Evaluation of food safety along the cold chain by deterministic and stochastic approaches

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Presentation outline

1. Background / Objective / Originality of the presented subject
2. Methodology combining deterministic and stochastic *approaches*

   2.1. Domestic refrigerator

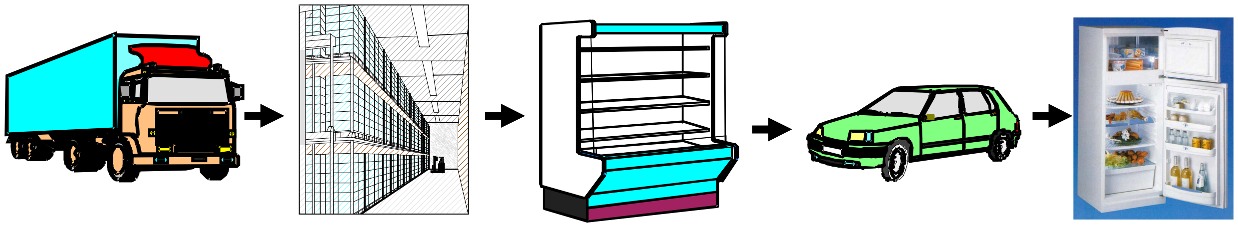
   2.2. Refrigerated display cabinet

   2.3. Logistic chain description

   2.4. Product evolution in logistic chain

3. Simulation result and discussion
4. Conclusion and perspective

1. Background



Prediction of product temperature evolution in cold chain by deterministic (heat transfer) models require an assumption that initial and operating conditions are accurately known

However, there are many "random » variables in practice :
- Product initial states.
- Position and residence time of products in equipment
- Equipment operating conditions: room temperature, thermostat setting temperature
- Equipment sequence

Limitation of the use of deterministic models

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1. Background

Refrigerated display cabinet

Consumer shopping basket

Domestic refrigerator

Food products were subjected to temperature abuse:

- **30% in display cabinets**
- **40 % in domestic refrigerator**

(Survey of Cemagref and ANIA, 2004).

Product temperature 2°C higher than the recommended preservation temperature.

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1. Objective

To develop a modelling methodology to predict the evolution of food products and its variability all along the cold chain.

This methodology was applied to the last 3 steps:

1. Originality

The model takes into account the variability observed in practice:

- Ambient temperature
- Product residence time in equipment
- Thermostat setting

etc.

This variability is randomness.

2. Methodology

The methodology is composed of:

Deterministic modelling

↓

Stochastic modelling

↓

Prediction of product evolution

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A large number of products items (10 000 to 100 000) was studied. Each product is characterized by state variables:

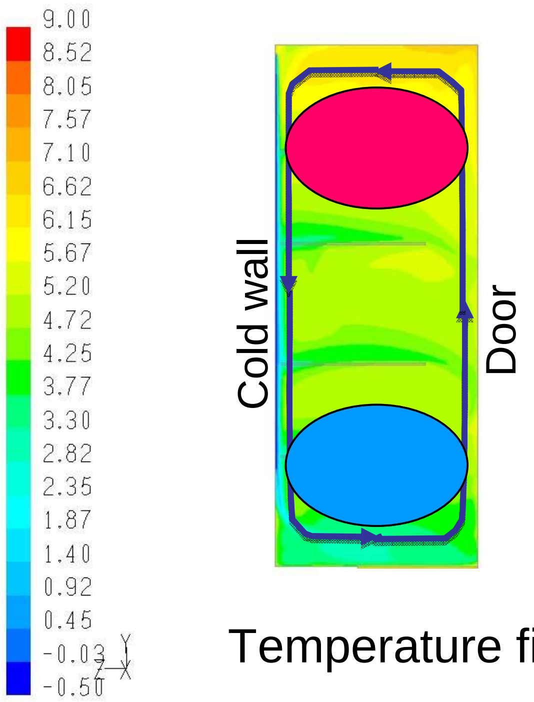
- Product temperature T
- Microbial load N

