Modeling and risk assessment

Dr. Roberto Rossi
Dr. Helga Høgåsen

CM 3, 6 July 2011 (project month 14)
Introducing ourselves...

• Dr. Roberto Rossi
  – Assistant Professor @ LDI, WUR, NL
  – Logistics, Decision, Information Sciences

• Dr. Helga R. Høgåsen
  – Researcher @ NVI, epidemiology
  – Risk assessment animal health and food safety
... + multiple levels: stay focused!

- World-wide
- EU
- Country
- Company
- Farm
- Produce

Different PRODUces

Different HAZARDS
Objectives of WP6

“WP6 must lead to a microbiological risk-assessment of fresh produce and derived food products in Europe, taking into consideration effect of packaging, logistics and globalisation in specific. The outcome of the risk assessment will lead to the discussion of acceptable risk on microbiological hazards related to fresh produce and geographical factor (globalisation) and reviewed in the frame of climate change scenarios.”
WP6 – Model and risk assessment

• Task 6.1 (Gro Johannessen): HAS development (months 1-18)
• Task 6.2 (Peter Ragaert): Packaging model (months 1-36)
• Task 6.3 (Roberto Rossi): Logistic model (months 1-36)
• Task 6.4 (Kofitsyo Cudjoe): HAS implementation (19-36)
• Task 6.5 (Helga Høgåsen): RA for fresh herbs (31-43)
• Task 6.6 (Leen Baert): RA for fresh produce and virus/protozoa (31-43)
• Task 6.7 (Liesbeth Jacxsens): RA for fresh produce and bacteria (31-43)
• Task 6.8 (Mieke Uyttendaele): Prioritisation and future trends (43-49)
STILL VERY OPEN!

Interest, contact and discussions are WELCOME!
From farm to consumer

Product flow

Information flow

Retail demand

Producer -> Transport -> DC -> Transport

Retail outlet

Consumer demand

Transport

SPOILAGE

contamination

2/8/17
Simple approach
Simple approach

FARM:
Contamination from human, animals, fertilizer, water…
HSMS (Safety Management) and HAS (Microbiological)
Simple approach

LOGISTICS:
- Time, temperature, processing, packaging…
- Growth and inactivation
Simple approach

Consumer:
Time, temperature, processing → Growth and inactivation
Consumption data, Dose-response → Infection and disease
Complex reality

Variability       Uncertainty       Randomness
Variability, uncertainty and randomness

- **Variability**: normal variation in biological systems
  - reducible by narrowing focus

- **Uncertainty**: lack of knowledge
  - reducible by gaining more knowledge

- **Randomness**: effect of chance
  - non-reducible, but effect depends on variability
Possible approaches

• A risk assessment must be defined
  – at a certain level, and
  – for certain products, and
  – for certain criteria

• Qualitative
  – feasible at global level?
  – feasible for more produces and criteria?

• Quantitative
  – need for modeling and data
Modeling

• Development
  – Logistics
  – Packaging
  – Consumer behaviour
  – Farm (variability distribution based on data + ?)

• Existing
  – ComBase
  – Dose-response
First challenge: common item

• Seems to be solved! (almost)
• Fresh herbs: from importer to consumer
  – basil
• Fresh produce: from producer to consumer
  – lettuce, crop and fresh-cut: Norway, Spain, Belgium, and Brasil
  – strawberries: Brasil, Egypt, Belgium and Norway. Importer and local production
  – raspberries: Serbia and Belgium, with processing / freezing. Importer and local production
Second challenge: choice of pathogen and quality criterium

• Fresh herbs (basil)
  – quality? darkening of leaves? (Paco)
  – Salmonella, E.coli

• Fresh produce:
  – lettuce, crop and fresh-cut: bacteria & virus
  – strawberries: damage and Botrytis cinerea, Salmonella, E.coli
  – raspberries: viruses
**Input data**

