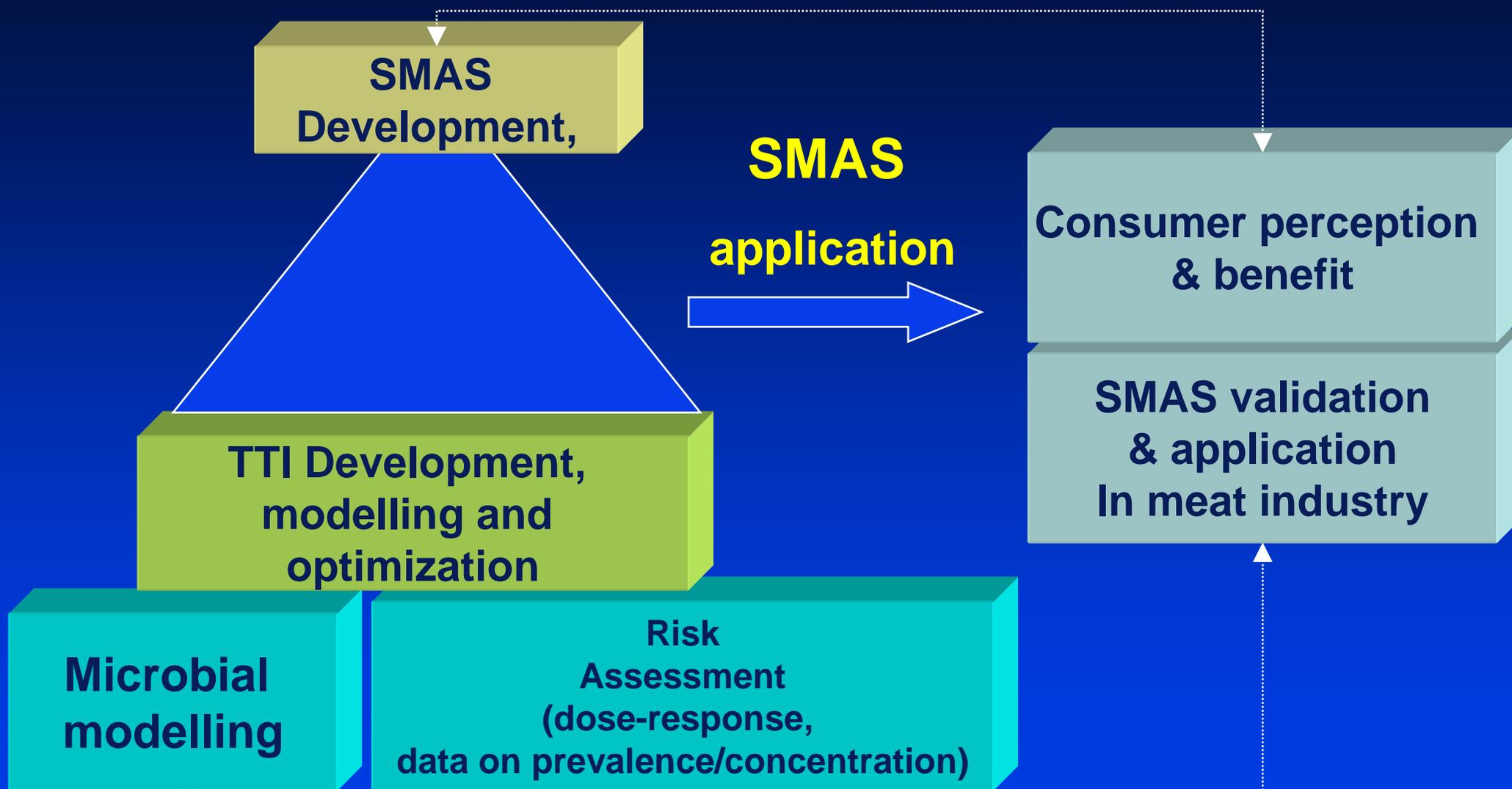
OVERALL OBJECTIVE

**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

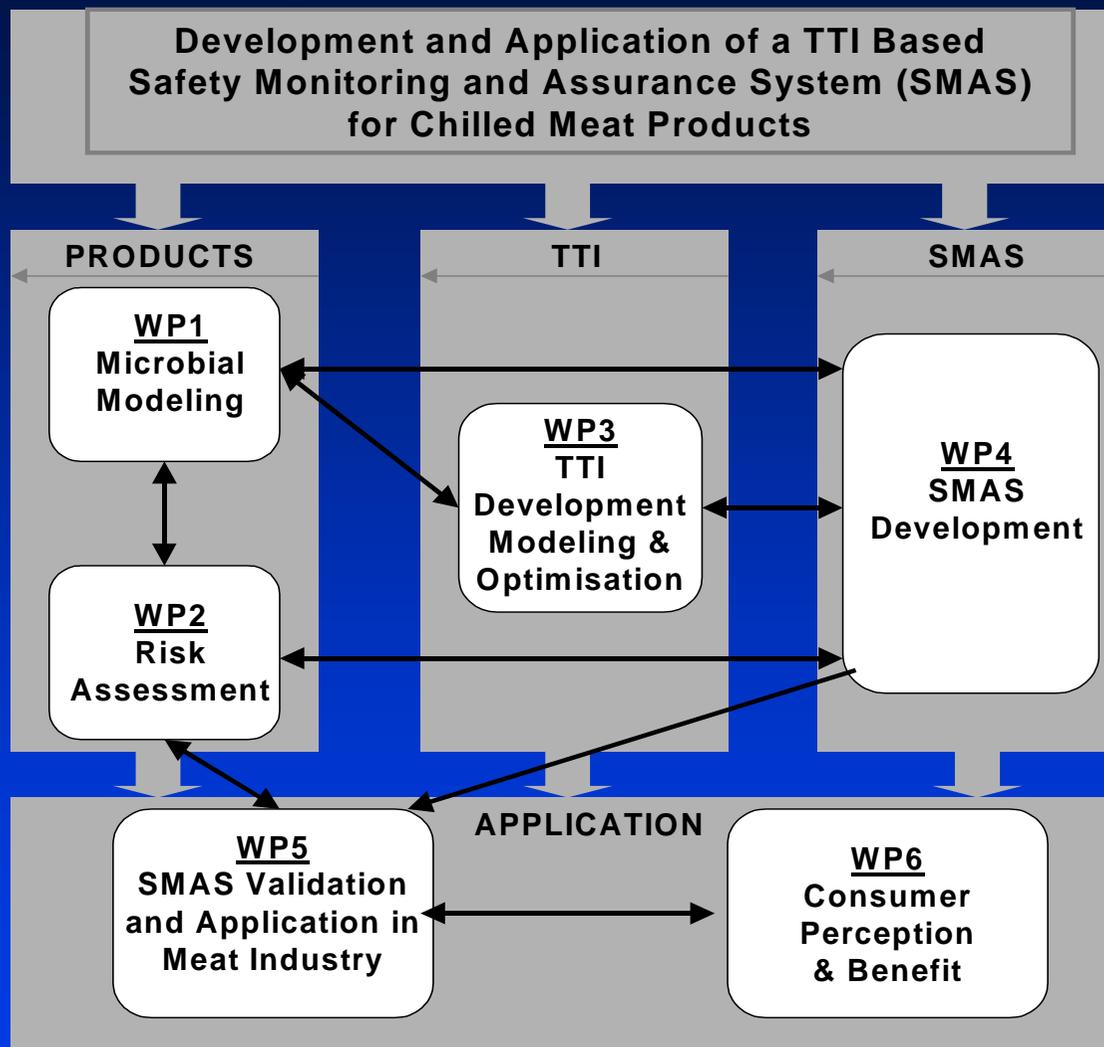
SMAS objectives



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

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Current practice: First In- First Out (FIFO)

Disadvantages:

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

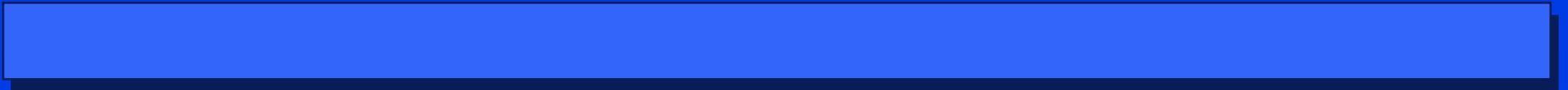
Proposed practice: SMAS

Main Advantages:

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

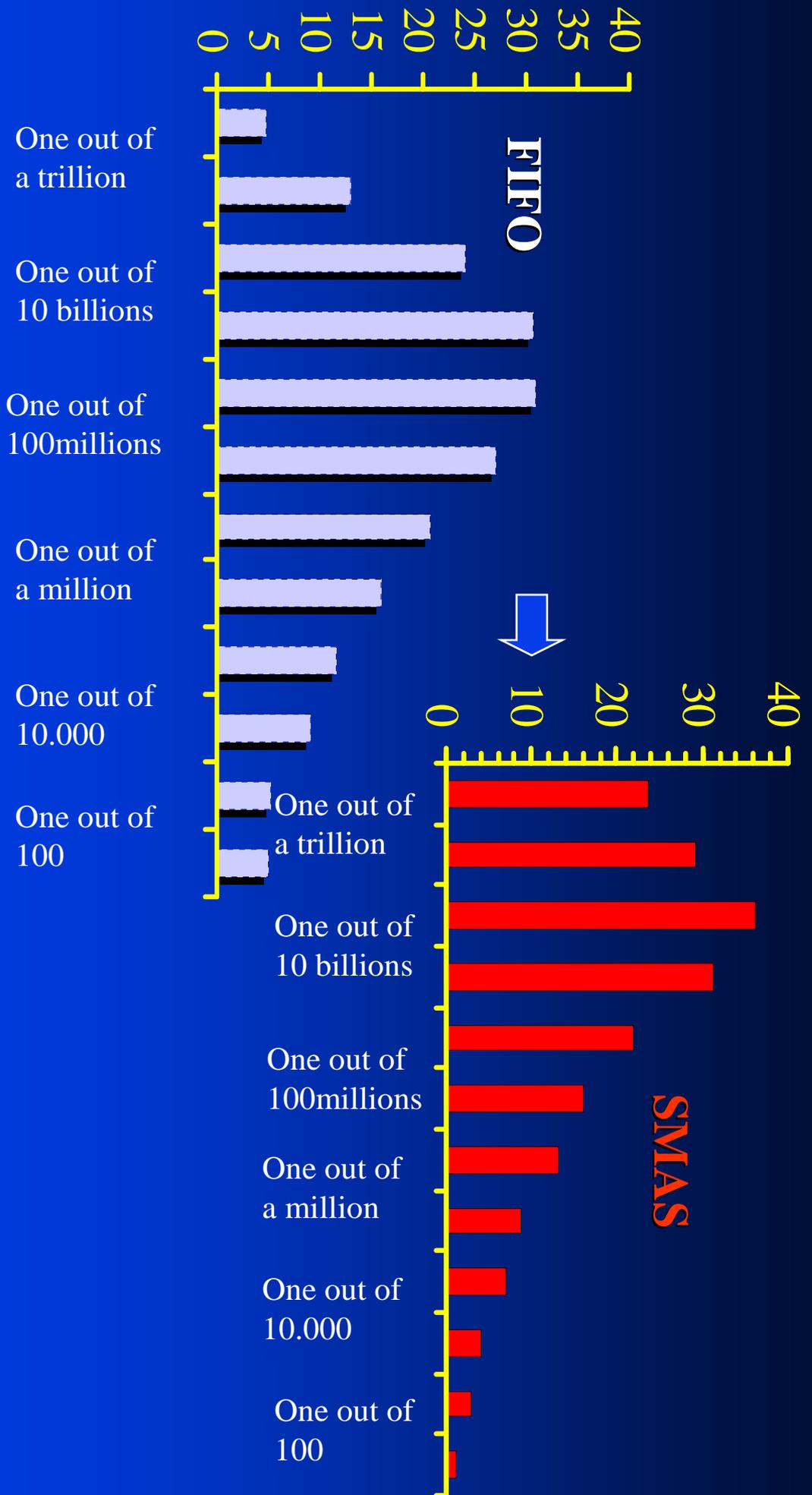
SMAS vs FIFO

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

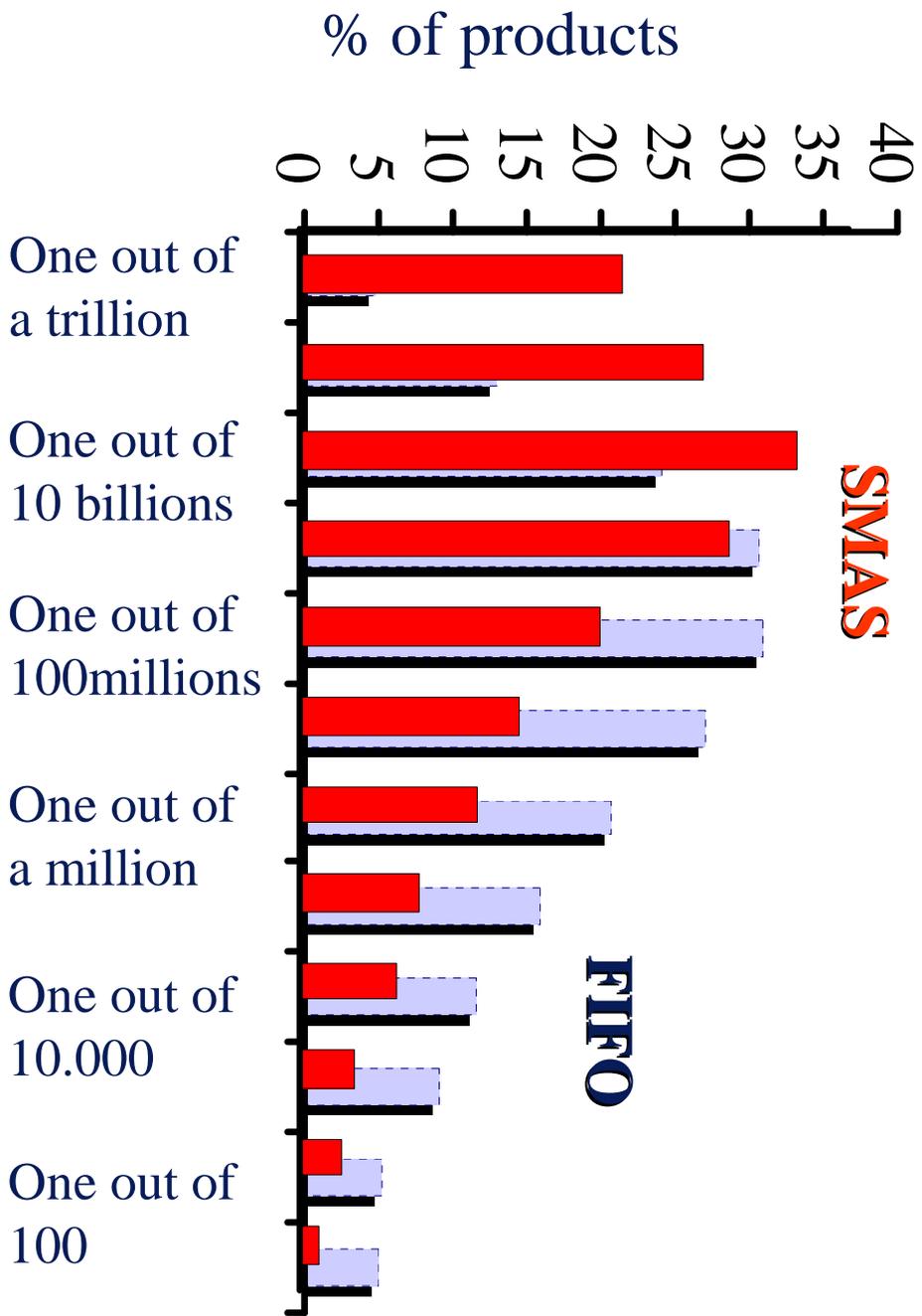


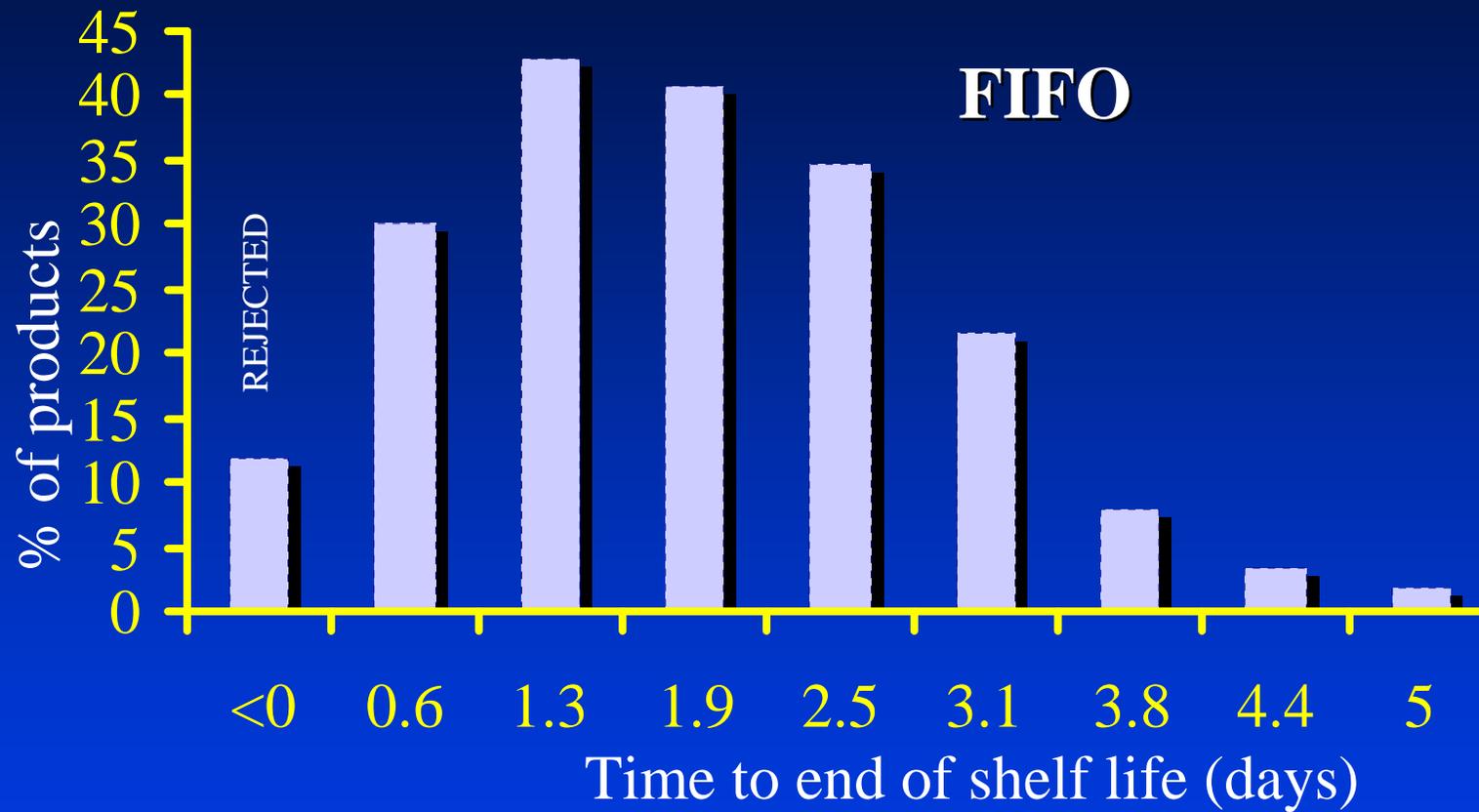
Probability of illness

% of products

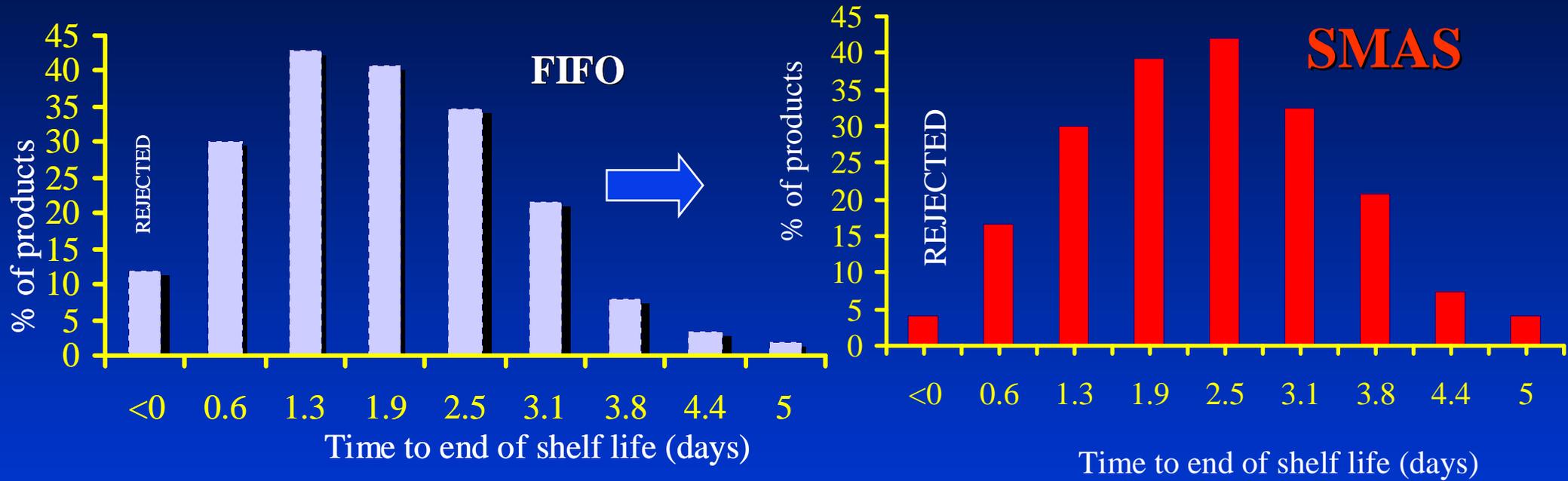


Probability of illness

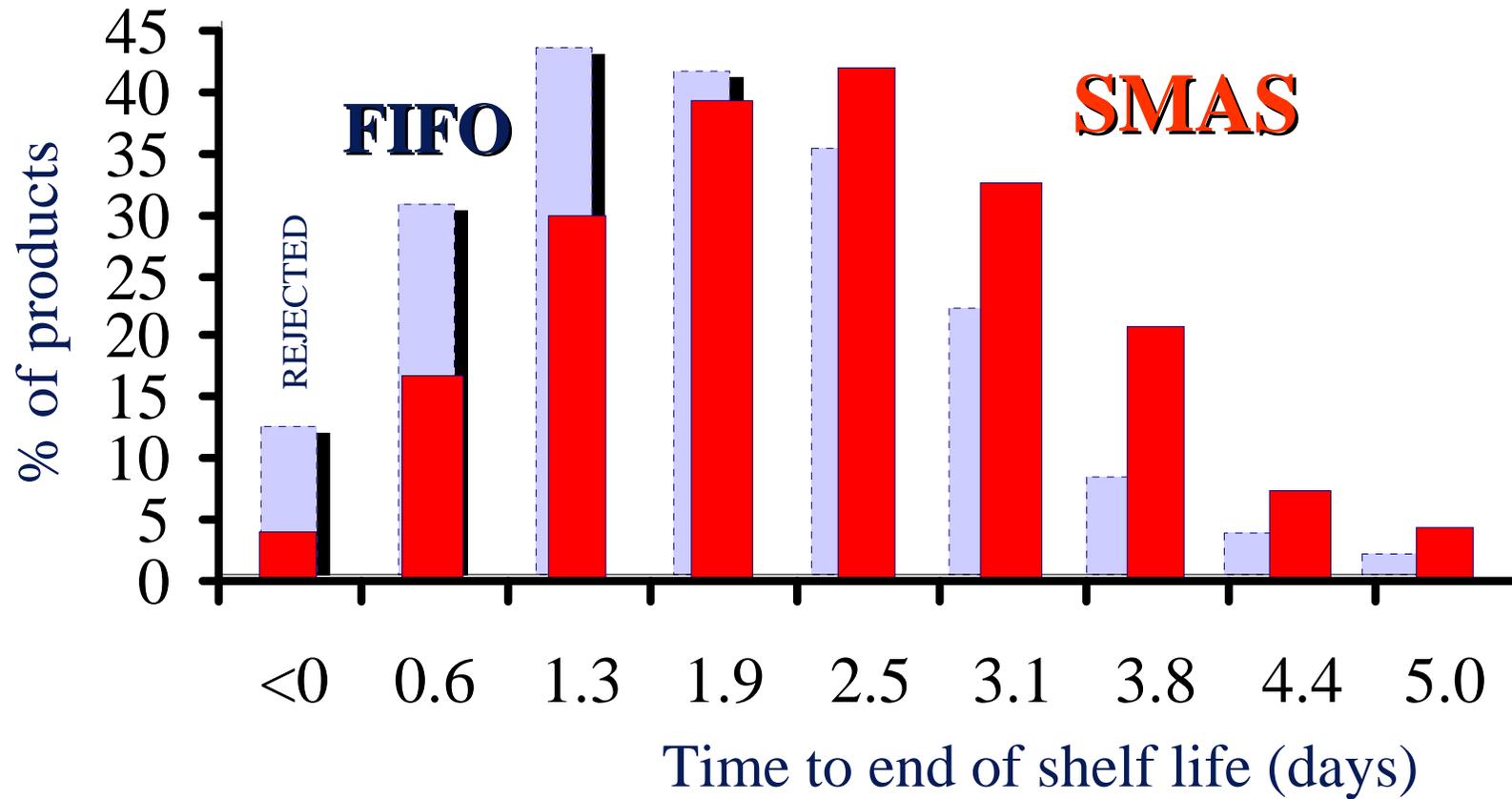




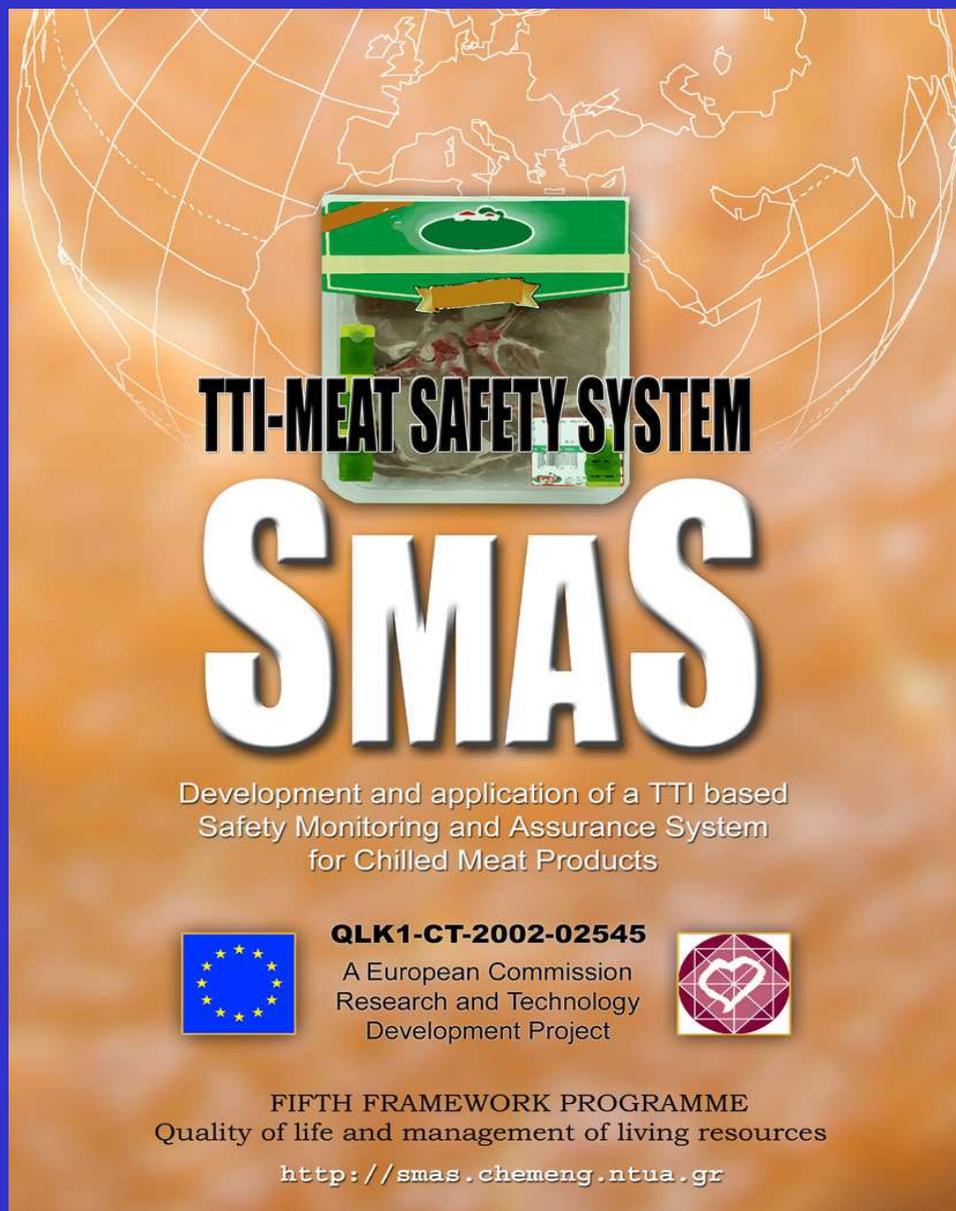
Product quality at consumption



Product quality at consumption



Product quality at consumption



TTI-MEAT SAFETY SYSTEM

SMAS

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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 pose 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**

CHARACTERISTICS OF THE ACTUAL CHILL CHAIN



Weak links in the chill chain

Electronic dataloggers



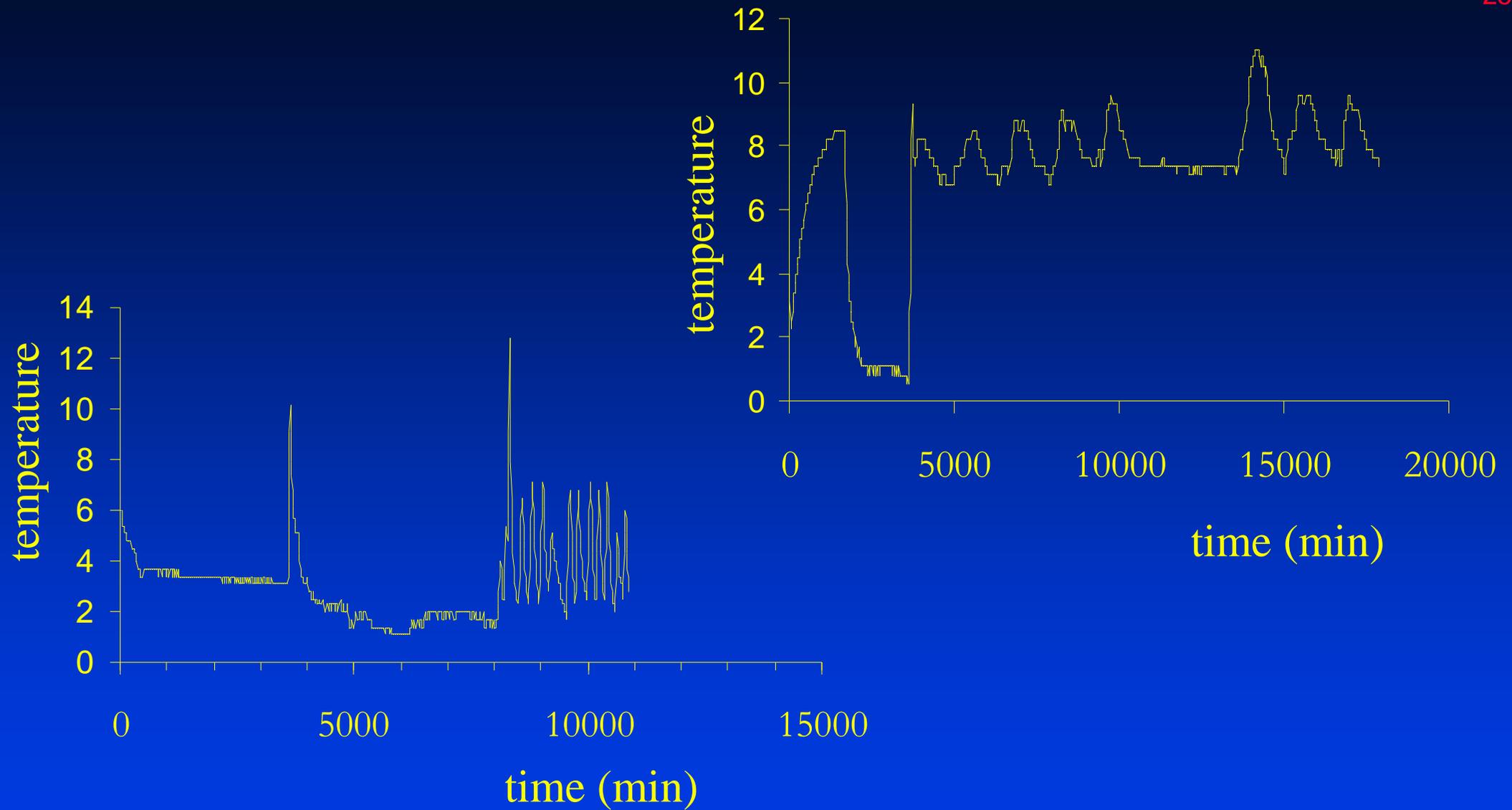
1st stage of the survey:



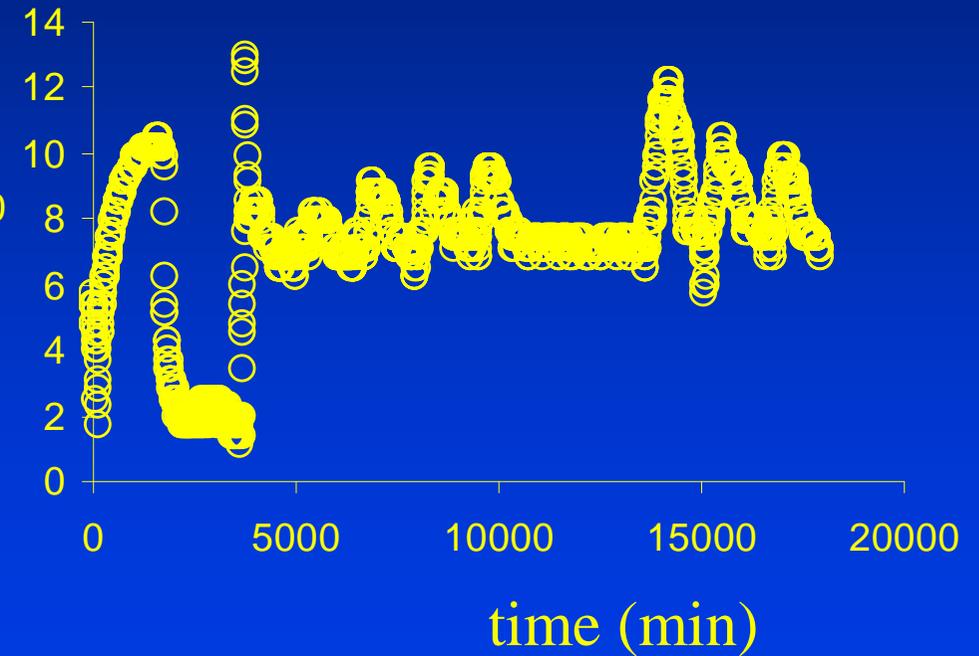
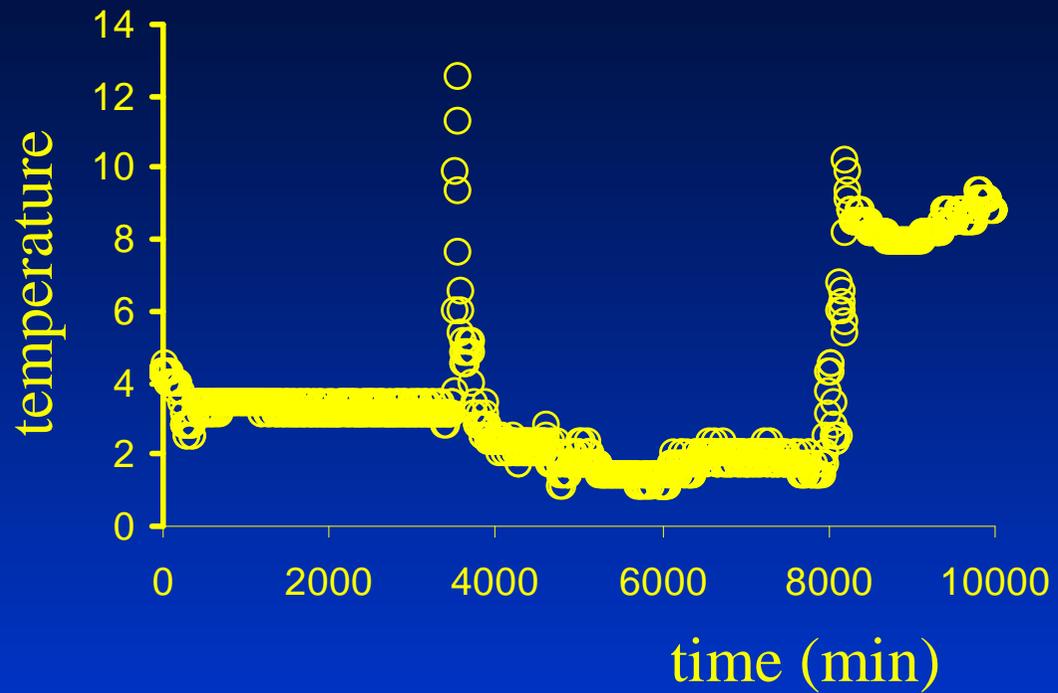
Data loggers were sealed in packages of ground beef and monitored from processing through distribution to delivery and storage in SuperMarkets all over Greece



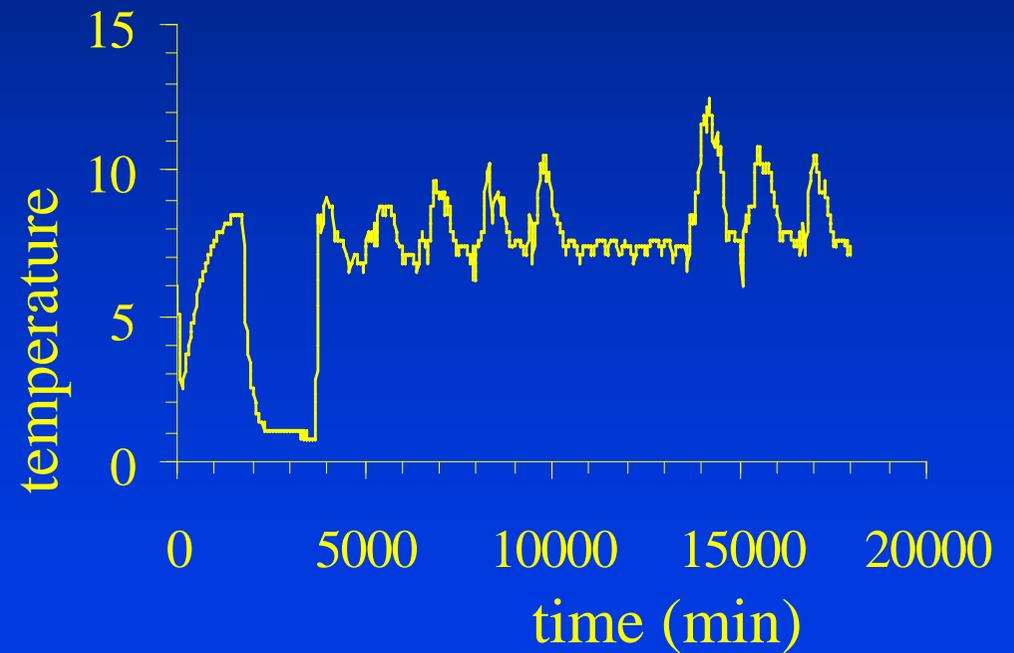
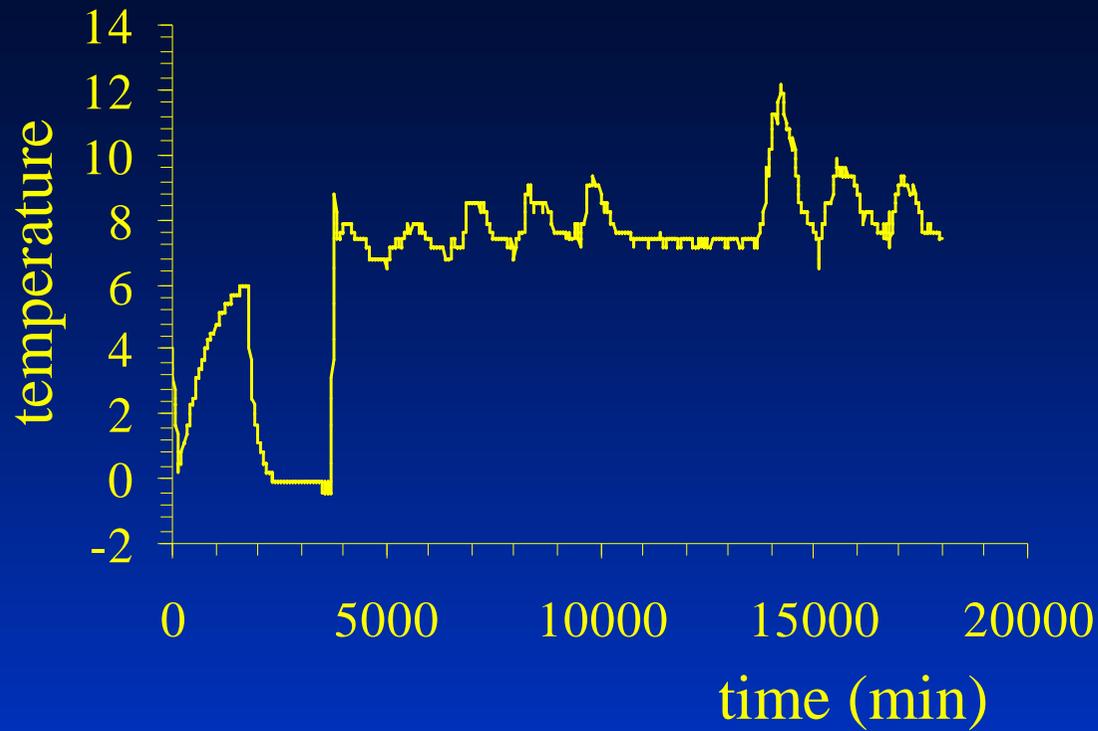
Survey for temperature conditions (1)