2. Methodology

2.1. Domestic refrigerator

Our previous study: CFD Approach

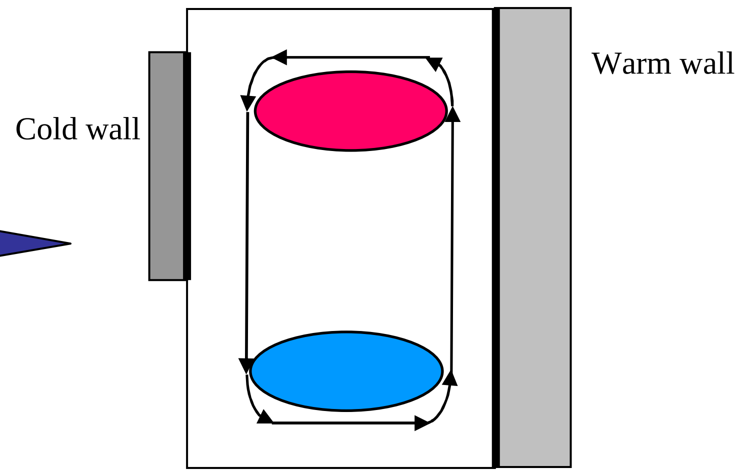
Fine knowledge of phenomena
Time-consuming calculation



Temperature field

Simplification of model

Zonal model



General equation

$$A.T = B.T_{ext} + C.T_{th}$$

matrix of temperatures to predict

matrix of dimensionless heat transfer coefficients

Numerical values used in estimation of A, B and C.

h_c	3.28 $W.m^{-2}.K^{-1}$	Laguerre and Flick (2004)
h_w	1.3 $W.m^{-2}.K^{-1}$	
h_r	3.85 $W.m^{-2}.K^{-1}$	
h_e	0.63 $W.m^{-2}.K^{-1}$	
h_s	3.26 $W.m^{-2}.K^{-1}$	Raithby and Hollands (1992)

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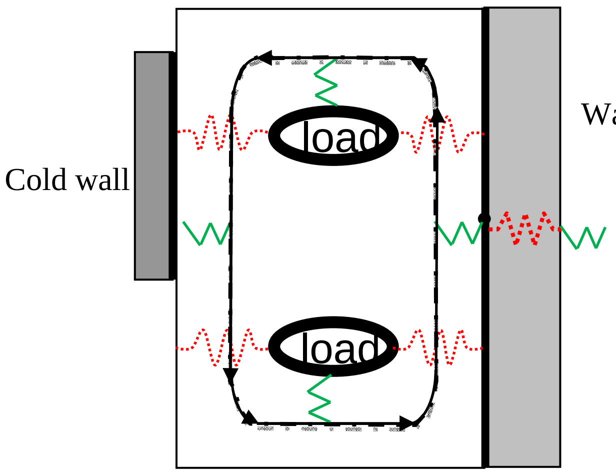

conduction in the wall

convection between the wall and the air

convection between the load and the air

radiation between the load and the wall

Static refrigerator:

$$T_{load.1} = 0.0723 T_{ext} + 0.9277 T_{th}$$
$$T_{load.2} = 0.0077 T_{ext} + 0.9923 T_{th}$$

Ventilated refrigerator:

$$T_{load.1} = 0.0343 T_{ext} + 0.9657 T_{th}$$
$$T_{load.2} = 0.0147 T_{ext} + 0.9853 T_{th}$$