- HAS: will result in prevalence/count data for model validation at company level
- HSMS: will result in semi-quantitative multivariable data at company level
- Prevalence data
- Quality criteria: quantitative
- Logistics: volumes, time, temperature, interactions
- ... etc
Complexity

Variability, uncertainty and randomness

SPOILAGE
Types of data determine the outcome

- Rare events vs. stable high levels of contamination
- Convenience sampling vs. representative sampling
- Picking one case at each level becomes complicated ... or limited
- Best/Worst/Most likely data vs. distributions
- Theoretical scenarios
- ”All models are wrong but some are useful”
Risk assessment outcomes

• Risk assessment for a population? (Ex: Europe; Spain)

• Risk assessment for a company? (Ex: SME in project)

• Risk assessment for a case? (Ex: Company-Product-Pathogen-Sample result)
Data needs

• Population risk assessment:
  Data REPRESENTATIVE for the population + acceptable number related to variation

• Company risk assessment:
  Data REPRESENTATIVE for the company + acceptable number related to variation
Food Safety Objective (FSO): The maximum frequency and/or concentration of a hazard in a food at the time of consumption that provides or contributes to the appropriate level of protection (ALOP).

Performance Criterion (PC): The effect in frequency and/or concentration of a hazard in a food that must be achieved by the application of one or more control measures to provide or contribute to a PO or an FSO.

Performance Objective (PO): The maximum frequency and/or concentration of a hazard in a food at a specified step in the food chain before the time of consumption that provides or contributes to an FSO or ALOP, as applicable.

Risk-based Microbiological Criteria?
“in the frame of climate change scenarios”

• Easy to change the inputs, but...

• How do inputs relate to climate change scenarios?
  • ... WP9 deals with crop productivity and distribution, not the effect on microorganisms
From farm to retail
From retail to consumer

"Farm to retail"
### Selected risk assessments in WP6 so far (task 6.5, 6.6 & 6.7)

<table>
<thead>
<tr>
<th>Chain level</th>
<th>Population level</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Produce</strong></td>
<td><strong>Pathogen</strong></td>
</tr>
<tr>
<td>Basil</td>
<td>Enteric (Salmonella/E.coli)</td>
</tr>
<tr>
<td>Fresh-cut lettuce</td>
<td>Enteric (Salmonella, E. coli, O157?)</td>
</tr>
<tr>
<td></td>
<td>Enteric pathogens</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Selected risk assessments in WP6 so far (task 6.5, 6.6 & 6.7)

<table>
<thead>
<tr>
<th>Produce</th>
<th>Pathogen</th>
<th>Involved partners</th>
<th>Produce</th>
<th>Pathogen</th>
<th>Involved partners</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raspberry fresh and processed</td>
<td>Virus</td>
<td>UGent/UB/W U logistics</td>
<td>Raspberry fresh</td>
<td>Virus</td>
<td>UGent</td>
</tr>
<tr>
<td>Strawberry fresh</td>
<td>Enteric (Salmonella, E. coli)</td>
<td>UGent/UB/W U logistics</td>
<td>Strawberry fresh and fresh-cut</td>
<td>Enteric (Salmonella, E. coli)</td>
<td>UGent</td>
</tr>
</tbody>
</table>
Example: Fresh herbs RA

- Basil, from importer to consumer, Salmonella + ?

- Point of export? (Bellaroma)
- Importer in Belgium (John Van Laethem Bellaroma)
- Logistic chain (Stefanie UGent and Roberto WUR)
- Processing (Stefanie UGent and Herba Frost Belgium)
Example: Fresh herbs RA

• Basil, from importer to consumer, Salmonella + ?

• Consumption pattern (WP1 – UGent? ; + ?)

• → Total risk assessment for a major importer to EU (Helga NVI with Stefanie and Roberto)

• → ... + Local assessment in Norway??
Example: Fresh herbs RA

• Effect of irrigation water? fertilizer? HSMS?