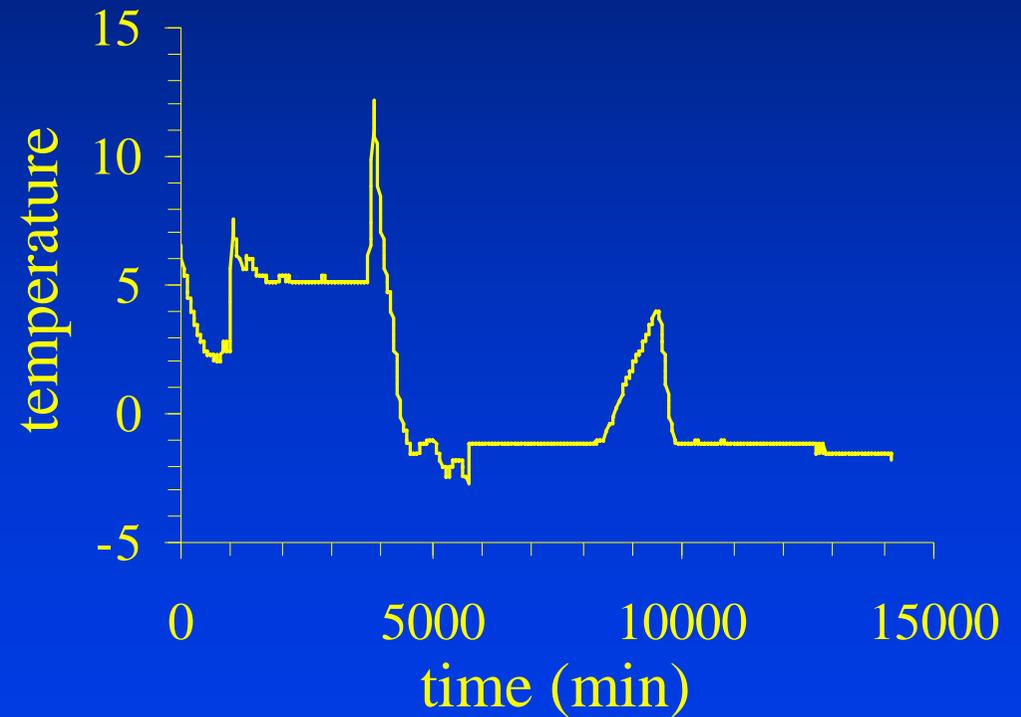
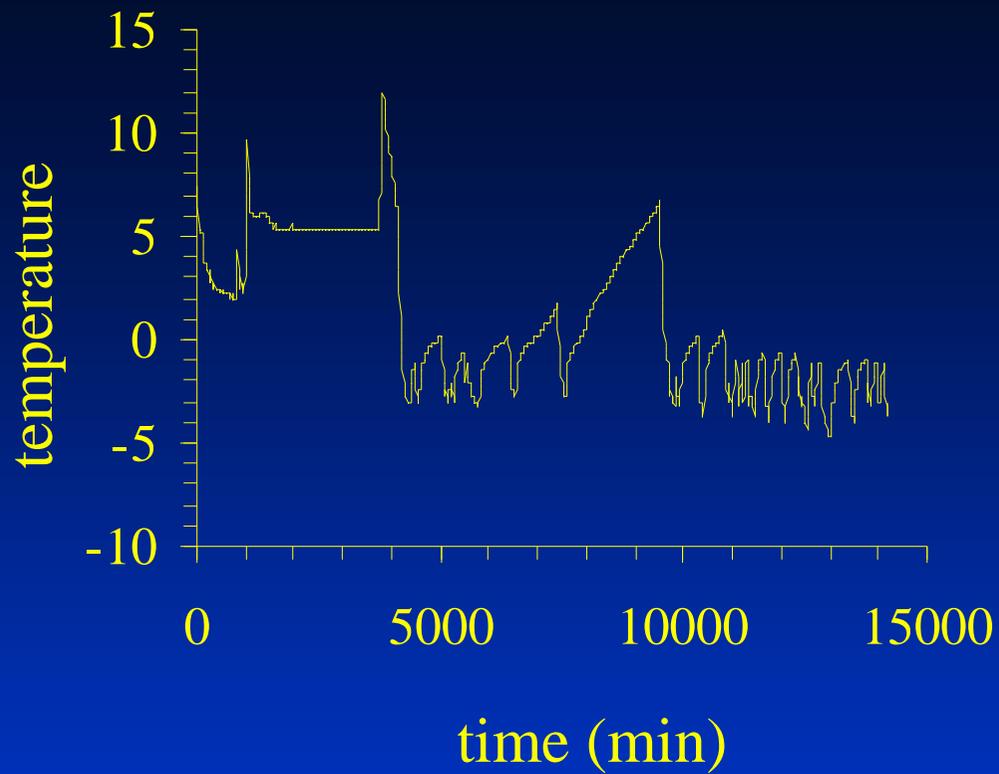
Temperature conditions FROM production TO the retail outlet



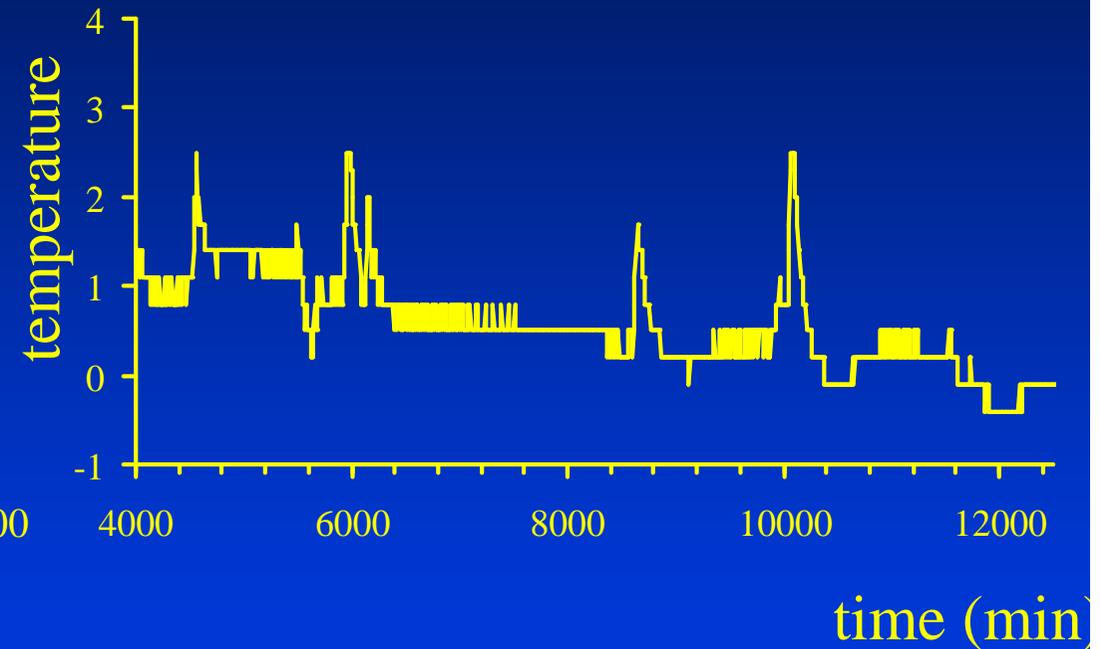
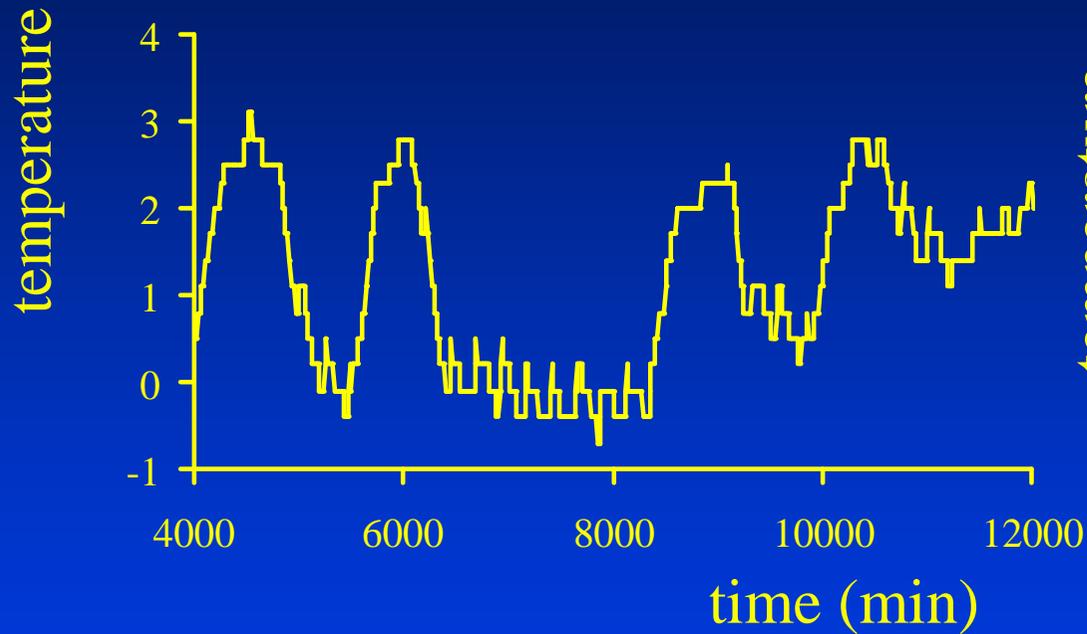
Temperature conditions FROM production TO the retail outlet



Temperature conditions FROM production TO the retail outlet



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 $> 7^{\circ}\text{C}$**
- **Significant temperature fluctuations**

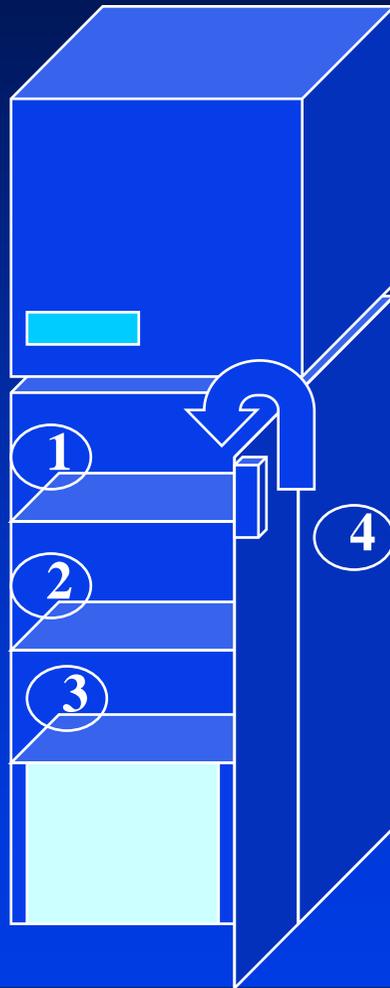
Temperature conditions FROM production TO the retail outlet

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

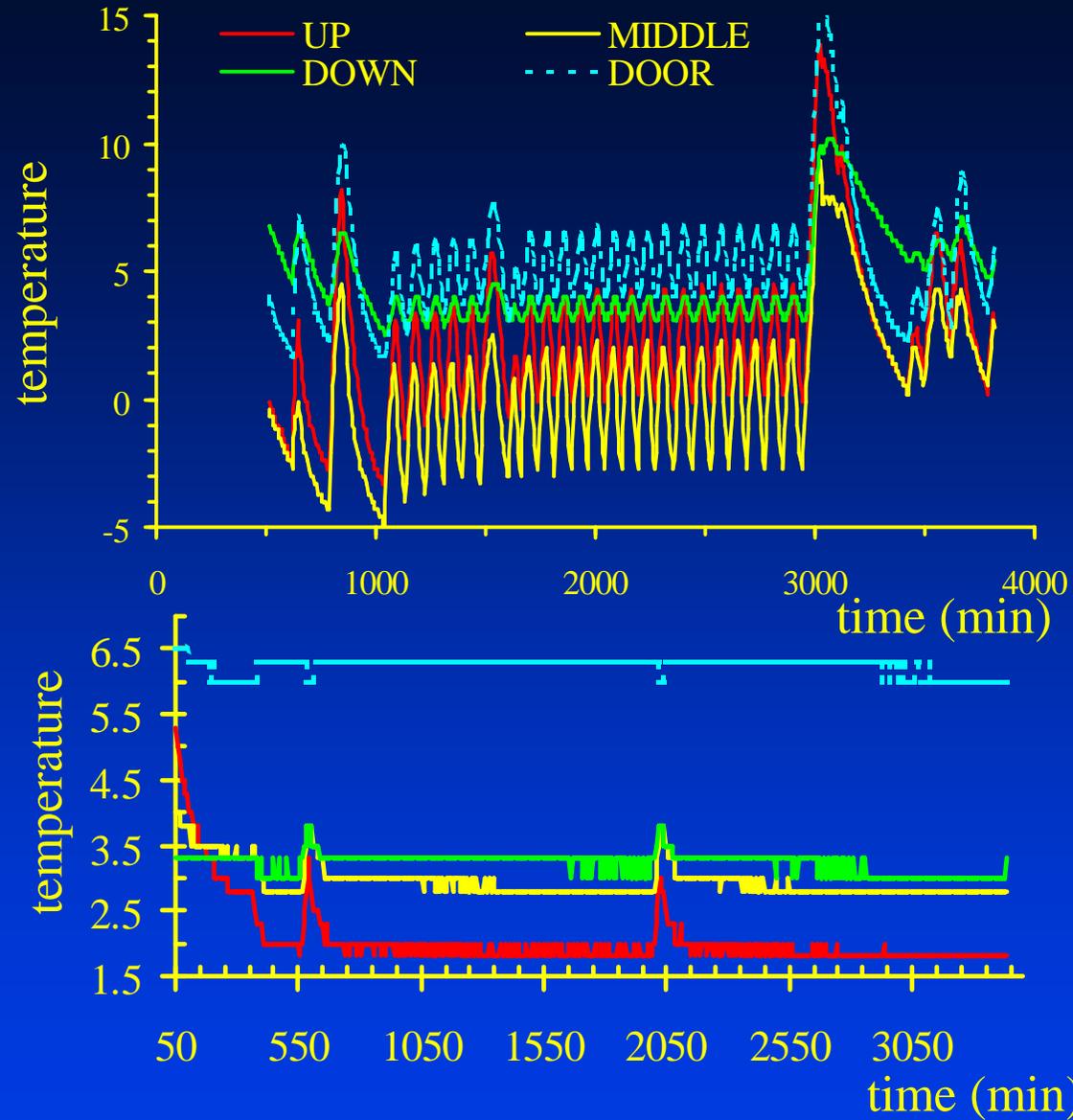
Electronic dataloggers



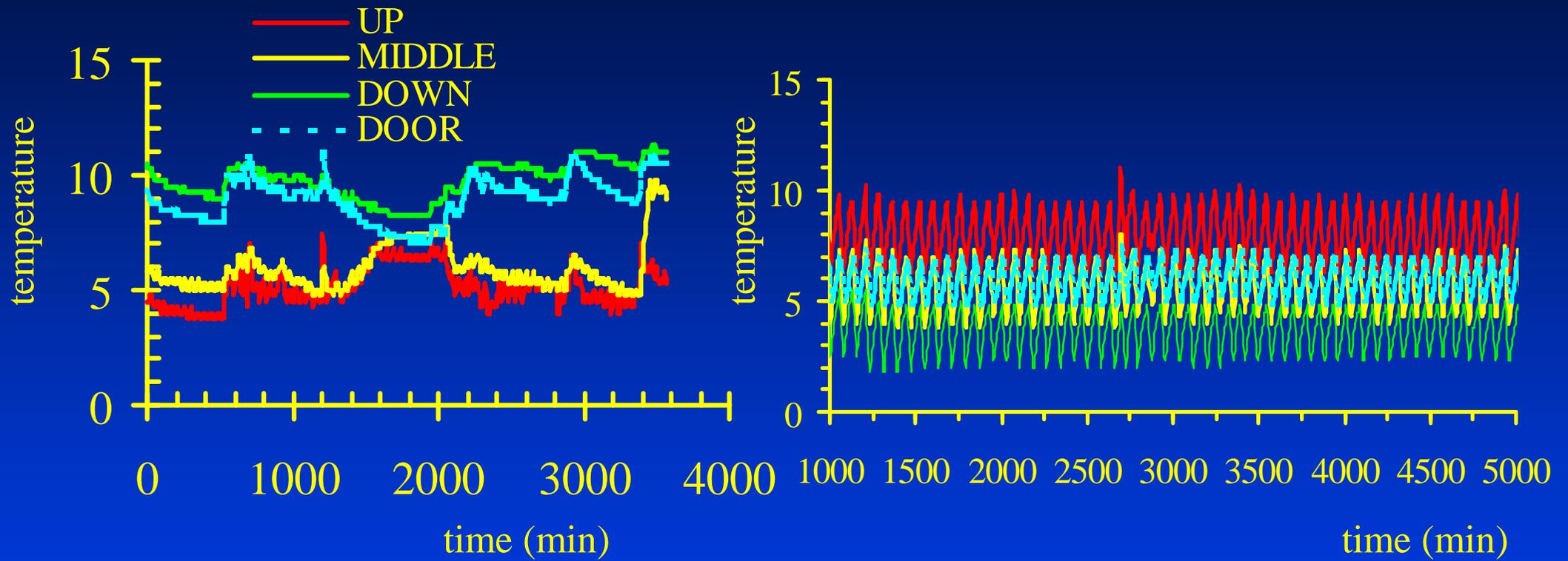
- 1: upper shelf
- 2: middle shelf
- 3: lower shelf
- 4: door



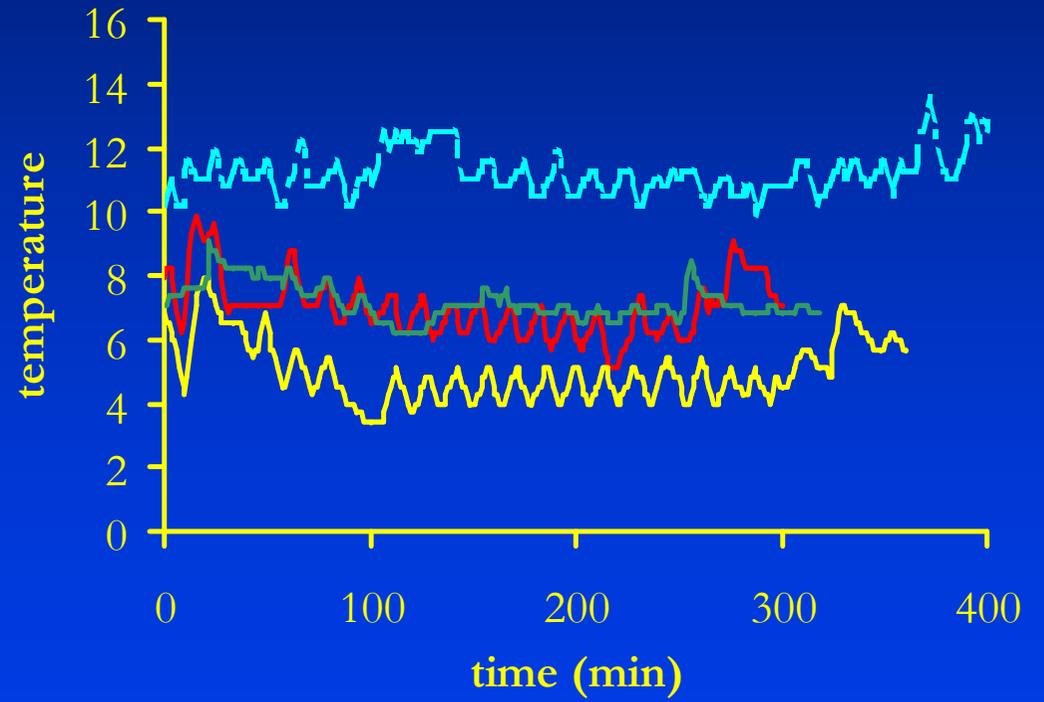
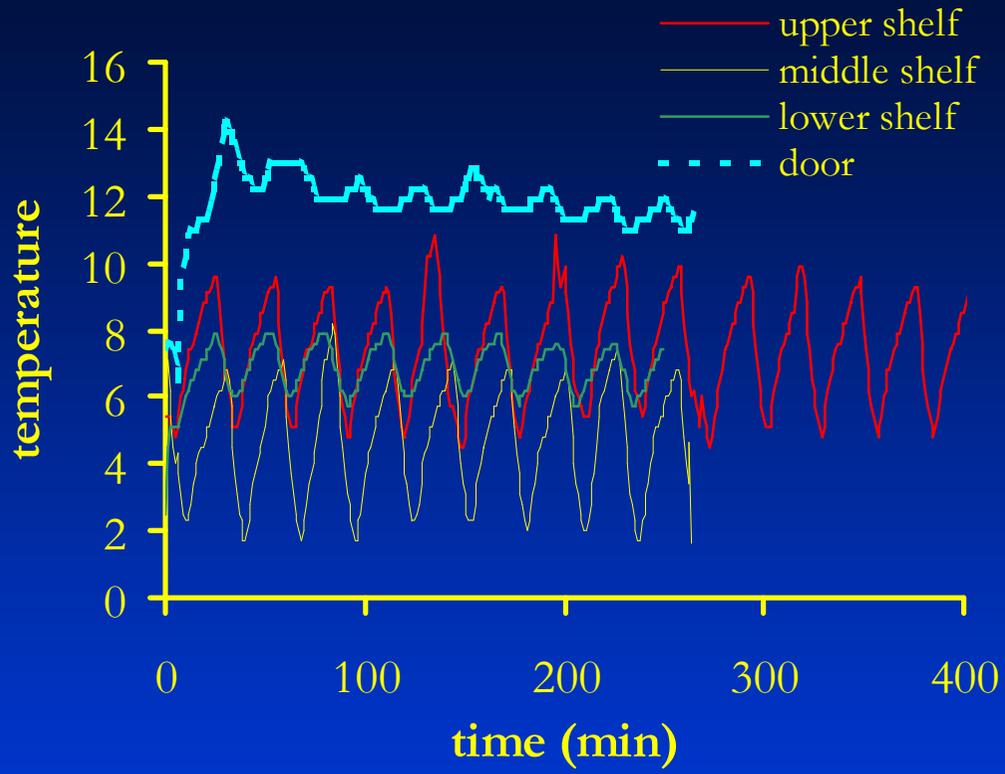
Survey for temperature conditions (2)