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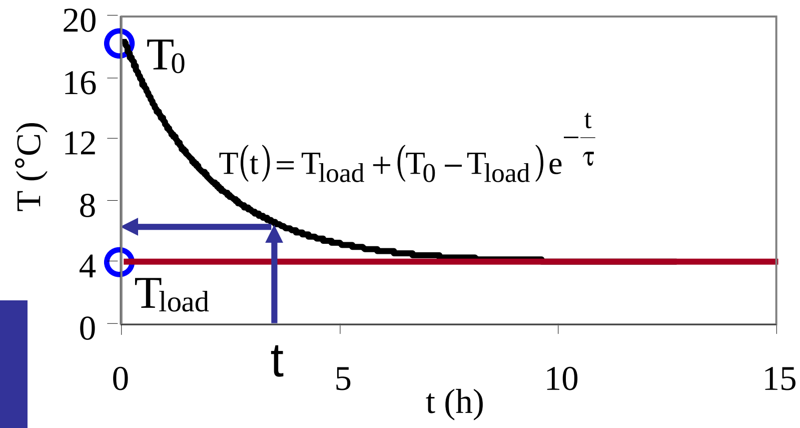
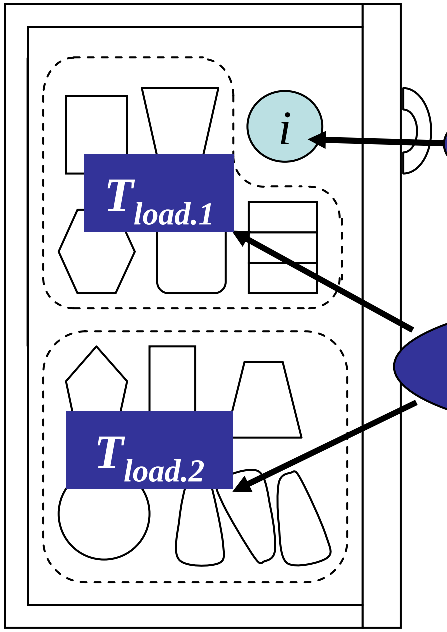