• Effect of certification?

• Effect of repeated exposure? (gut immunity)

• Effect of consumer behaviour?
Stratified sampling scheme so far for WP 3 (HSMS-DI + HAS)

<table>
<thead>
<tr>
<th>Involved partners</th>
<th>Lettuce</th>
<th>Leafy herbs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Primary production</td>
<td>Processing</td>
</tr>
<tr>
<td>NVI/Gartnerhallen/NHV - Norway</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>UGent/PIVAL/ALLGRO - Belgium</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>CSIC/Prima Flor/Vegamajor - Spain</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>UFRGS - Brazil</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>UGent/Bellaroma – different countries to Belgium</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Stratified sampling scheme so far for WP 3 (HSMS-DI + HAS)

<table>
<thead>
<tr>
<th>Involved partners in HAS</th>
<th>Raspberries</th>
<th>Strawberries</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Primary production</td>
<td>processing</td>
</tr>
<tr>
<td>UB - Serbia</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>UGent - Belgium</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>UFRGS - Brazil</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RIIL - Egypt</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UGent/Special Fruit/CSIC</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>NVI - Norway</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Microbiological Risk Assessment in Logistic Chain Modeling

Dr. R. (Roberto) Rossi
Prof. J. (Jack) G.A.J van der Vorst

Logistics, Decision and Information Sciences

WAGENINGEN UNIVERSITY
Logistic Modeling

• The aim of our task (6.3) is to develop a simulation model that can assess the impact of different logistics systems designs (scenarios) on specific product quality parameters and total logistics costs, to be used on specific cases in task 6.5, 6.6 and 6.7.

"VEG-i-TRADE will provide a simulation model that can assess the impact of different logistics systems designs (scenarios) on specific product quality parameters and total logistics costs, based on current logistics practices in global fresh produce chains (including distribution time/temperature information) and identification of critical points. With the developed dynamic integrated model for the global logistics chain VEG-i-TRADE will be able to evaluate the impact of different logistics scenarios on logistics costs and product quality parameters. This model can be applied for the risk assessments."

Veg-i-trade proposal, 2010
Global supply chain network
Strategic decisions:
- open/close a hub
- produce/not produce
- serve a given area
- …
Decision support system

Tactical decisions:
- how frequently to deliver
- production cycles
- target stock level at hub
- …
Decision support system

Operational decisions:
- production quantity on a given day
- order quantity at DC
- truck load from DC to Retail outlet
The current model

Product flow
Information flow

Producer → Transport → DC → Transport → Retail outlet → Transport → Consumer

Retail demand

Consumer demand
Modeling Logistic Performance in Quantitative Microbial Risk Assessment

Hajo Rijgersberg,¹ Seth Tromp,¹,* Liesbeth Jacxsens,² and Mieke Uyttendaele²

In quantitative microbial risk assessment (QMRA), food safety in the food chain is modeled and simulated. In general, prevalences, concentrations, and numbers of microorganisms in media are investigated in the different steps from farm to fork. The underlying rates and conditions (such as storage times, temperatures, gas conditions, and their distributions) are determined. However, the logistic chain with its queues (storages, shelves) and mechanisms for ordering products is usually not taken into account. As a consequence, storage times—mutually dependent in successive steps in the chain—cannot be described adequately. This may have a great impact on the tails of risk distributions. Because food safety risks are generally very small, it is crucial to model the tails of (underlying) distributions as accurately as possible. Logistic performance can be modeled by describing the underlying planning and scheduling mechanisms in discrete-event modeling. This is common practice in operations research, specifically in supply chain management. In this article, we present the application of discrete-event modeling in the context of a QMRA for Listeria monocytogenes in fresh-cut iceberg lettuce. We show the potential value of discrete-event modeling in QMRA by calculating logistic interventions (modifications in the logistic chain) and determining their significance with respect to food safety.