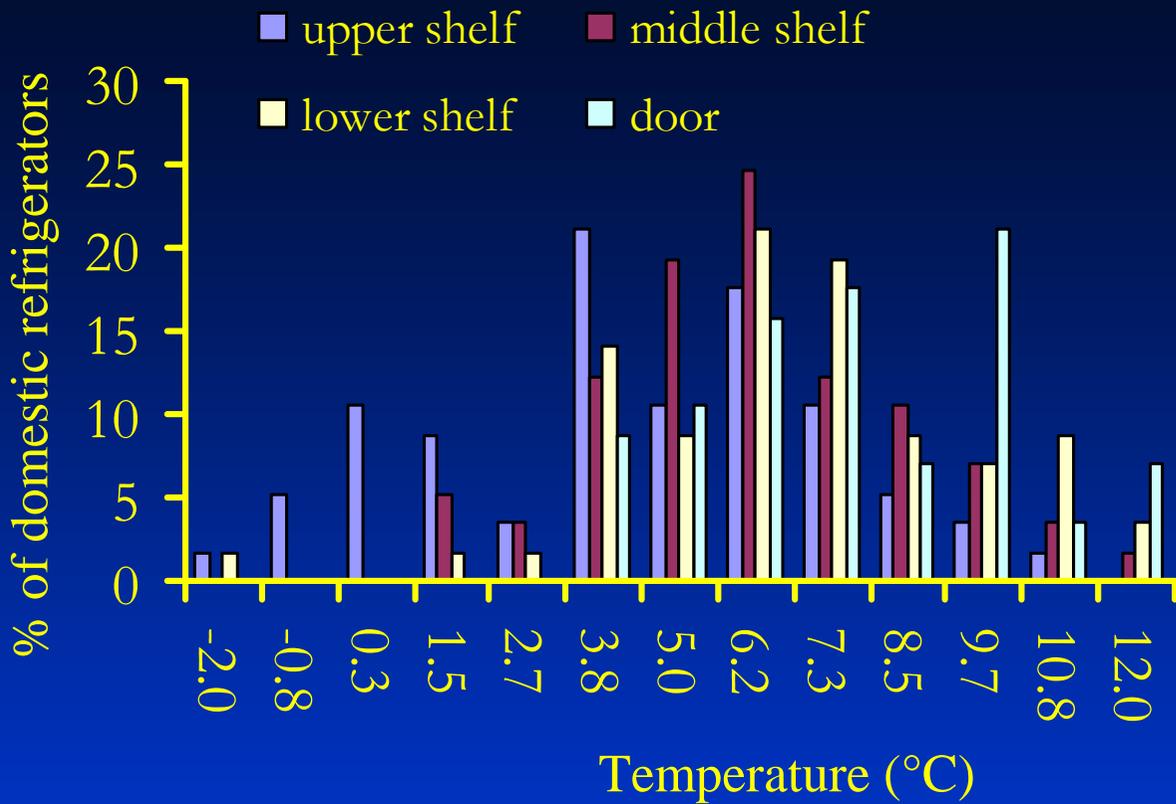


Temperature conditions IN the domestic refrigerator



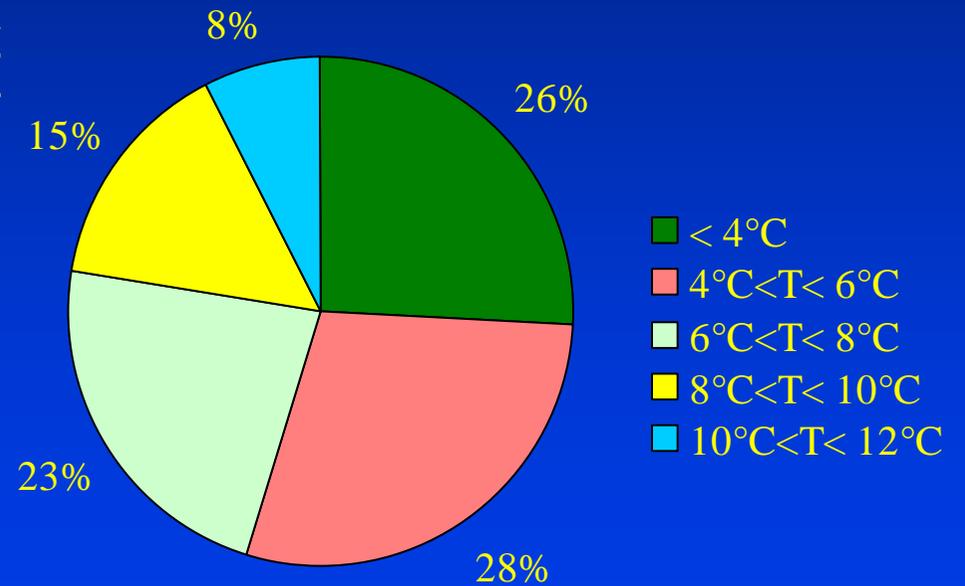
Temperature conditions IN the domestic refrigerator





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**



**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



TTI -3M

Time Temperature Indicators

TTI



TTI - Temptime

Time Temperature Indicators



TTI - Fresh Point

Time Temperature Indicators

Microbiological indicator



**Fresh
product**

✓ **Not readable barcode**

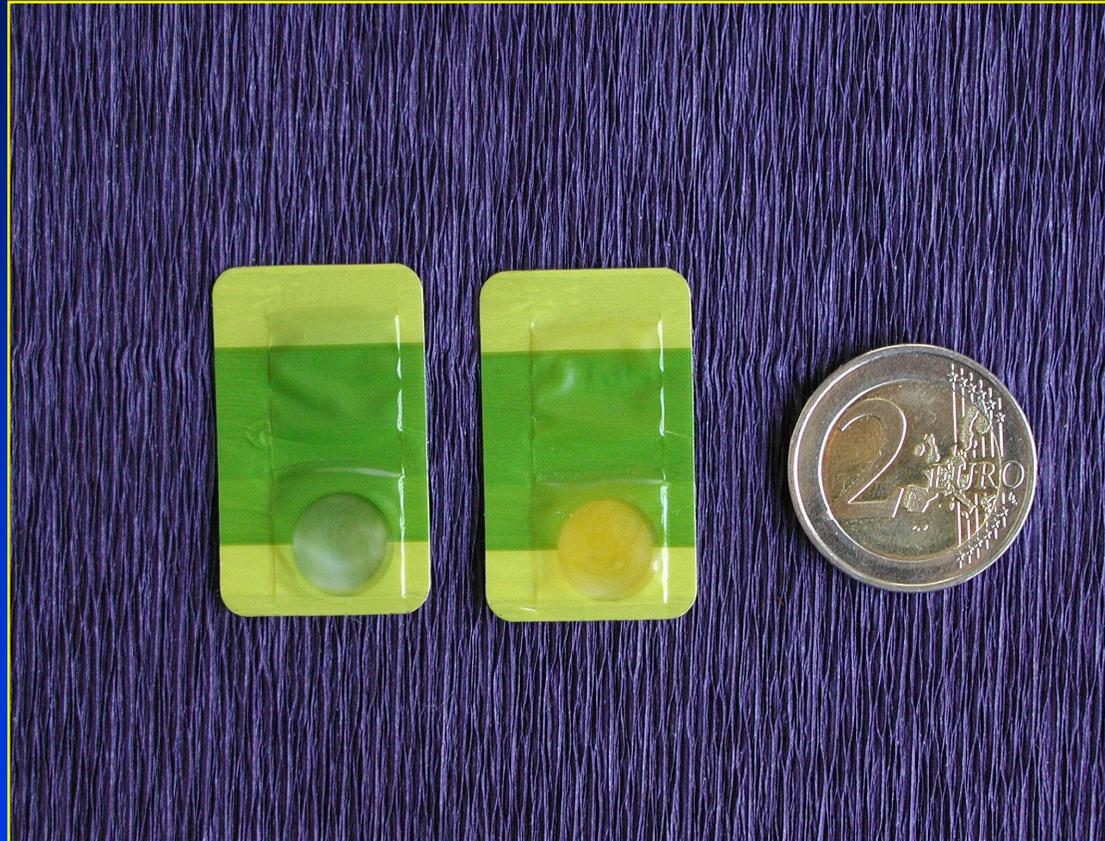


**No longer
fresh**

TTI- TRACEO Cryolog

Time Temperature Indicators

TTI



TTI - Vitsab

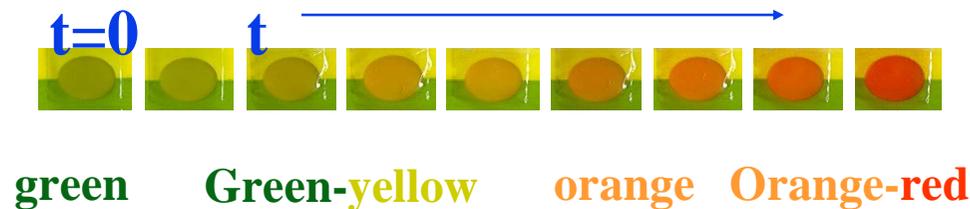
Time Temperature Indicators



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



TTI

Multiple TTI configuration

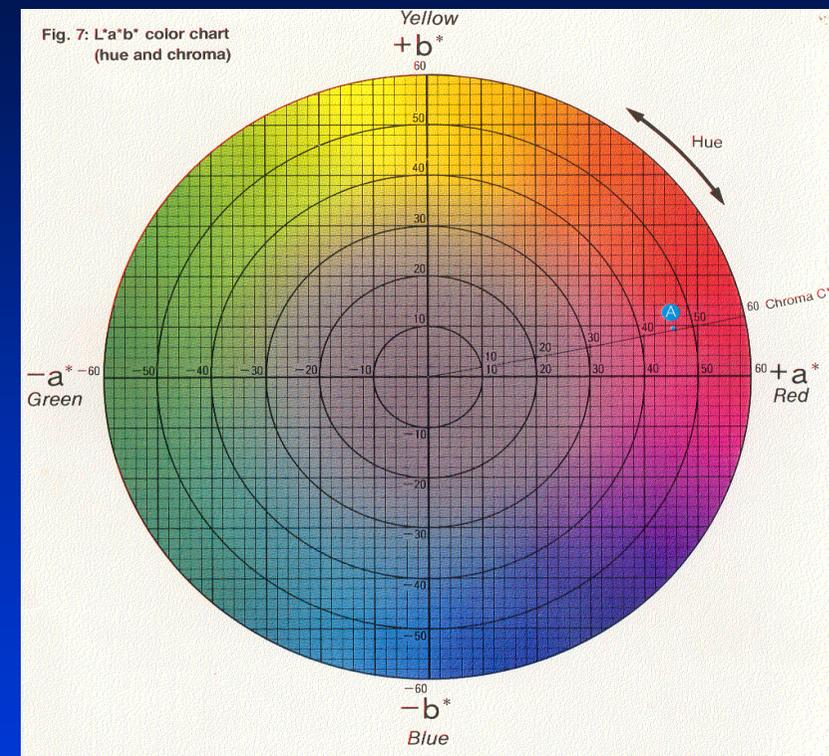
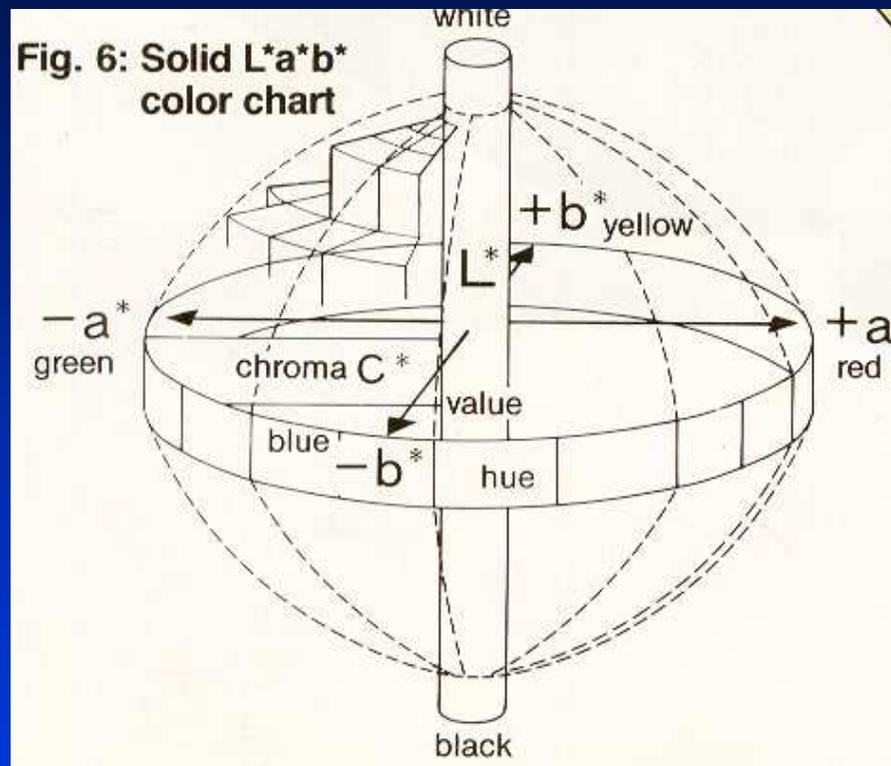


Safety indicator. This window with a shelf life e.g. of 1 day at 10°C , will respond and warn for exposure at abuse temperatures that could cause increased safety risk

Chill chain monitoring and Consumer active “end of shelf life” date. This opening integrates Time-temperature but shows a clear visual change close to the end of shelf life indicating to the consumer expiration of the product.

Chill chain monitoring. This window will integrate the time temperature history of the product during its distribution and give a gradual response that will be read by a monitoring instrument for chill chain management

TTI study



TTI –measurement

COLOUR MEASUREMENT

Colour parameters:

1. Lightness **L**
2. Redness **a**
3. Yellowness **b**



TTI response measurement

TTI RESPONSE KINETICS

X: measurable change of TTI

Response function:

$$F(X) = k t$$

Temperature dependence - expressed by E_a

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

Enzymatic TTI RESPONSE

- $L^*a^*b^*$ measurements

chroma value:

$$C = \sqrt{a^2 + b^2}$$

normalized chroma:

$$X_C = \frac{C - C_{\min}}{C_{\max} - C_{\min}}$$

Response function

$$F(X_C) = \sqrt{\ln\left(\frac{1}{1 - X_C}\right)} = kt$$

- $F(X_C)$ vs time \longrightarrow k
- Arrhenius plots ($\ln k = f(1/T)$) \longrightarrow E_a

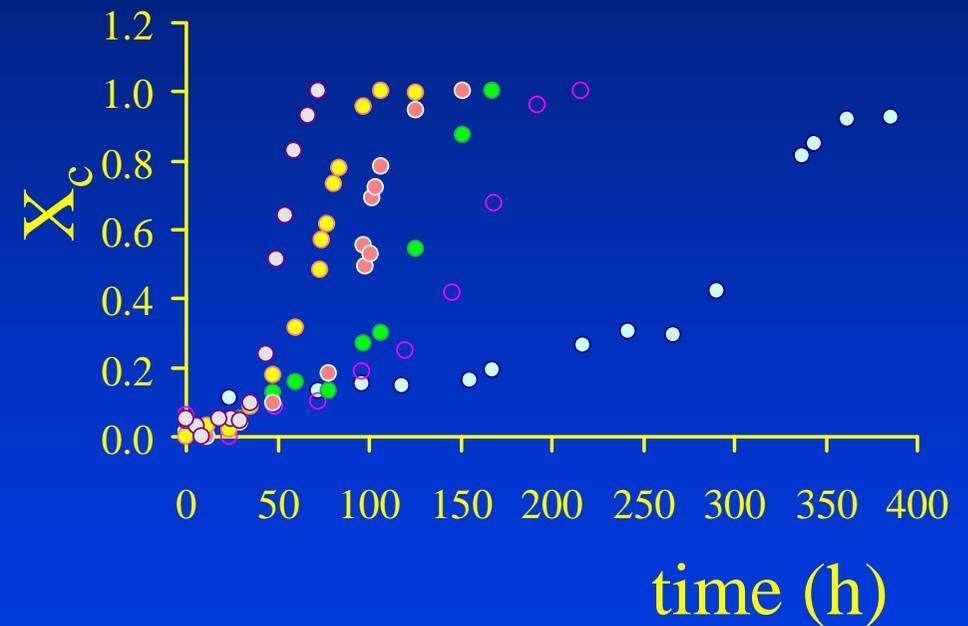
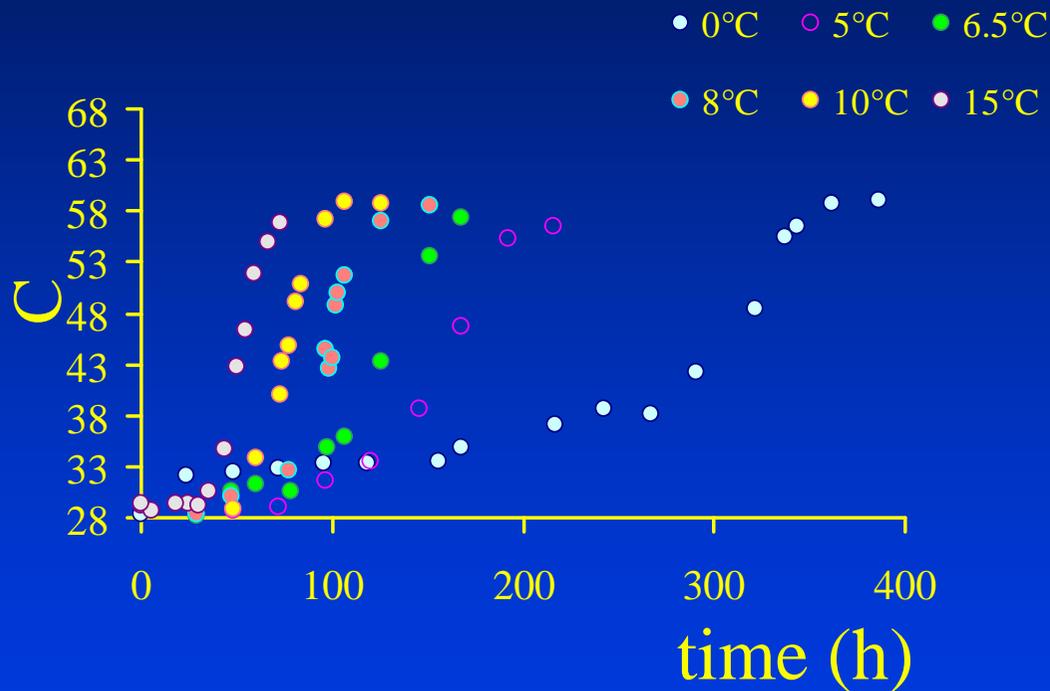
TTI – response kinetics

Kinetic study of enzymatic TTI

- M4-5, M4-10 & M4-20
- L10-1, L10-3 & L10-5
- C4-5, C4-10 & C4-20
 - B7-24
- M4-5 & L5-8 tricolor