Deterministic modelling of domestic refrigerator
Transient state



Product of interest i

Temperature evolution

Loads

Constant Temperature

Transient st

$$\tau = \frac{mC_p}{hA}$$

$$T(t) = T_{load} + (T_0 - T_{load}) e^{-\frac{t}{\tau}}$$

Steady State

$$AT_{load} = BT_{ext} + CT_{th} + D$$

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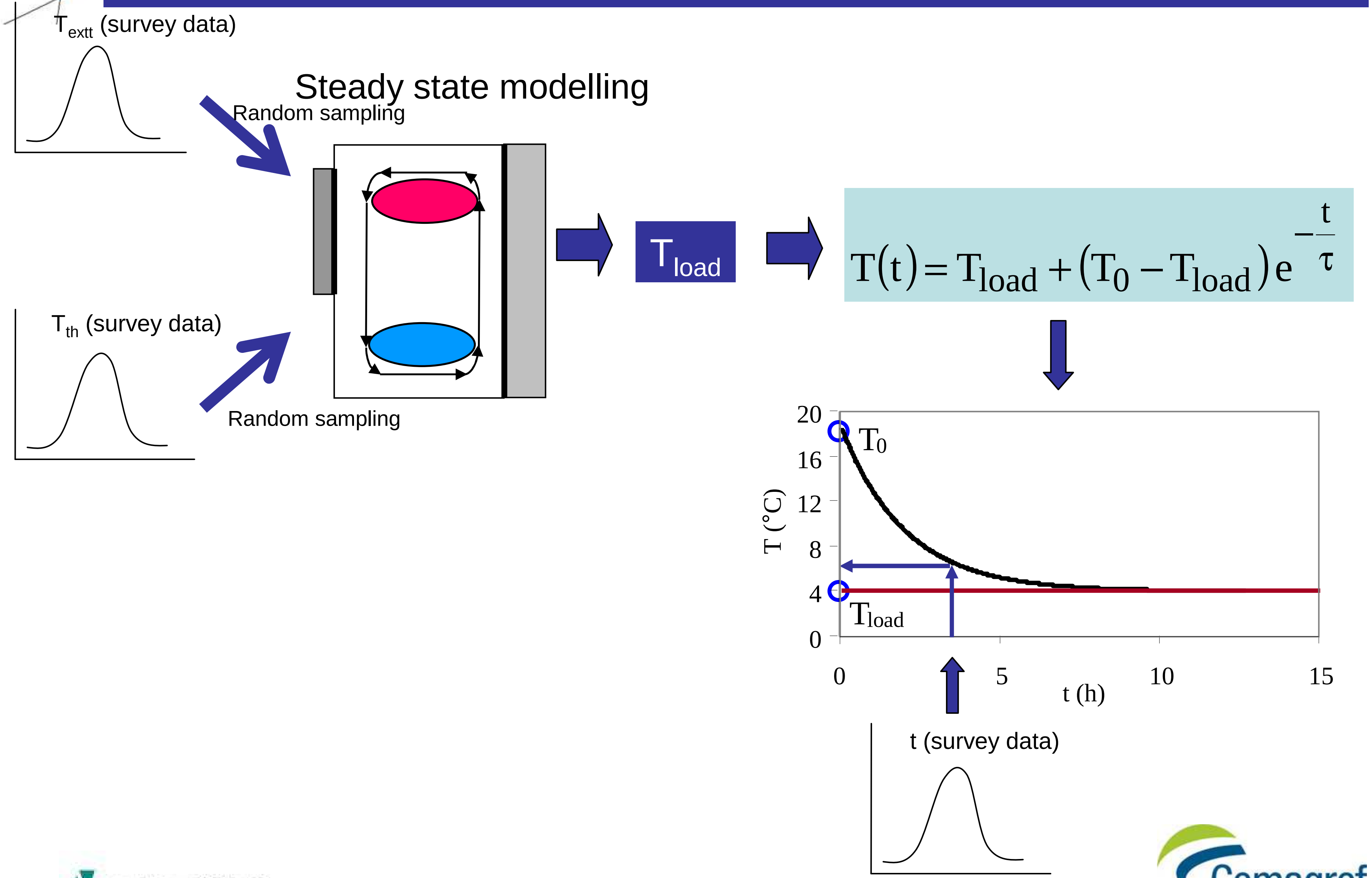
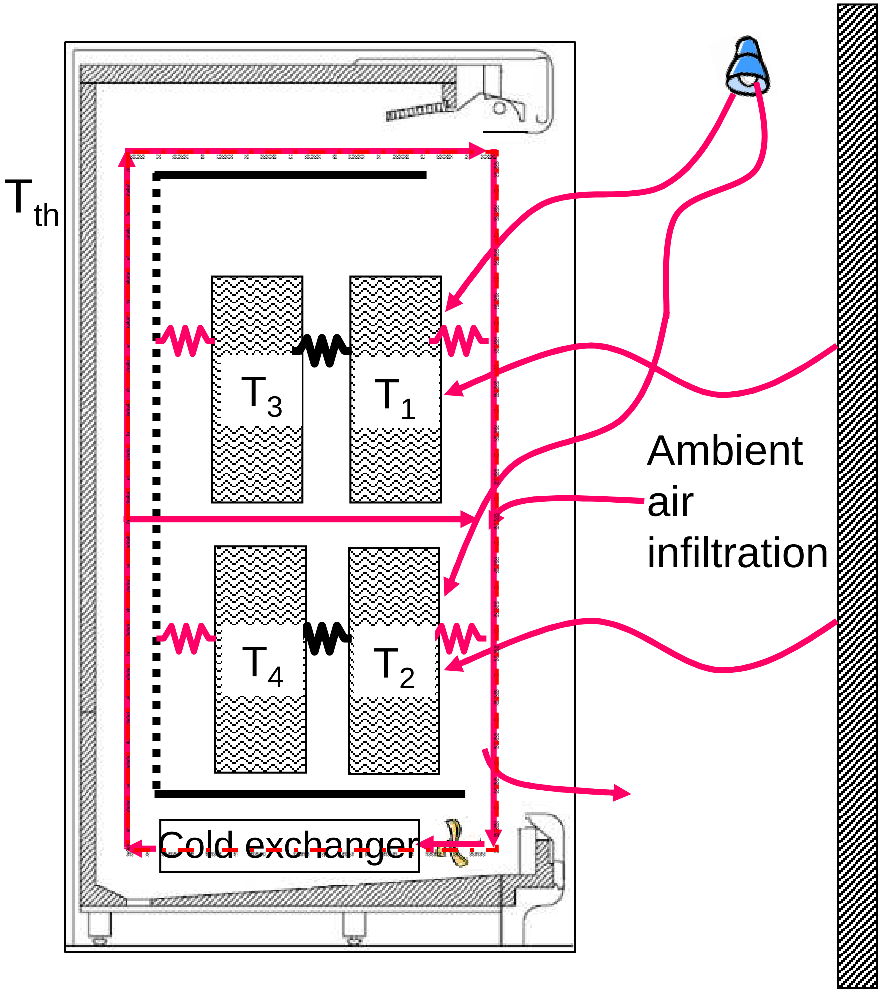
Combined deterministic and stochastic modelling for domestic refrigerator