KEY WORDS: Discrete-event simulation; fresh-cut vegetables; Listeria monocytogenes; logistic performance; quantitative microbial risk assessment
Quality/Safety change models (Task 6.2)

\[ P(t) = P_0e^{rt} \]
A global logistic chain
Research overview

Managerial Decisions (scenarios)

Data

Logistics

Risk

Constraints

KPIs

?
Methods

Simulation
• Discrete event simulation in Java
• SSJ Library (Stochastic Simulation in Java)

Optimization
• Stochastic Constraint Programming
• Sample-based filtering

Both
• Find “good” management decisions (by properly accounting for risk and uncertainty) and then assess them to the desired level of confidence by using an advanced simulation model
Optimal Ordering Policies for Perishable Inventory

“Since, except for small problems, the actual computation of optimal policies (in stochastic inventory systems involving perishables) in the dynamic problem requires the solution of a multidimensional dynamic program, such computations are not realizable” [1]

Many authors agree that one key area for further investigation is the comparison of various simple non-optimal policies and the determination of approximate computational methods [2]

Drawbacks of existing models

• As pointed out by Lütke Entrup (2005), in several Advanced Planning Systems shelf-life aspects of food are not adequately incorporated.

• Existing APS employ very simple “order-up-to-level” policies at the producer and at the retailers.

• These policies do not consider the available mix of stock ages while computing the order quantity.

• This immediately translates to poor service level performances and an increased chance of high bacteria count at consumer level, due to the nervousness of the control action.
Retailer inventory
Retailer/Producer Inventory

Production (leadtime)

Order up to level

Distribution (leadtime)

Inventory position

Inventory level
Discrete event simulation (SSJ Library)

- Current day: 364
- mSecs per day: 55
- Objects created: 39158
- Objects disposed: 38363

Histograms showing:
- Listeria monocytogenes count at consumption over 14378 observations
- Product age at consumption over 14378 observations
- Product quality at consumption ranging from 0 (max quality) to 5 (unacceptable) over 14378 observations
Shorter production cycles
Discrete event simulation (SSJ Library)

Current day: 364
mSecs per day: 49
Objects created: 31687
Objects disposed: 30961

Listeria monocytogenes count at consumption over 15453 observations

Product age at consumption over 15453 observations

Product quality at consumption ranging from 0 (max quality) to 5 (unacceptable) over 15453 observations
Longer cycles: a simple order-up-to-policy is not adequate

non-negligible interaction among different ages of stock!
A hybrid simulation/optimization approach
Stock-age dependent policy

K. Pauls, R. Rossi, R. Haijema, J. van der Vorst, E. Hendrix,

“Computing Replenishment Cycle Policy Parameters for Perishable Items with Non-Stationary Stochastic Demand”,

in preparation for OR Spectrum
Discrete event simulation (SSJ Library)
stock-age-dependent-policy (3 days at the retailer)
Discrete event simulation (SSJ Library)
stock-age-dependent-policy (expire in 6 days, at least 1 day at the retailer)
Simulation of global supply chain network

risk assessment at trade/company level
Case 1: Strawberry

- **Industrial partner**
  - Special Fruit, Meer, Belgium

- **Import areas**
  - Egypt
  - Spain
  - Netherlands

- **Quality**
  - growth of Botrytis cinerea

- **Safety**
  - Salmonella, E. Coli

- **Academic partner**
  - UGent (Liesbeth, Peter & Paco)
  - UBelgrade (?)
  - WUR (Roberto)

models not available yet
Quality (Straberries)

- Botrytis cinerea in strawberries (Hertog et al 1999)
- Percentage of strawberries affected:
  \[ \frac{dN}{dt} = Rel_{MR} \times k_s \times N \times \left( \frac{(N_{max} - N)}{N_{max}} \right) \]
- Model includes the effect of temperature \( (k_s) \) and storage atmosphere \( (Rel_{MR}) \).
Case 2: Raspberries