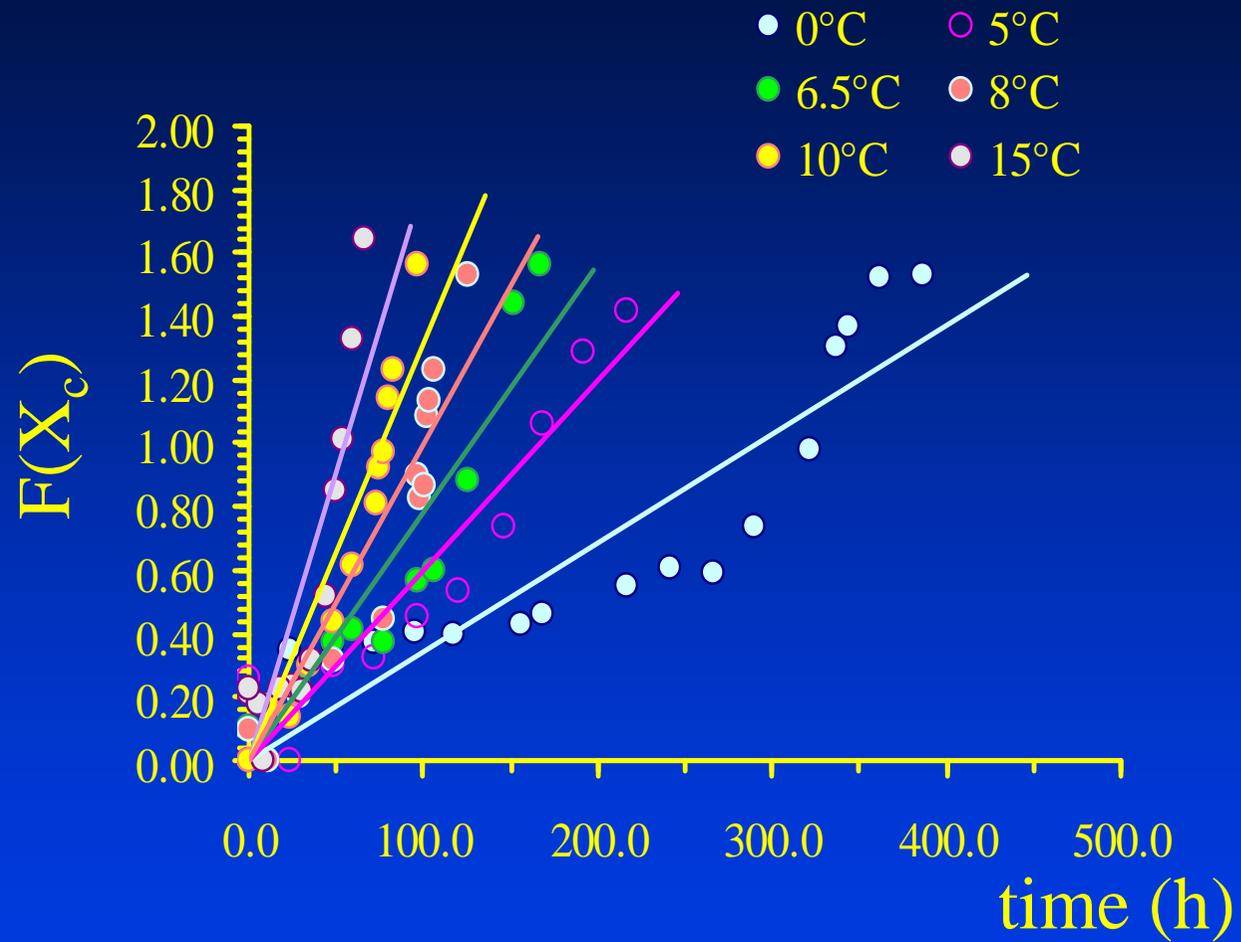
Kinetic study of TTI

isothermal experiments



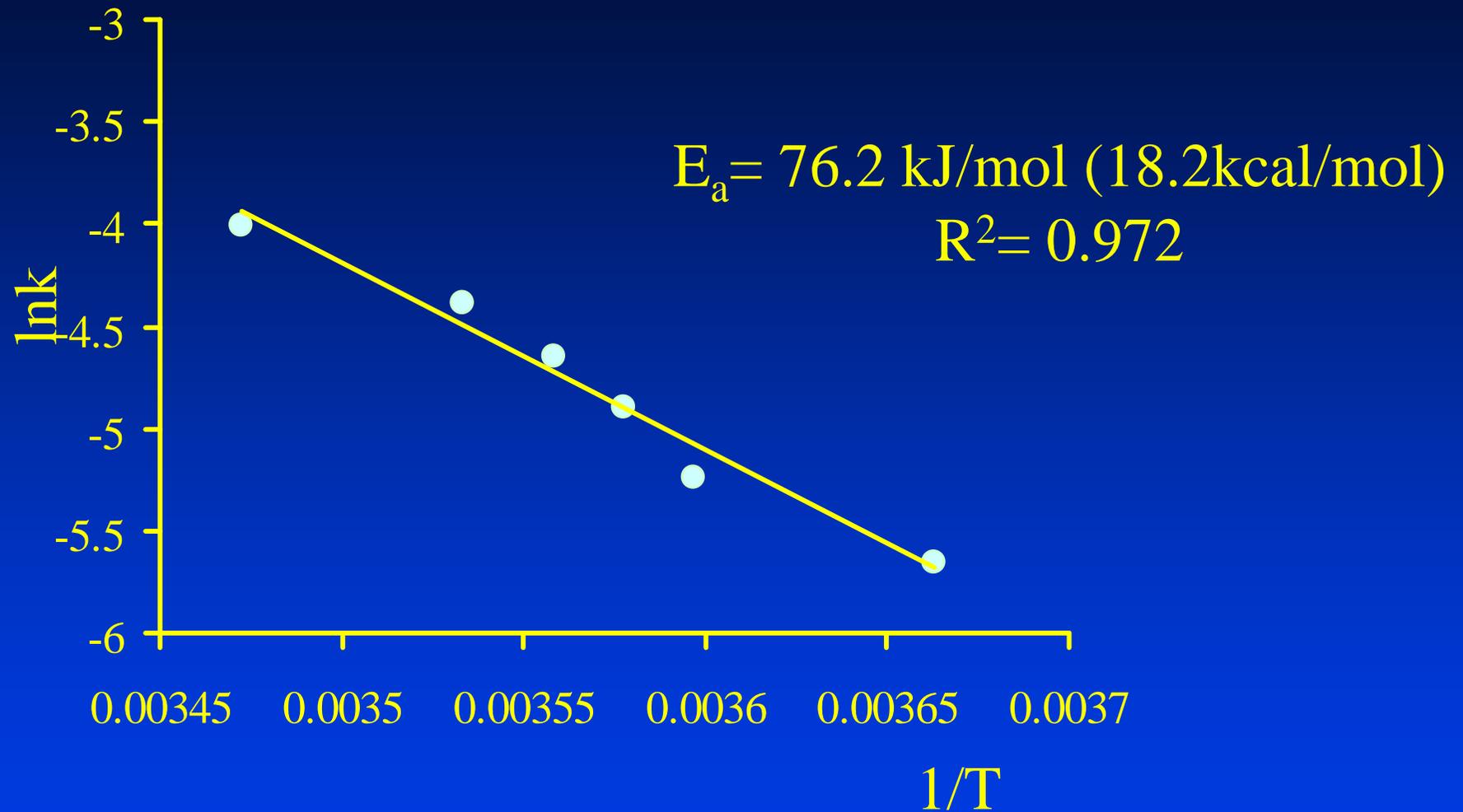
M4-10

TTI



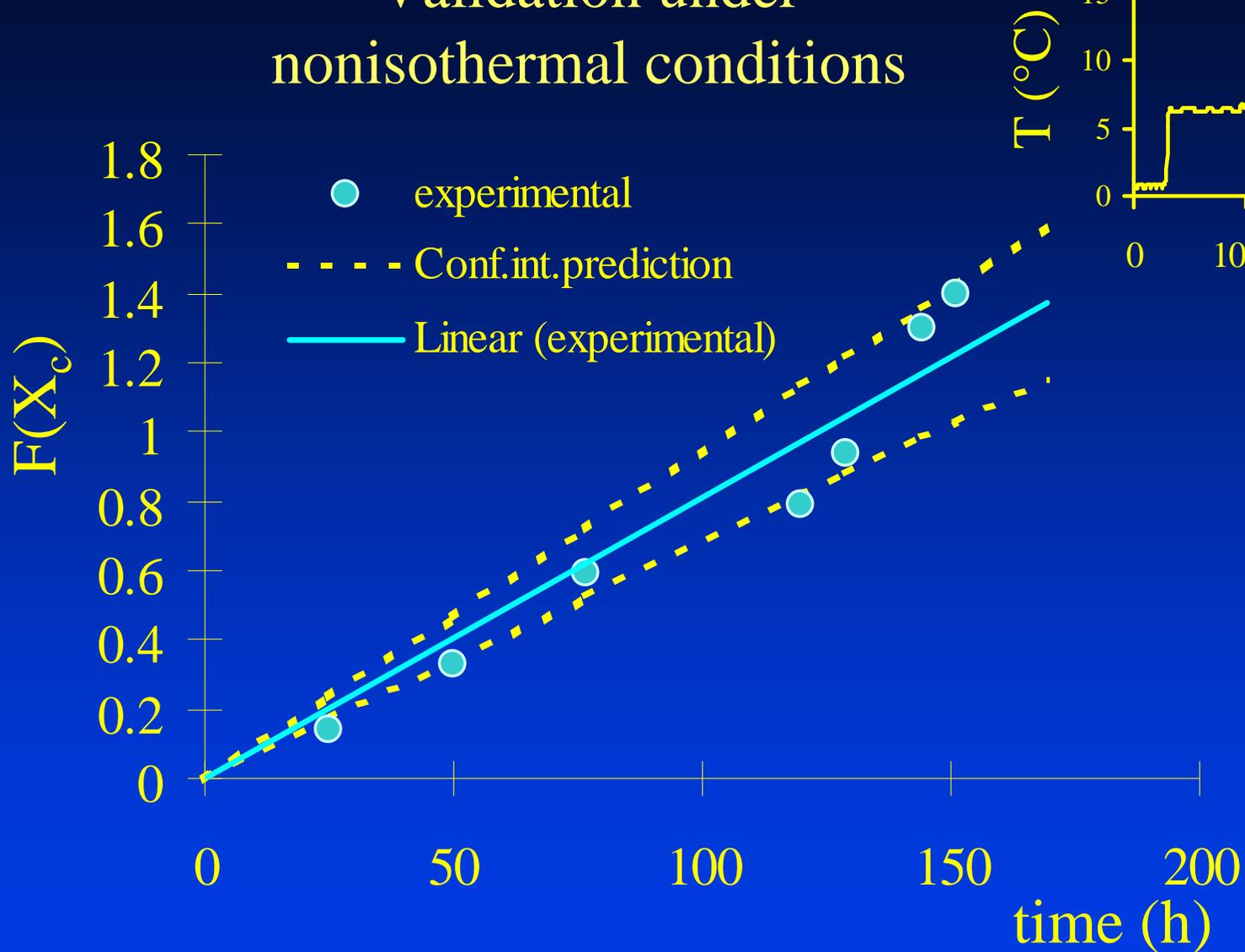
M4-10

Arrhenius plot for TTI



M4-10

Validation under nonisothermal conditions

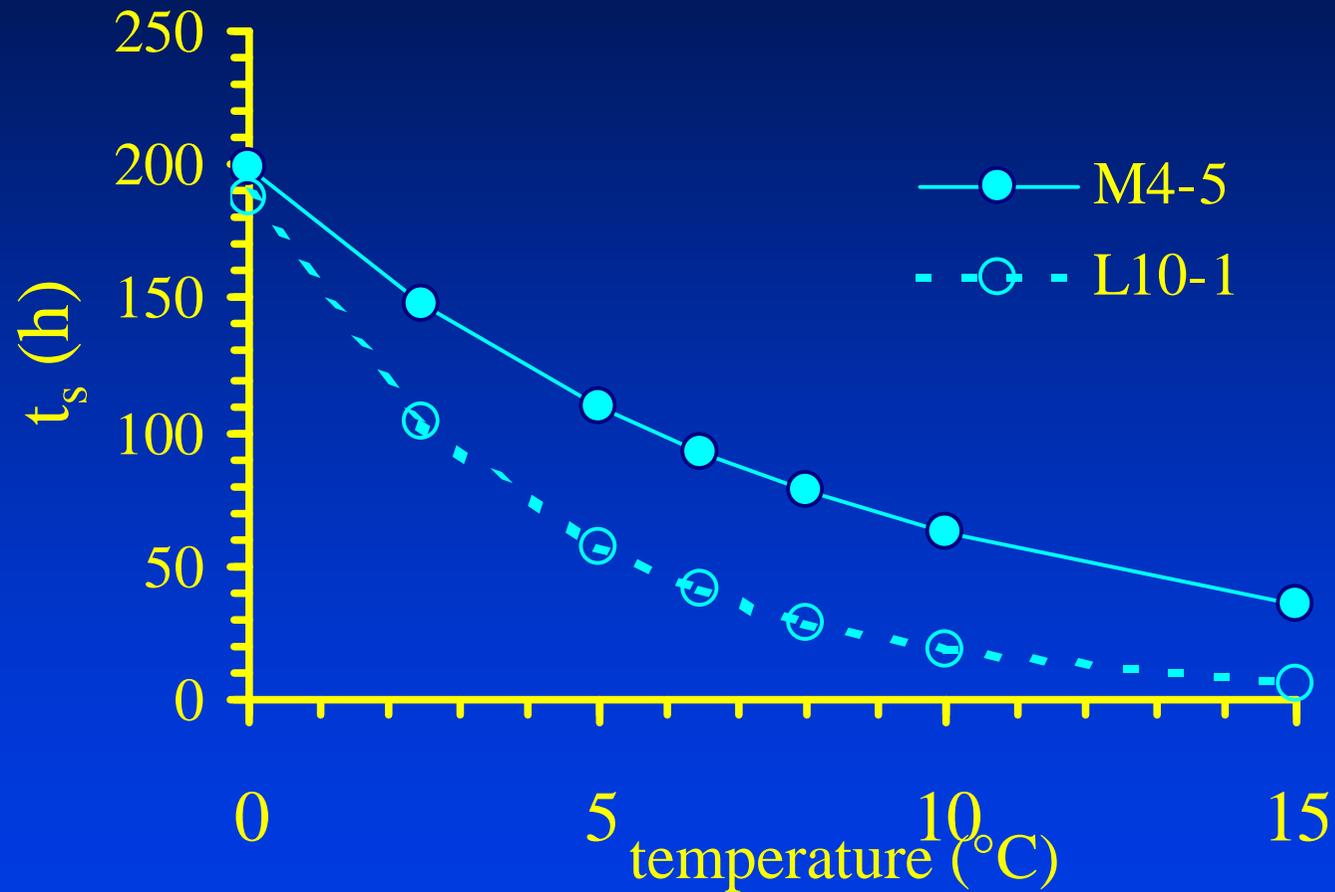


$$T_{\text{eff}} = 8.2^{\circ}\text{C}$$

M4-10

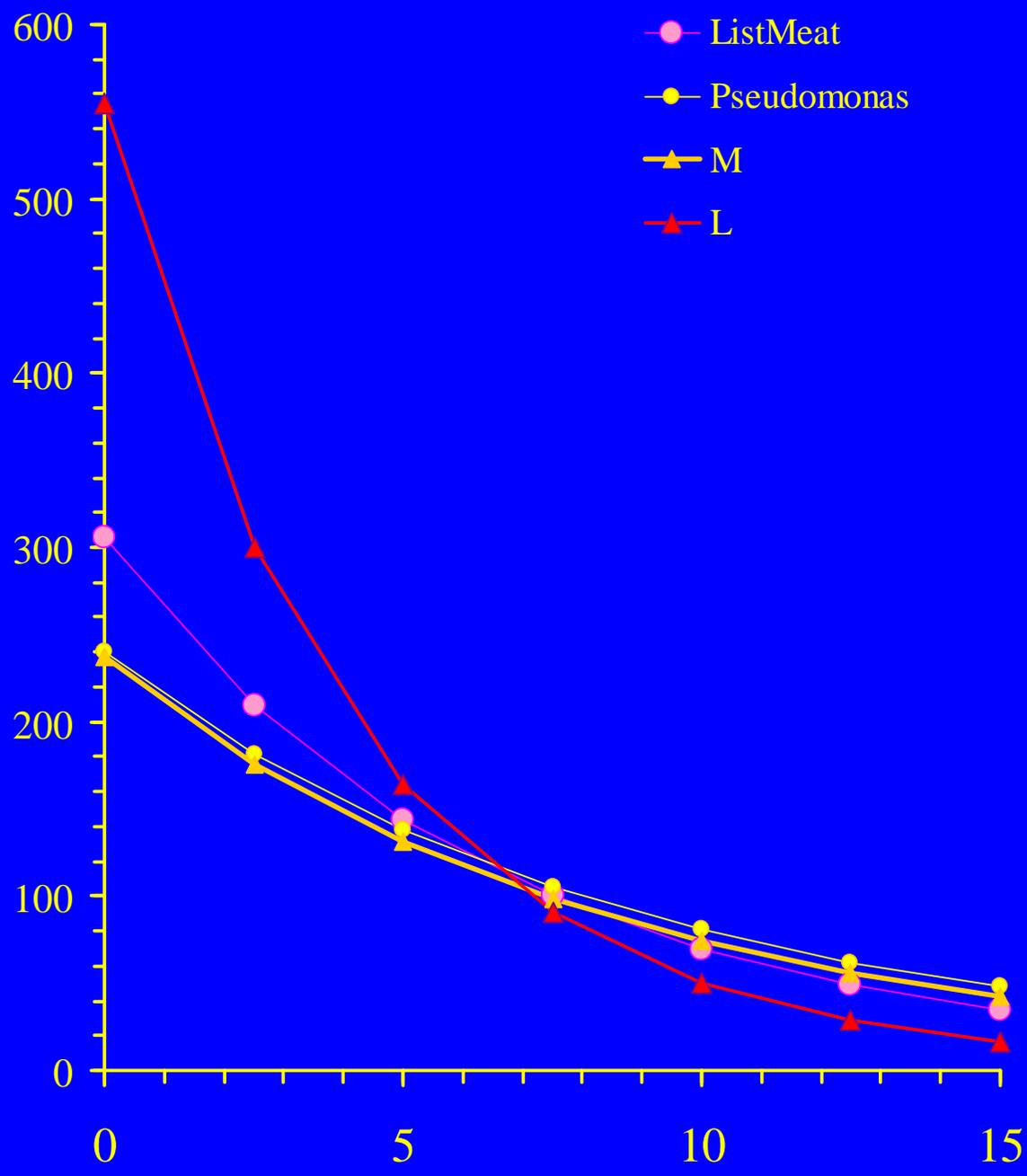
Type TTI	E_A (kcal/mol)–(kJ/mol)	Time to endpoint of Indicator (h)				
		0°C	5°C	8°C	10°C	15°C
L10-1	35.8 – 149.8	264	85	35	20	8
L10-3	36.4 – 152.3	940	300	145	70	25
L10-5	35.5 – 148.5	1070	800	300	180	72
M4-5	16.9 – 70.7	210	165	82	60	35
M4-10	18.5 – 77.4	410	250	155	120	80
M4-20	16.3 – 68.2	917	630	370	270	160
C4-5	10.2 – 42.7	200	165	147	122	67
C4-10	11.1 – 46.4	400	260	230	200	150
C4-20	12.6 – 52.7	570	70	370	300	210
B7-24	15.8 – 66.1	67	42	28	20	10
M4-5 tricolor	21.4 – 89.5	412	190	97	74	57
L5-8 tricolor	47.9 – 200.4	880	197	100	52	11





TTI kinetic results – Comparison Type L vs M

Time h



Temperature

KINETICS OF MICROBIAL GROWTH

⊕ Growth for **variable** temperature distribution

$$\begin{aligned} f(\mathbf{N})_t &= \int_0^t \mu_{\max} [T(t)] dt = \mu_{\text{ref}} \int_0^t \exp\left(\frac{-E_A}{R} \left(\frac{1}{T}\right)\right) dt \\ &= \mu_{\text{ref}} \exp\left(\frac{-E_A}{RT_{\text{eff}}}\right) t \end{aligned}$$

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:

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

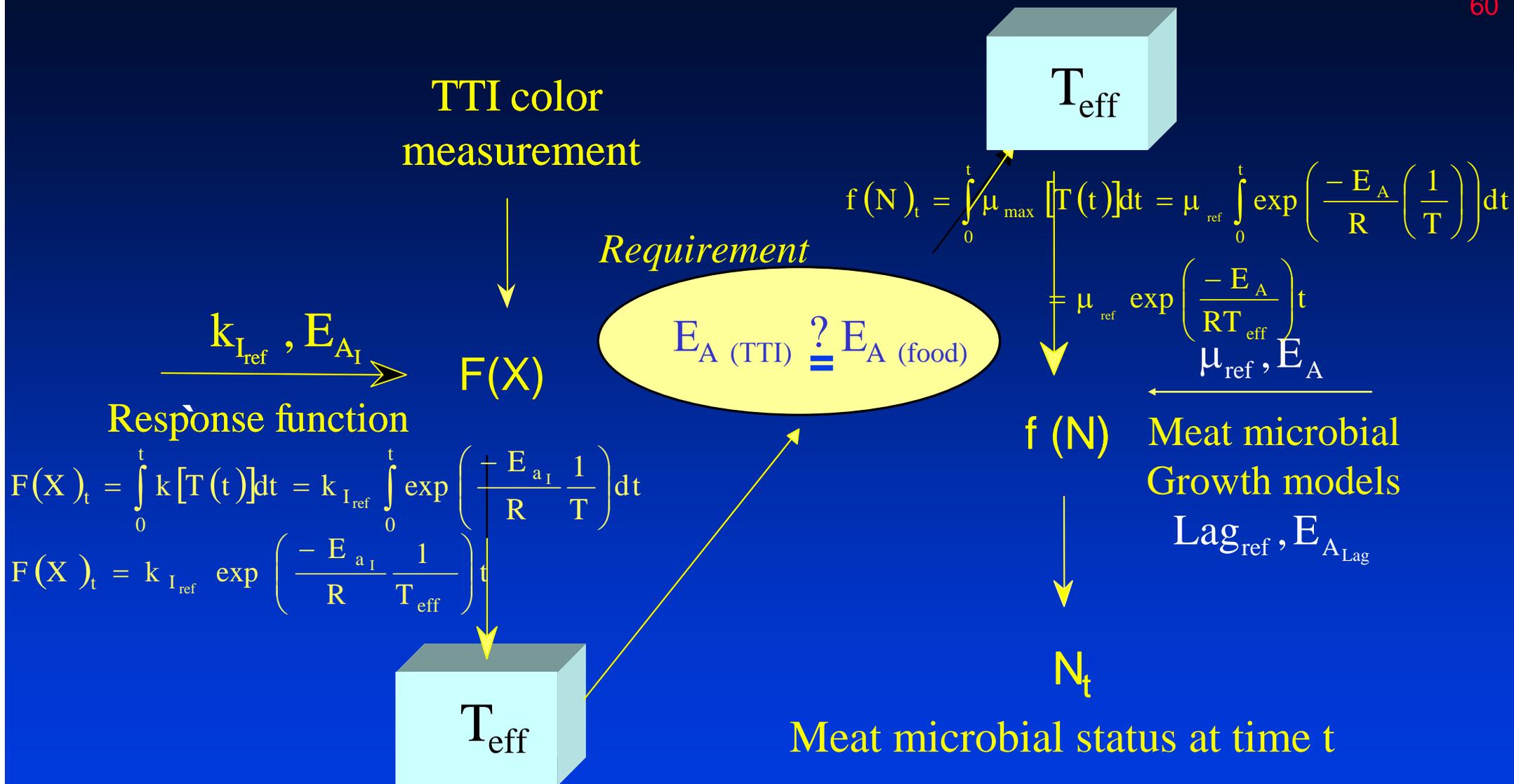
✍ For variable temperature distribution:

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

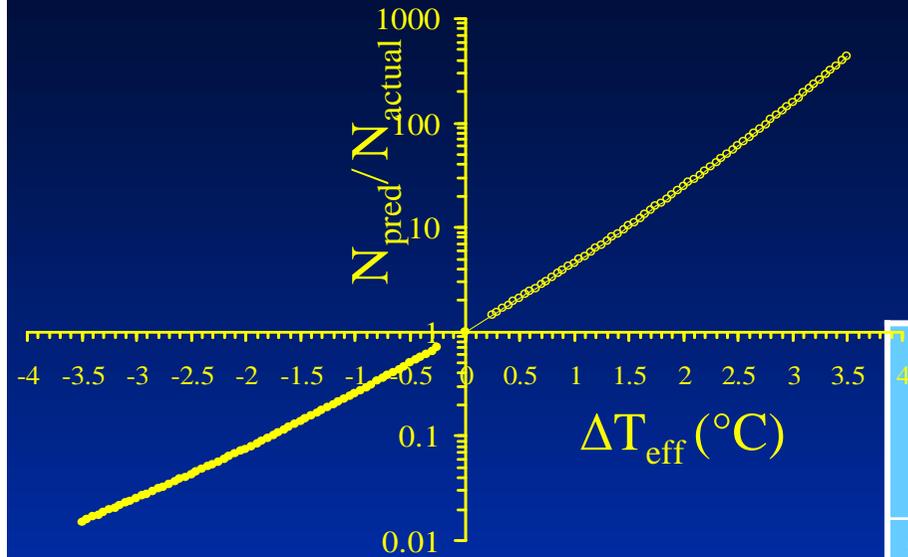
✍ Using effective

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



$\log N_o = 2.5$, $\log N_{final} = 8$
 ($E_a \cong 70.3$ kJ/mol, Shelf life @ $4^\circ\text{C} = 305\text{h}$)

	E_A (TTI) (kJ/mol)	T_{eff} ($^\circ\text{C}$) (predicted)	ΔT_{eff} ($^\circ\text{C}$) T_{eff} (TTI) - T_{eff} (actual)	$N_{\text{pred}}/N_{\text{actual}}$
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

OUTPUT

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

Food Characteristics

T(t) data

TTI response models

OR

Datalogger profile



TTI response

- Lab scale
- Visual scale



T_{eff} calculation

Acceptability limit
(e.g. N_s for microbial growth),
Initial status (N_0),
Food spoilage model

Remaining Shelf Life

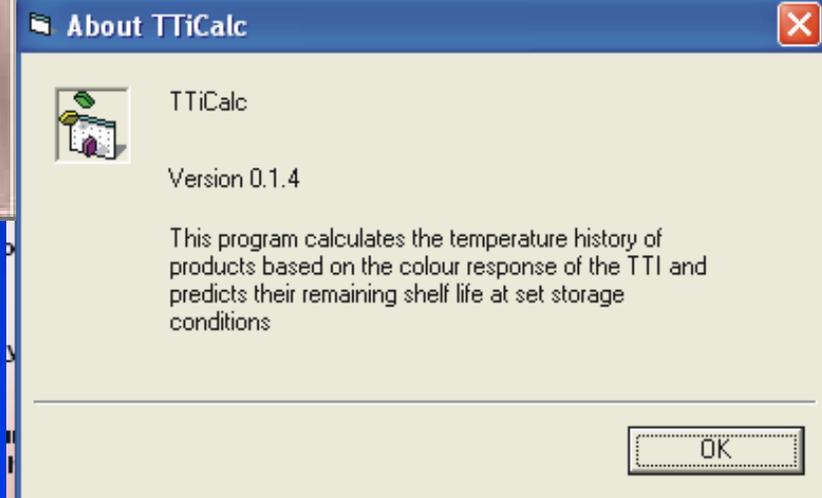


This program calculates
the effective storage temperature of
products
based on time-temperature data
from data loggers
and predicts their remaining shelf life
at set storage conditions

SMAS

TTI - Meat Safety System

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



TTI Calculator - L,a,b Method

Meat Type: ground pork, Creta Farm

Microorganism Type: Pseudomonads

TTI Type: M4-10

2nd TTI Type: L10-3

Measurement Time (hours): 107

Continue

Teff:

Shelf life remain. at 0°C pred. (h):

SMAS TTI - Meat Safety System
Development and Application of a TTI based Safety Monitoring and Assurance System for Chilled Meat Products

(1)

(TTI 1)

(TTI 2)

(2)

Chromatometer Values

Insert Values for L, a, b for TTI : M4-10

L: 54

a: -13

b: 34

Insert Values for L, a, b for TTI : L10-3

L: 58

a: -6

b: 53

If you want to predict shelf life enter values below :

Reference Temperature: 0

Initial Population: 1000

Final Population Accepted: 10000000

OK

Cancel

(RESULTS)

T_{eff}, Shelf life

(3)

TTI Calculator - L,a,b Method

Meat Type: ground pork, Creta Farm

Microorganism Type: Pseudomonads

TTI Type: M4-10

2nd TTI Type: L10-3

Measurement Time (hours): 107

Continue

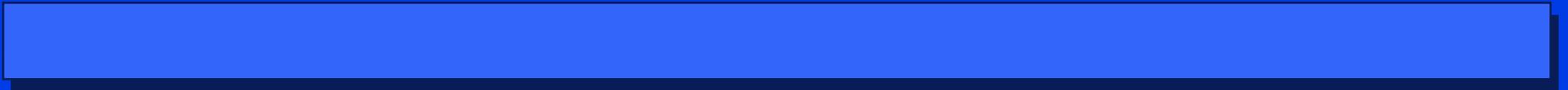
Teff: 5.07 °C

Shelf life remaining pred. (h): -41.44

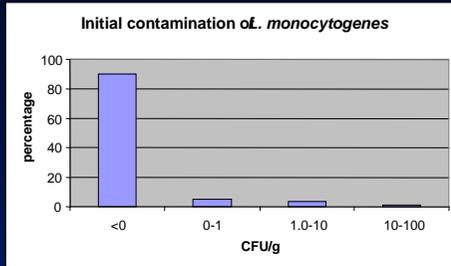
SMAS TTI - Meat Safety System
Development and Application of a TTI based Safety Monitoring and Assurance System for Chilled Meat Products

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

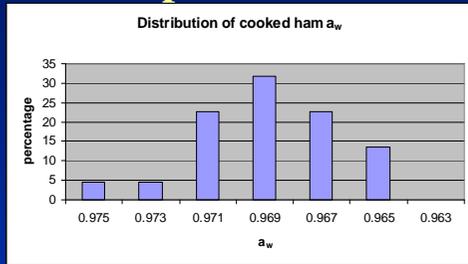
SMAS PRINCIPLES & APPLICATION



chill chain scenario



Final product



Storage
(12h at 4 °C)

Transport
(8h at 6 °C)

Distribution Center
(24h at 4 °C)

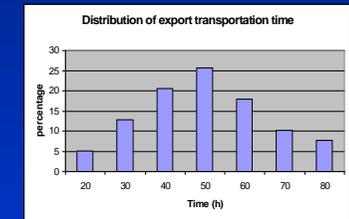
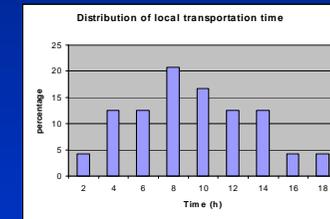
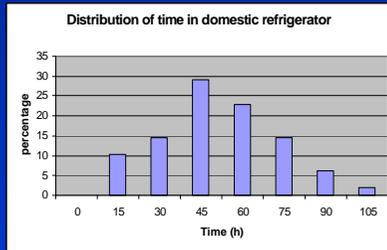
Product promotion

1st Decision point

(4 °C)

Local market

Export market



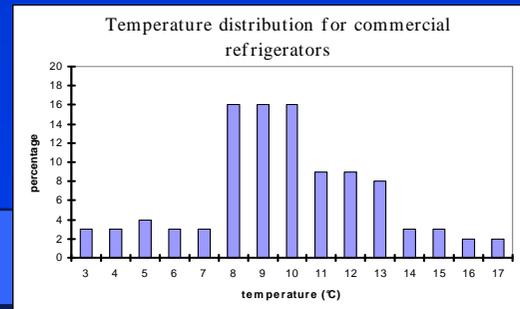
Display Cabinet

(6, 18, 30h)

Retail Storage

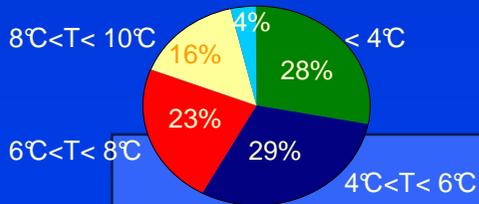
(Super Market)

Stock Display
2nd Decision point

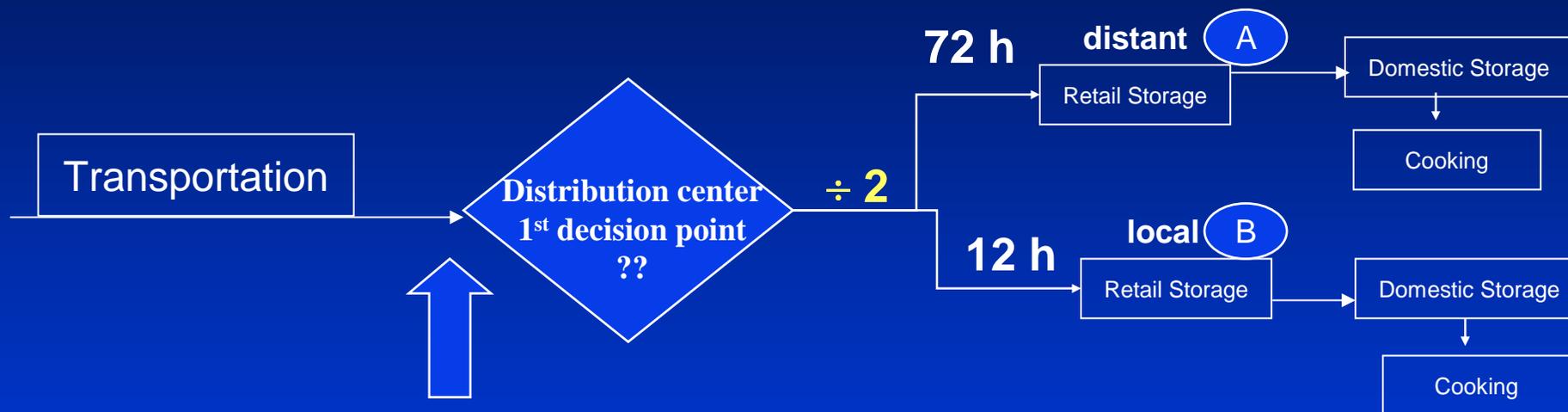


Consumption

Temperature distribution for domestic refrigerators
10°C < T < 12°C

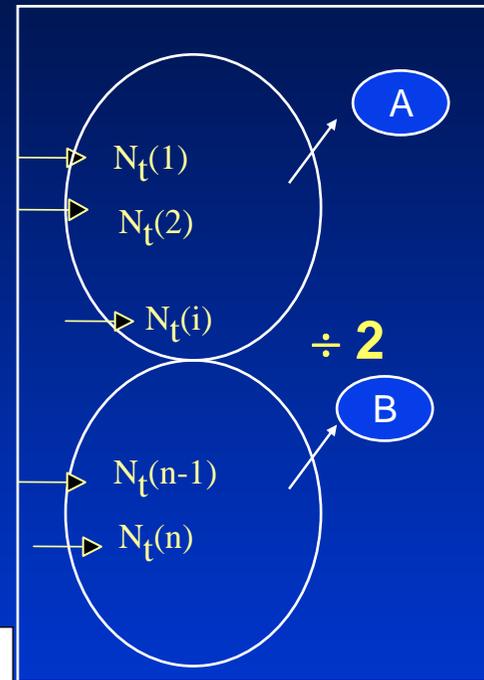
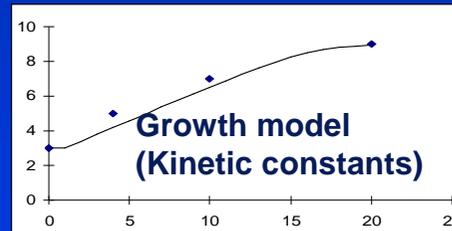
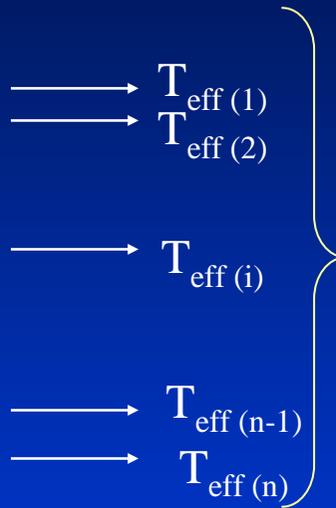
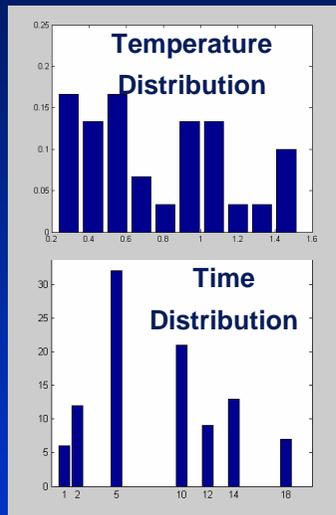


Domestic Fridge

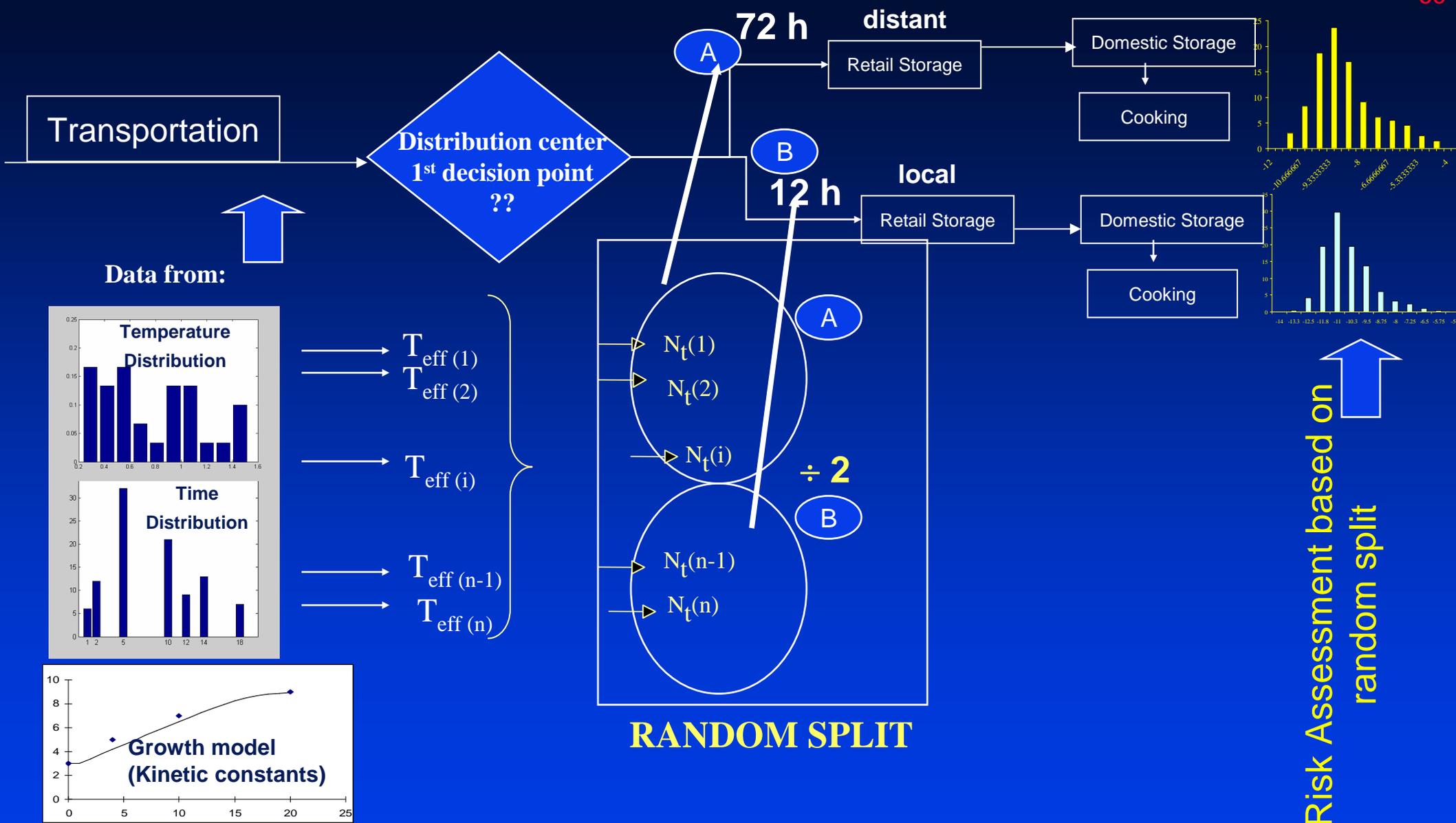


1. Random Split
- OR
2. SMAS based split

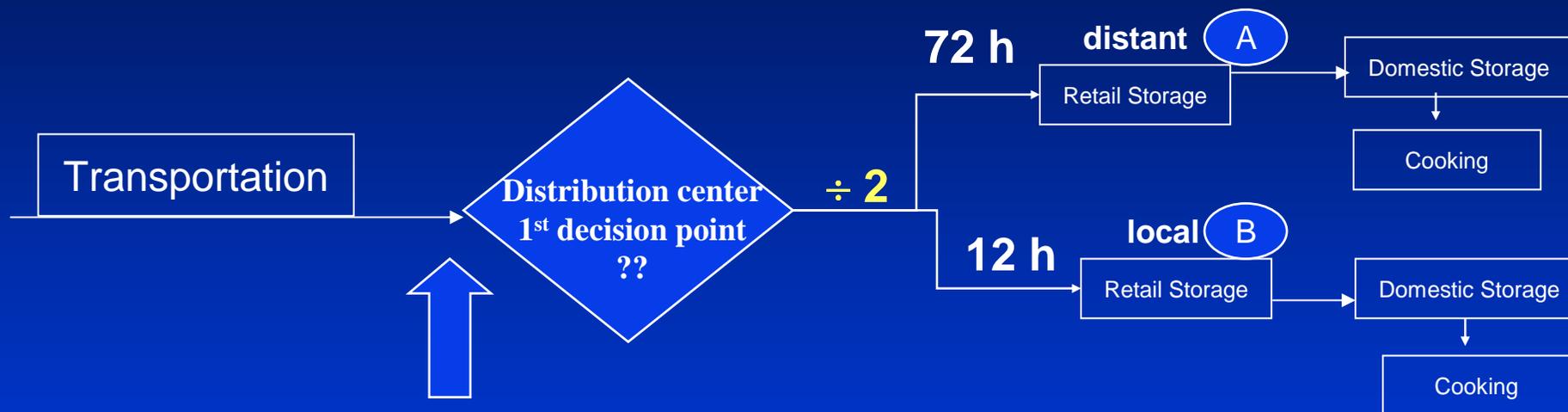
Data from:



1. Random Split

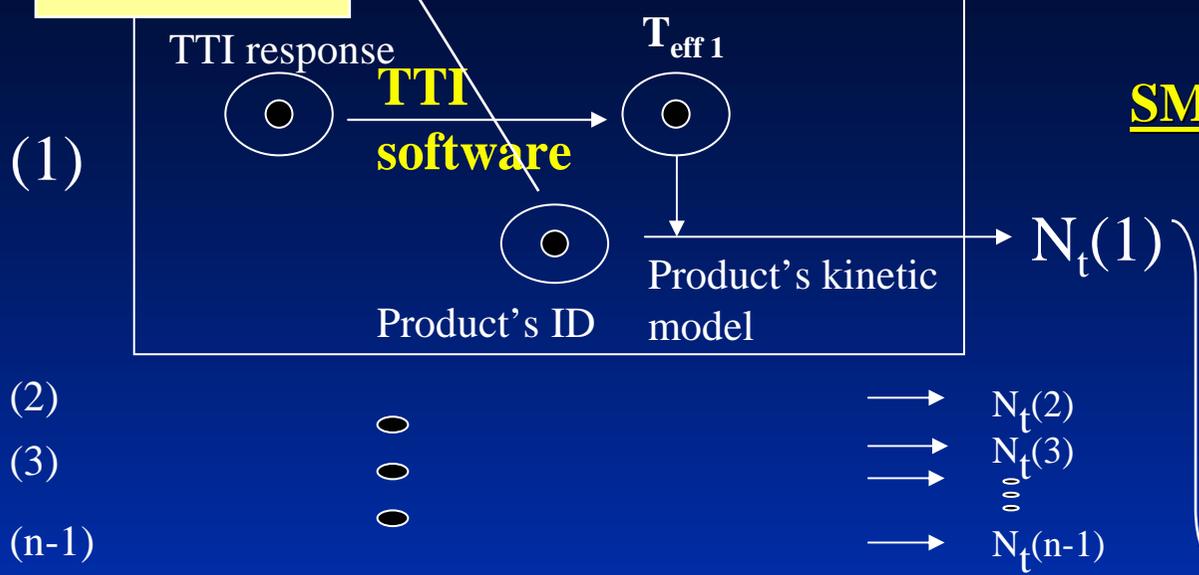


1. Random Split



1. Random Split
- OR
2. SMAS based split

pH, a_w, ...