2.2. Display cabinet
Steady state heat transfer modelling



Front:

$$T_{load.1} = 0.0117 T_{ext} + 0.1831 T_{rad} + 1.3534$$
$$T_{load.2} = 0.1040 T_{ext} + 0.1889 T_{rad} + 1.4178$$

Rear:

$$T_{load,3} = 0.0027 T_{ext} + 0.0430 T_{rad} + 1.4655$$
$$T_{load,4} = 0.0244 T_{ext} + 0.0435 T_{rad} + 1.4814$$

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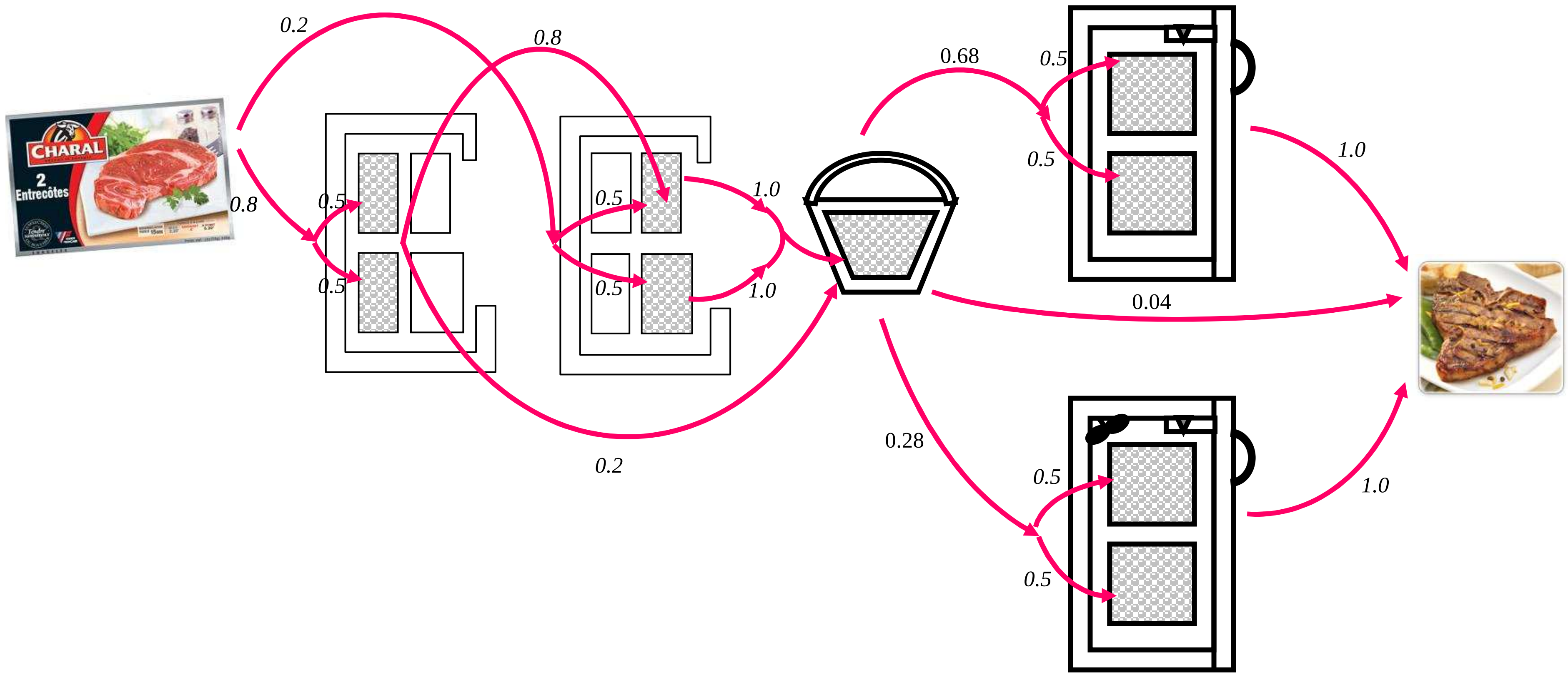
2.3. Logistic chain description

Probability for a "product of interest" to be transferred from one to another equipment



2.4. Product evolution: Microbial load

First order growth

$$\frac{dN(t)}{dt} = \mu N(t)$$

N(t): microbial contamination at time t ($CFUg^{-1}$)

μ: specific growth rate (s^{-1})

Square root model (Ratkowsky *et al.*,1982):

$$\sqrt{\mu} = b(T - T_{\min})$$

T_{min}: minimum temperature under which there is no bacterial growth (°C)

b: coefficient ($s^{-1/2}K^{-1}$)

For *Listeria monocytogenes, Tmin=0℃* and *b=0.00035 s-1/2K-1* (Duh and Schaffner,1993)

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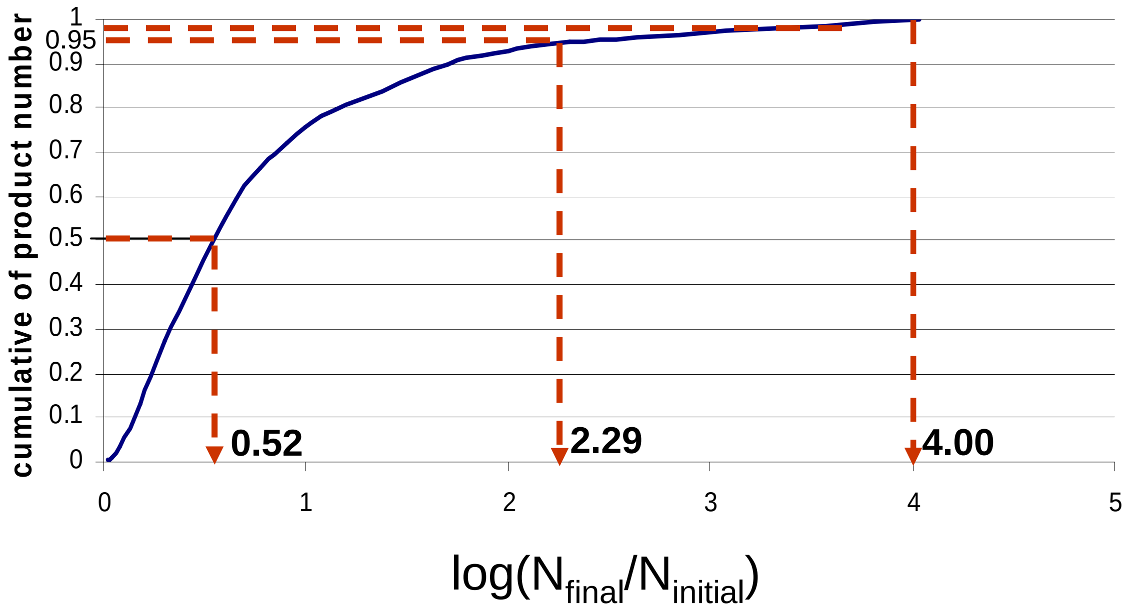
3. Simulation result and discussion