÷ 2
SMAS based split



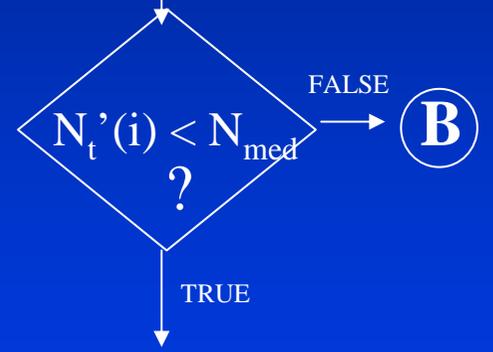
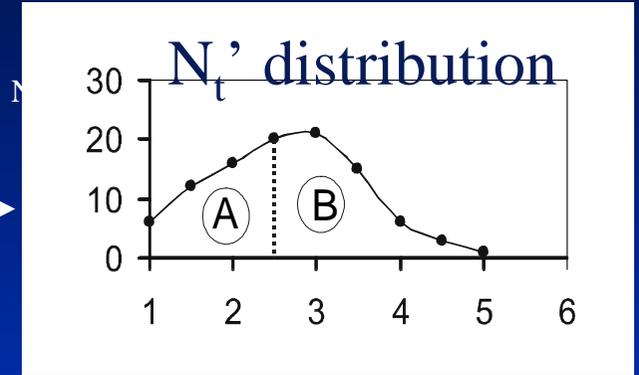
N'_t(1)

N'_t(2)

N'_t(3)

N'_t(n-1)

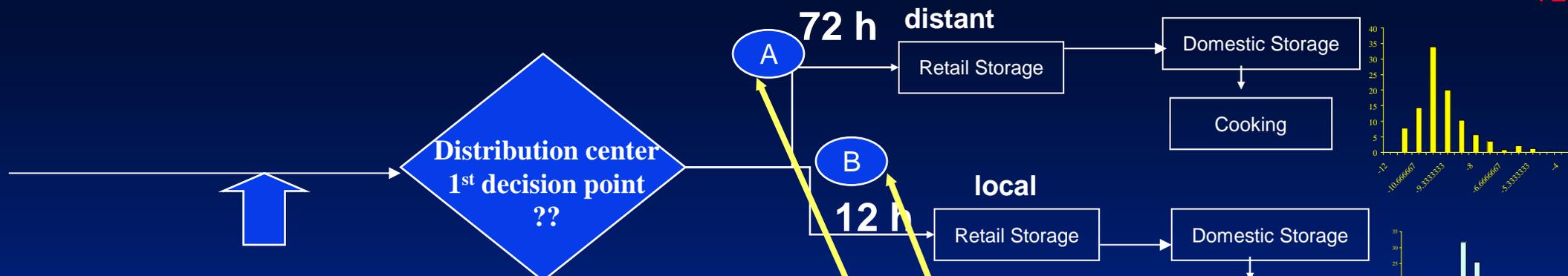
N'_t(n)



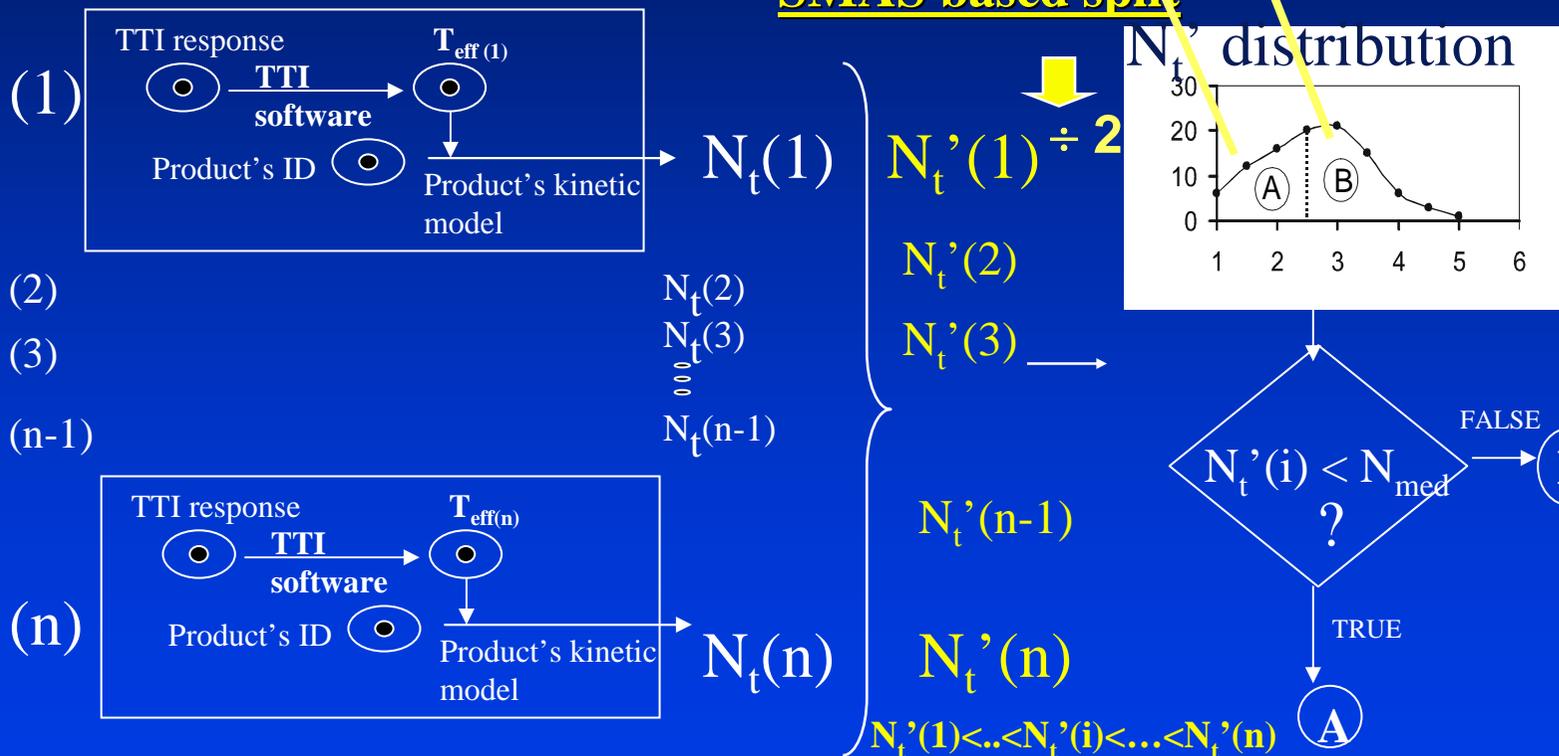
N'_t(1) < .. < N'_t(i) < ... < N'_t(n) A

pH, a_w, ...

2. SMAS based split



SMAS based split

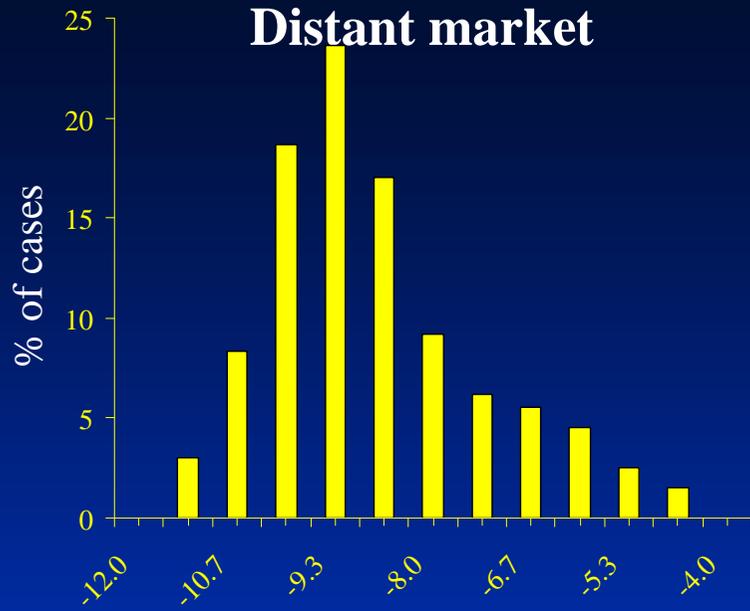


SMAS BASED SPLIT

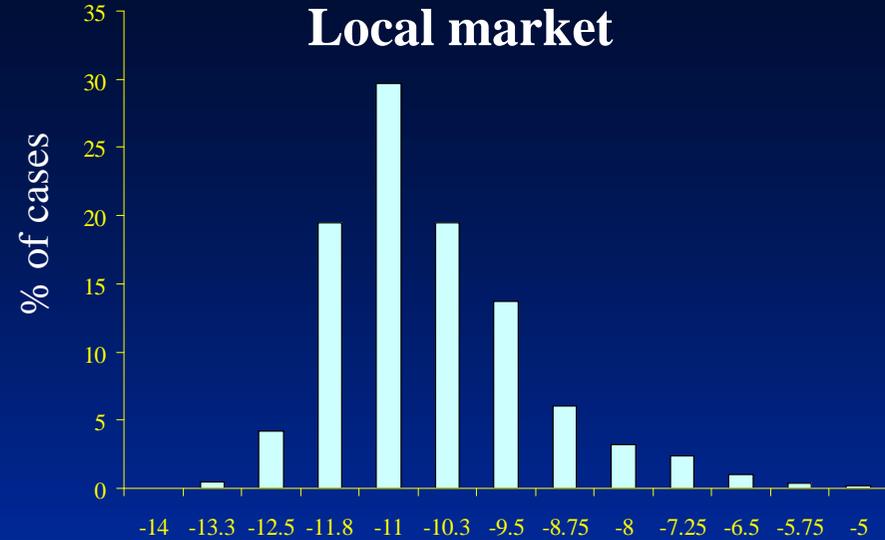
Risk Assessment based on SMAS split

2. SMAS based split

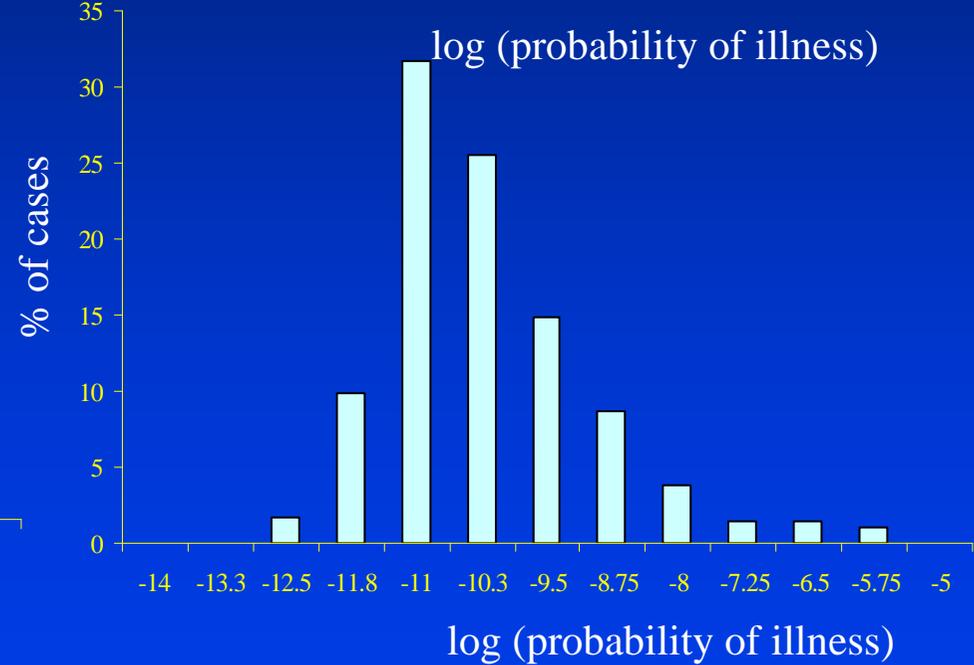
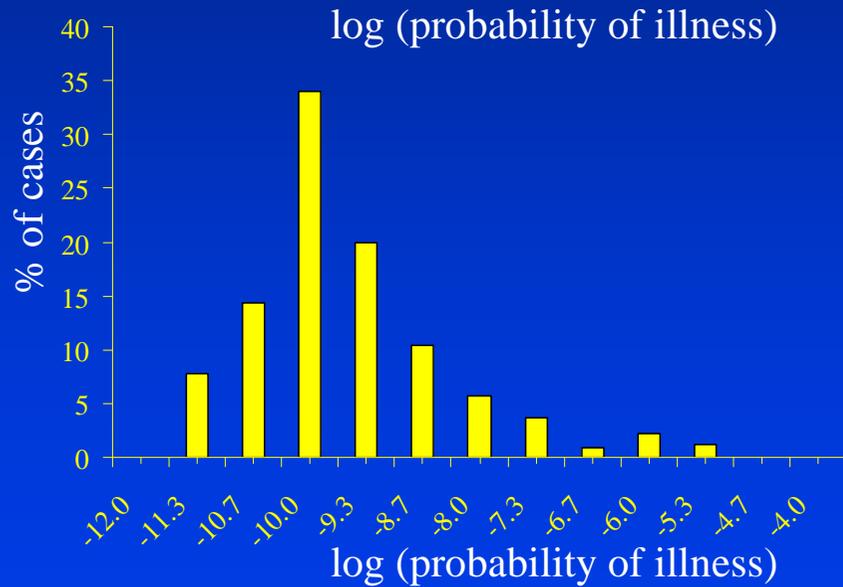
Random Split



Local market



SMAS based Split



Typical results

Microbial growth kinetic models for:

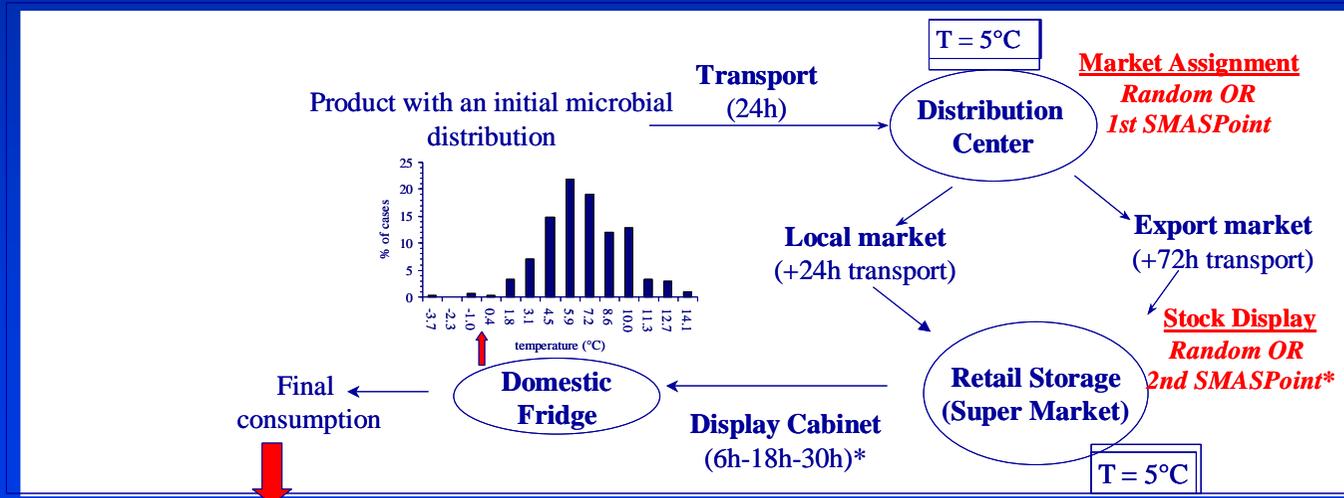
➤ ***Listeria monocytogenes*** ($E_A \cong 94.5 \text{ kJ/mol}$ and $\mu_{\text{ref}}@10^\circ\text{C} \cong 0.058\text{h}^{-1}$) and **spoilage microorganisms, *Pseudomonas*** ($E_A \cong 73.1\text{kJ/mol}$ and $\text{shelflife}_f@0^\circ\text{C} \cong 190\text{h}$).

For product monitoring and management at the SMAS points:

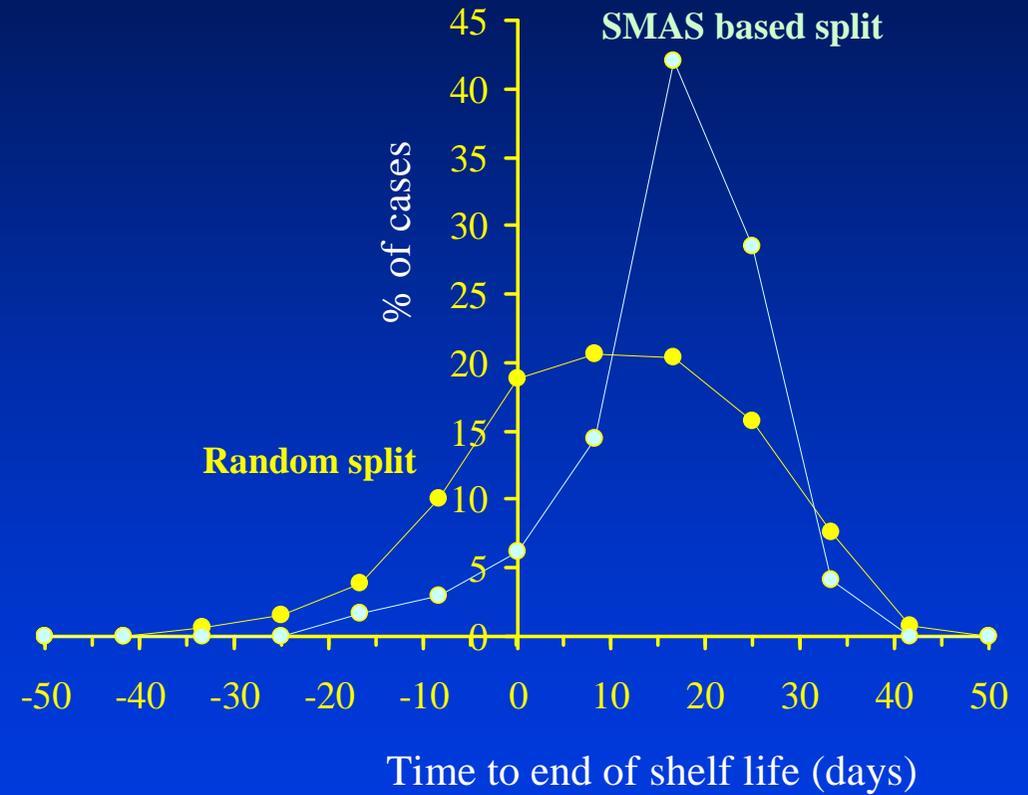
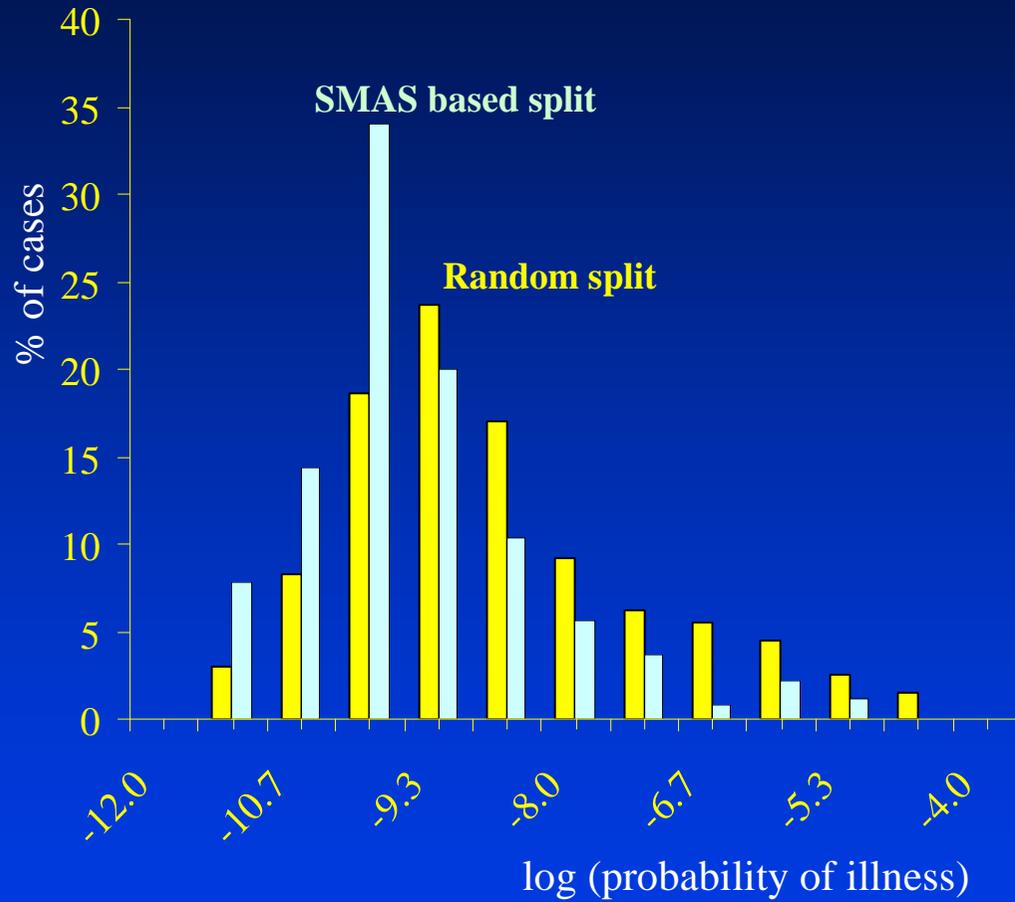
➤ an enzymatic TTI (**VITSAB® Type L10-3**) ($E_A \cong 158.5 \text{ kJ/mol}$ and $\text{max response time}_f@5^\circ\text{C} \cong 150\text{h}$)

➤ 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 ($\text{logreduction} \cong 3.0 \pm 1.5\text{CFU/g}$) and a **dose-response model** (Farber et al 1996) was applied for the estimation of the probability of illness.