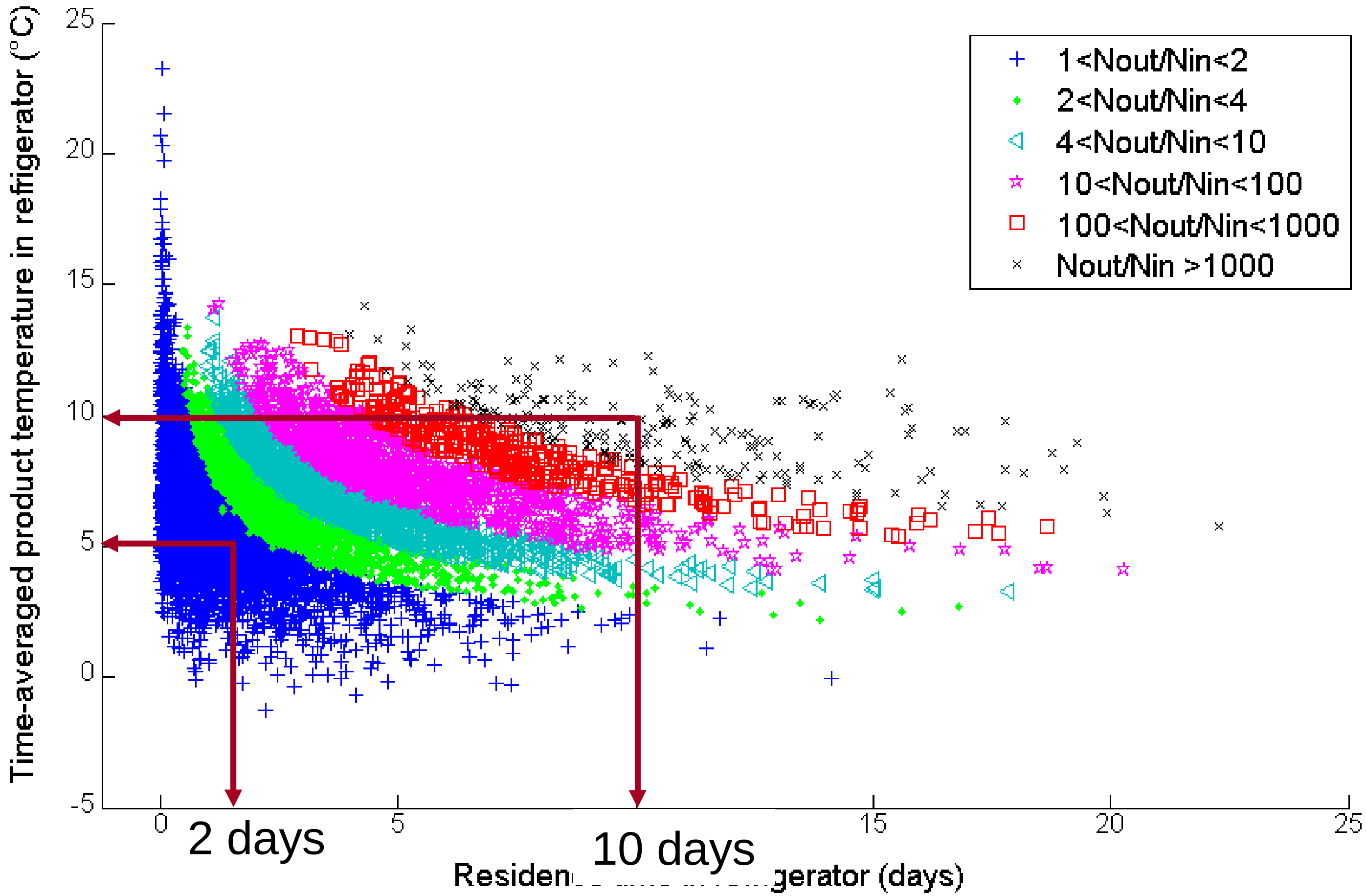
Cumulative distribution of $\log(N_{final}/N_{initial})$ at the end of the cold chain for total product items of 100 000



3. Simulation result and discussion

Domestic refrigerator

Relation between residence time and time-averaged product temperature on N_{out}/N_{in} (number of product items =10 000).



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4. CONCLUSION

- A methodology combining deterministic and stochastic models was proposed. It takes into account various sources of randomness in the cold chain.

- It enables the prediction of the temperature and microbial evolution of a large number of product items.

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Tool for food safety evaluation along the cold chain.

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4. Perspective

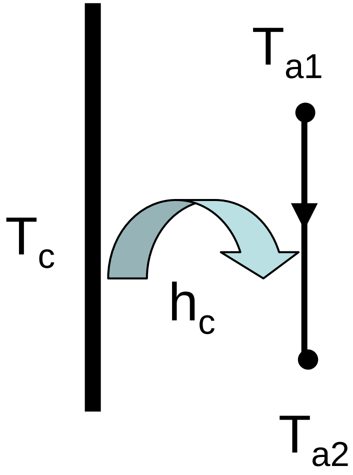
- Development of simplified heat transfer model for refrigerated vehicle and cold room.

- Integration of quality models: microbiological model taking into account the variability of growth parameters.

- Integration of energy models: Improvement of existing refrigeration technologies.

Equation development: steady state

Heat transfer between air and cold wall

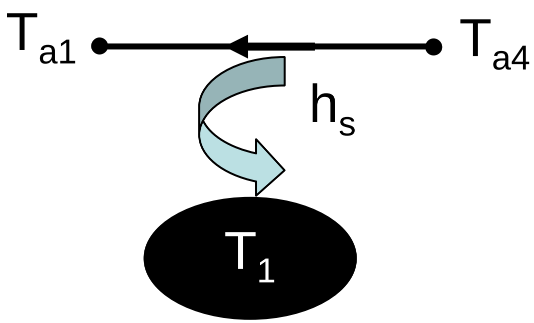


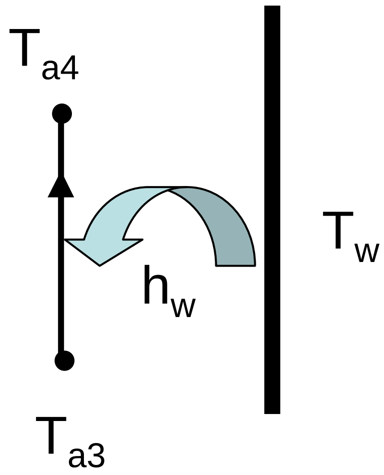
$$\dot{m}Cp\, dT_a = h_c(T_c - T_a)\, dA \Rightarrow \ln\left(\frac{T_{a2}-T_c}{T_{a1}-T_c}\right) = \left(-\frac{h_c A_c}{\dot{m}C_p}\right) \Leftrightarrow$$

$$(T_{a2} - T_c) = \alpha_c (T_{a1} - T_c) \quad \text{----------- (1)}$$

where $\alpha_c = \exp\left(\frac{h_c A_c}{\dot{m}C_p}\right)$

The same reasoning was applied:





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