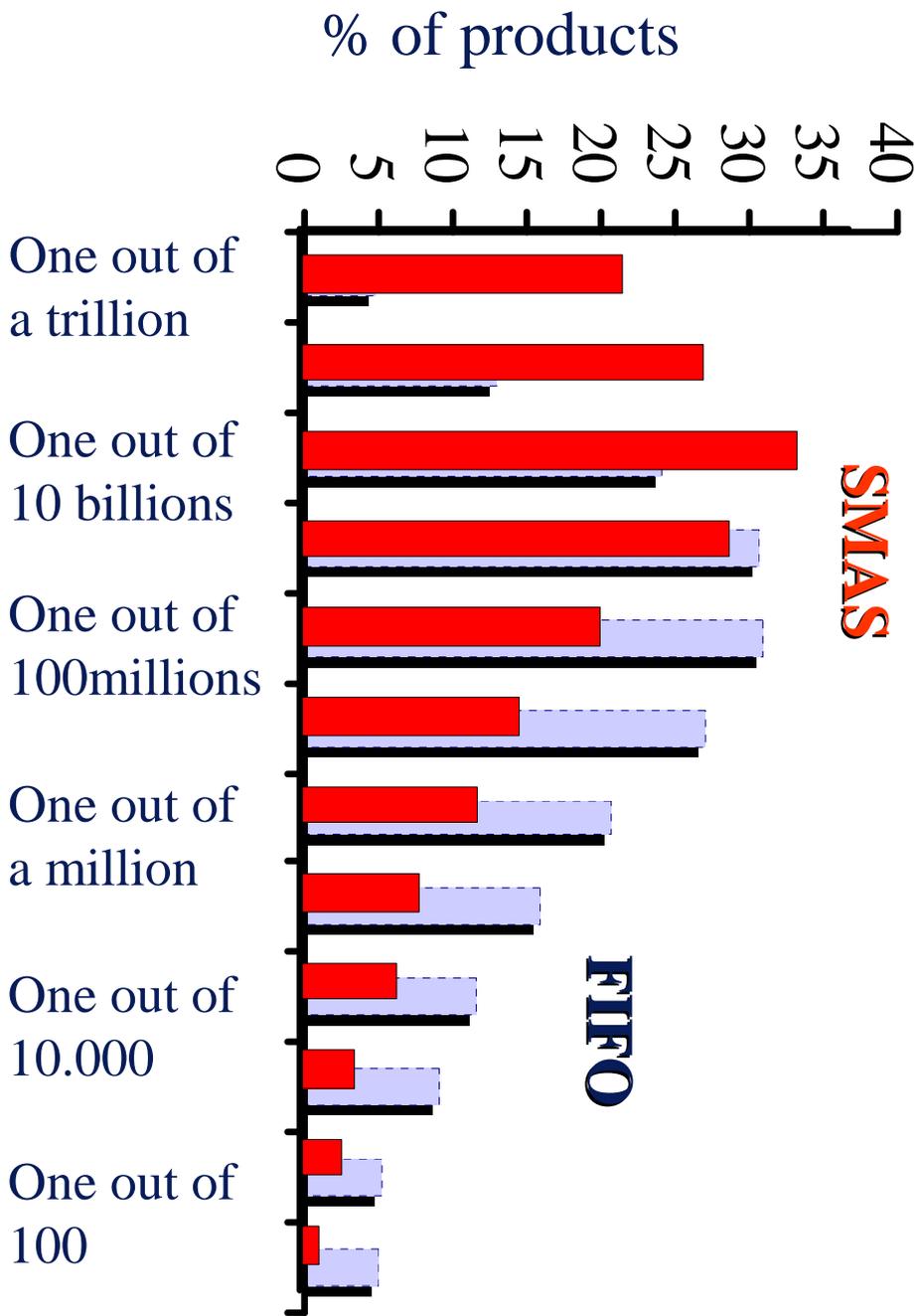


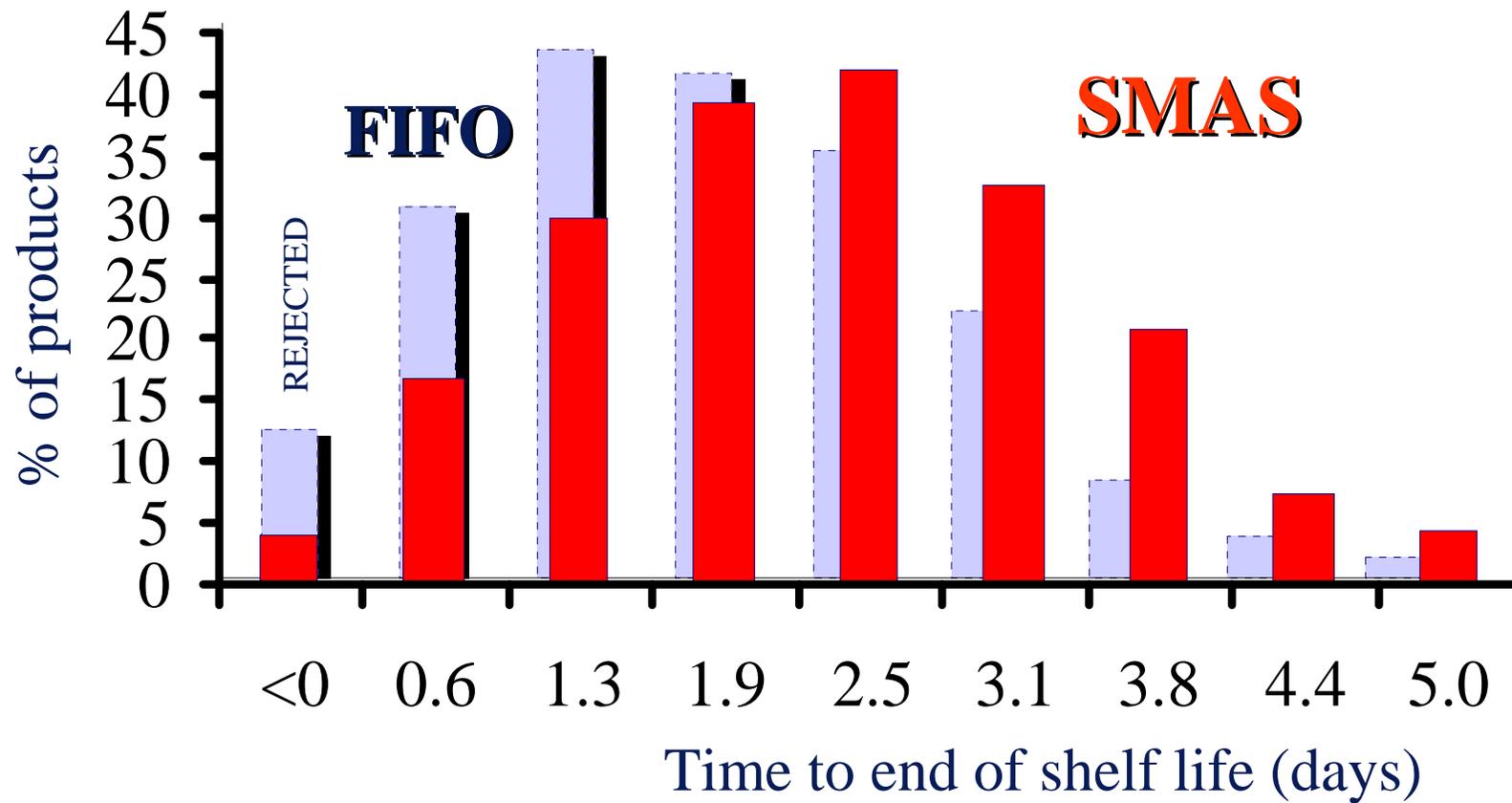
1st Example of SMAS application



Distant market

Probability of illness





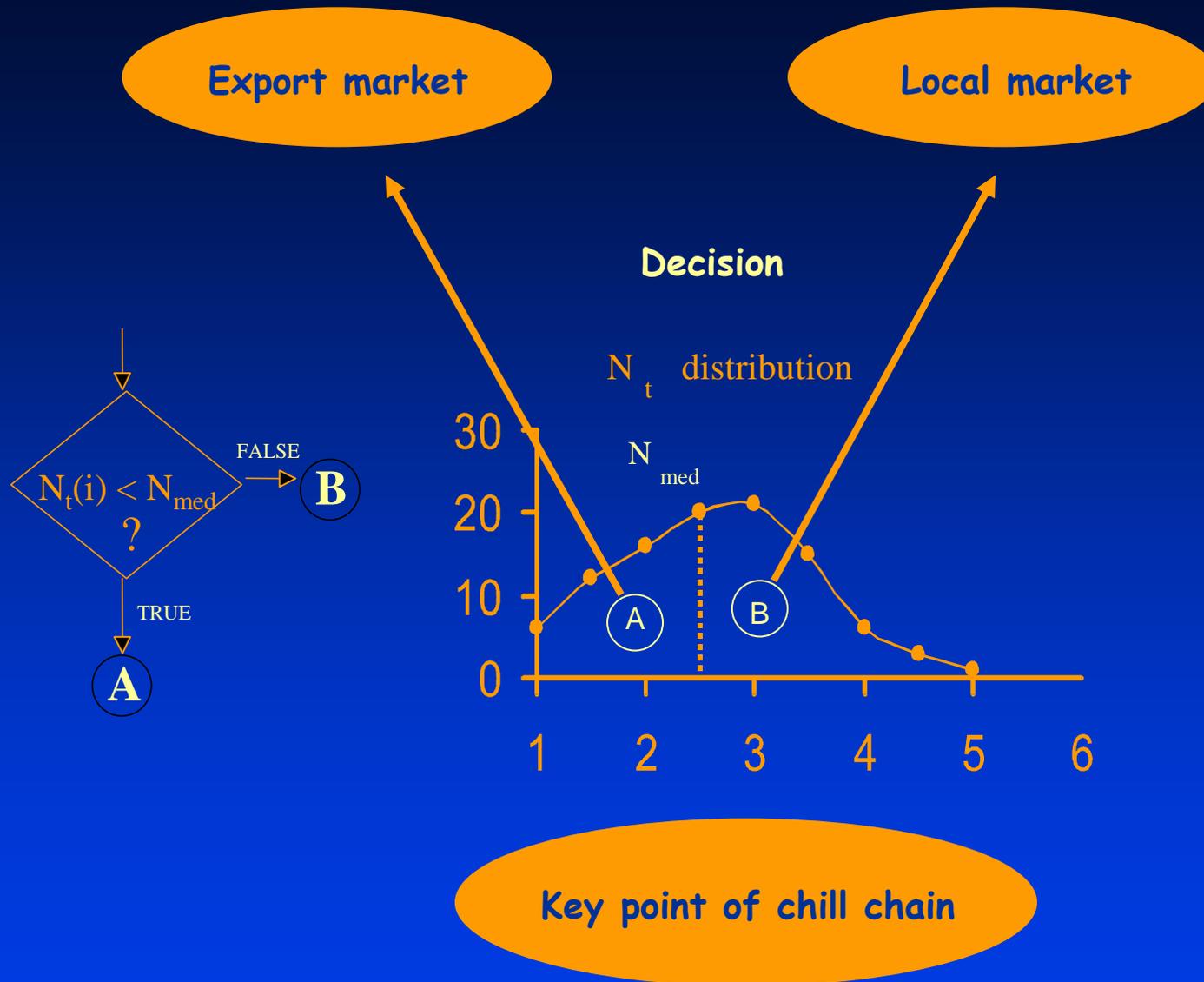
Product quality at consumption

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 1. Distribution Center
in the chill chain: 2. Stock display (retail level)

2nd Example of SMAS application

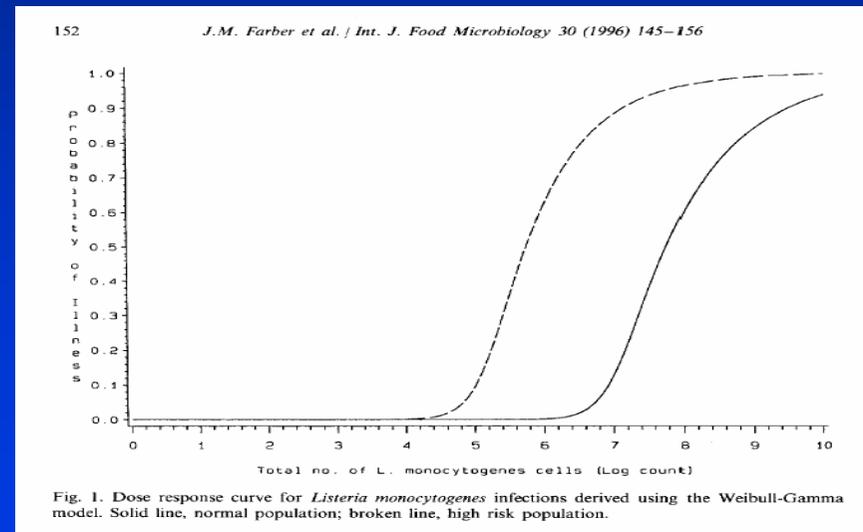


SMAS principles

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

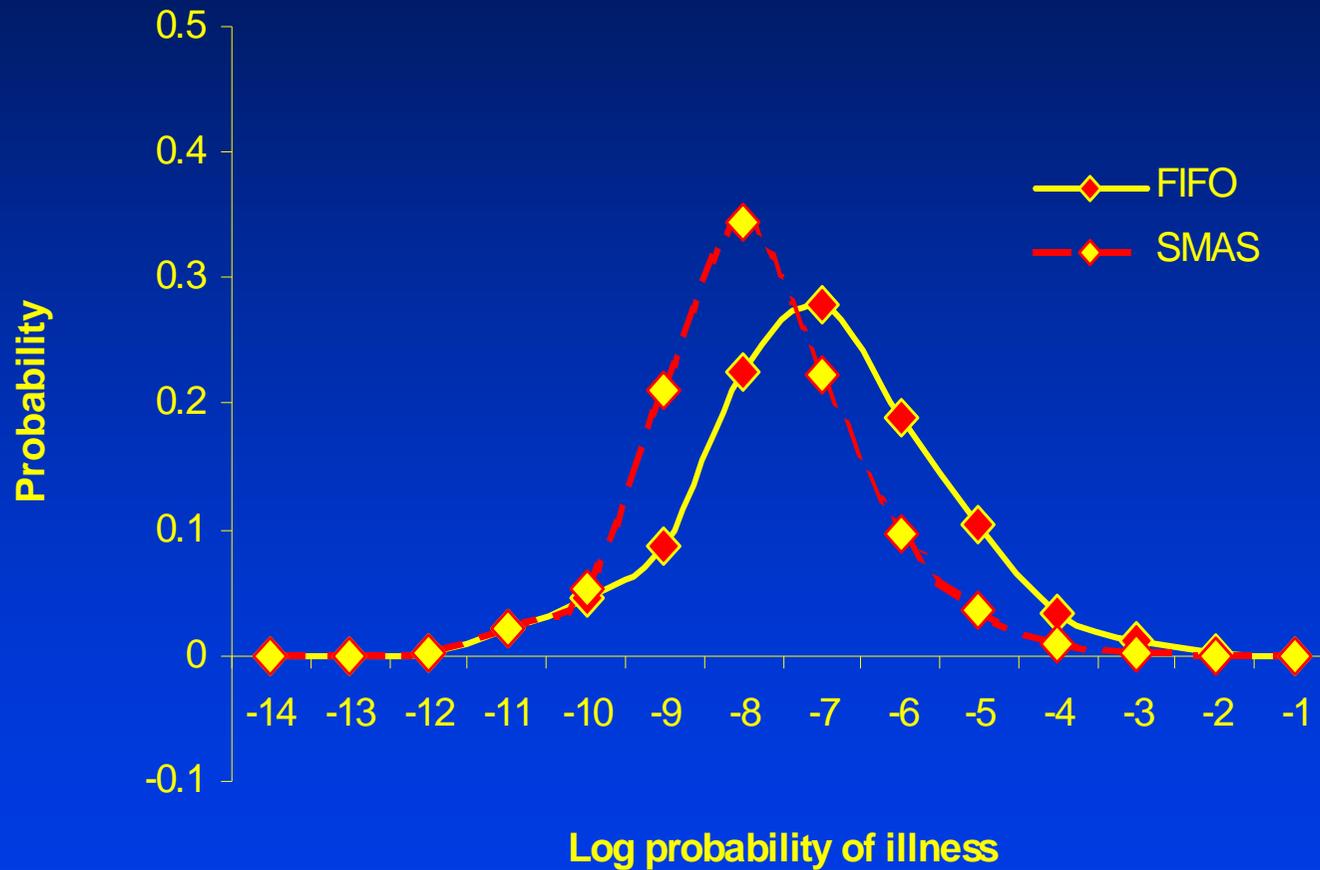
Evaluation of SMAS effectiveness Risk estimation

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



Evaluation of SMAS effectiveness

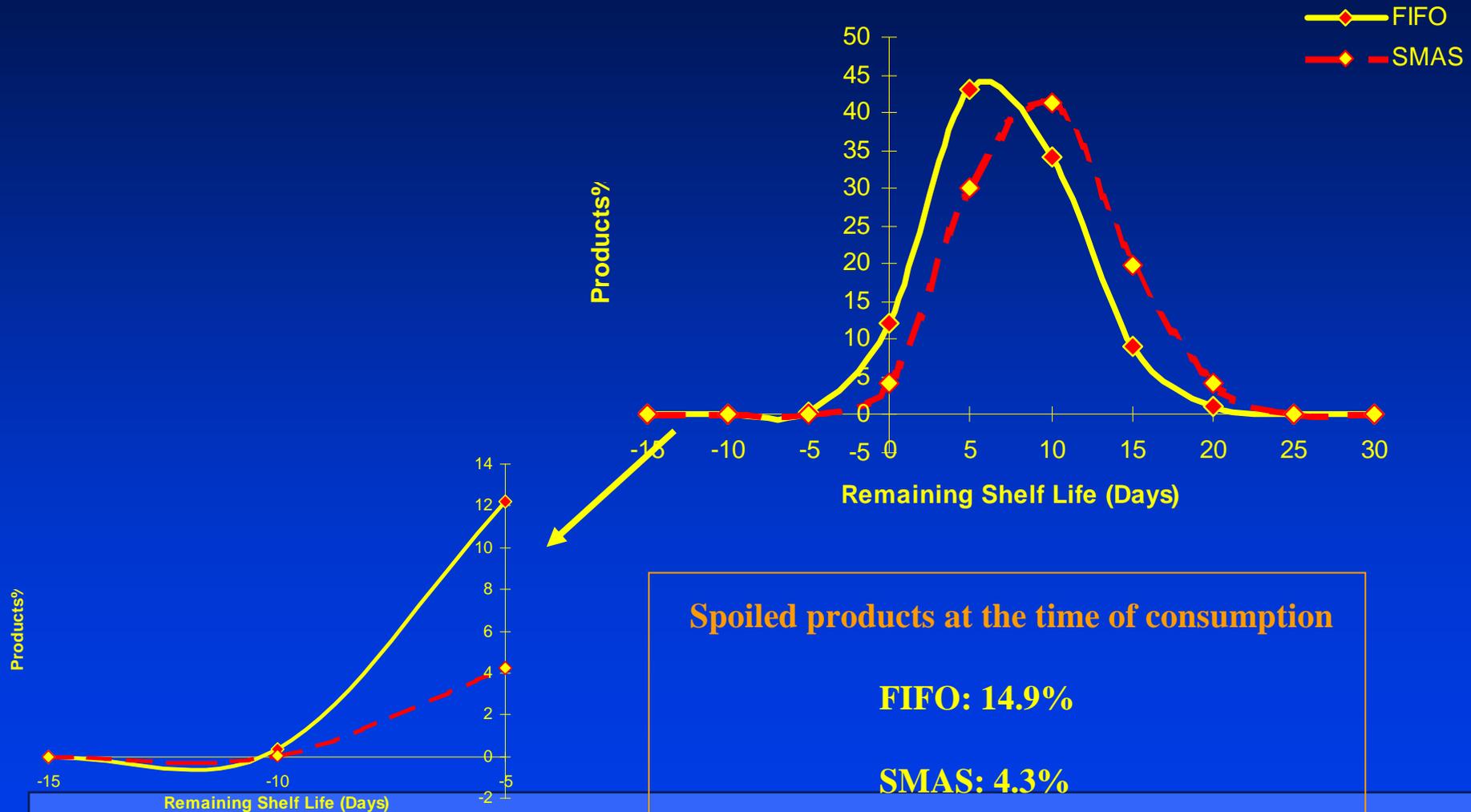
Results



Evaluation of SMAS effectiveness

Product Quality (shelf life)

Results



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



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>