• Industrial partners
  – ADK, Serbian producers

• Import areas:
  – Serbia

• Quality
  – moulds

• Safety
  – Salmonella, E. Coli

• Academic partner
  – UBelgrade (Andreja)
  – UGent (Anne, Peter & Paco)
  – WUR (Roberto)

  *models not available yet*
Case 3: Basil

• Industrial partner
  – Bellaroma (John van Laethem)

• Import areas
  – Israel (plane)

• Quality
  – Darkening of leaves

• Safety
  – Salmonella, E. Coli

• Academic partner
  – NVI ? (Helga)
  – UGent (Peter & Paco, Stephanie)
  – WUR (Roberto)
Quality (Basil)

• Darkening of basil leaves
  – Interview of John Van Laethem (Bellaroma) with the suppliers
  – It is a preharvest problem and therefore out of the scope of this WP
Safety (Basil)

• Growth of Salmonella & pathogenic E. coli on fresh-cut leafy vegetables
  – Model of Koseki & Isobe (2005):
    • Only for fresh-cut iceberg lettuce.
    • E. coli O157:H7 & Salmonella.
    • Takes into account lag phase and maximum population density.
    • Predicted growth rate is too high comparing it with literature data.
  – Model of Danyluk & Schaffner (2011):
    • Leafy greens.
    • E. coli O157:H7
    • Doesn’t takes into account lag phase and maximum population density.
    • Predicted growth rate is based in literature data.
Case 4: Fresh cut lettuce

- Industrial partner
  - Primaflor, Vega Major
- Import areas
  - Europe
- Quality
  - Enzymatic browning
  - Growth spoilage microorganisms
- Safety
  - Salmonella, E. Coli (O157)

- Academic partner
  - Murcia (Ana)
  - UGent (Peter & Paco, Stephanie)
  - WUR (Roberto)
Quality (Fresh-cut Iceberg lettuce)

• Available models:
  - Piagentini et al. (2005): for chlorine-washed product (own experimental data).

• Limitations:
  Deterioration rate is over-predicted because the effect of storage atmospheres is not included in these models.

• Next step:
  Integration of the effect of storage atmospheres.
Safety (Fresh-cut Iceberg lettuce)

• **Growth of natural microbiota, UGent Model (2011):**
  • Model based in literature data, suitable for lettuce and other fresh-cut leafy vegetables.

• **Limitations**
  • Lag phase at low temperatures is not included in the model.
  • Possible relationship between temperature and maximum population density is not included.
  • Not validated for a supply chain temperature profile.
Papers that acknowledge veg-i-trade

Published

  ISI impact factor(2009): 2.093

  ISI impact factor(2009): 1.318

  ISI impact factor(2009): 0.803

  ISI impact factor(2009): 2.068
Papers that acknowledge veg-i-trade

Submitted

- R. Rossi, B. Hnich, S. A. Tarim and S. Prestwich, "Finding (α,ϑ)-solutions via Sampled SCSP", to be presented at the International Joint Conference on Artificial Intelligence, IJCAI 2011, Barcelona, Spain


- B. Hnich, R. Rossi, S. A. Tarim and S. Prestwich, "Filtering Algorithms for Global Chance-Constraints", in preparation for Artificial Intelligence
  ISI impact factor(2009): 3.036
Papers that acknowledge veg-i-trade Working

- R. Rossi and J.G.A.J van der Vorst, "Connection and Integration of Food Supply Chain Design and Microbiological Risk Assessment", working paper


- S. Prestwich, S. A. Tarim, R. Rossi, B. Hnich, "A New Forecasting Method and Error Measure for Intermittent Demand", in preparation for the International Journal of Forecasting
  ISI impact factor(2009): 1.064

- R. Rossi, S. A. Tarim, B. Hnich and S. Prestwich, "Sample-based Filtering for Global Chance-constraints", in preparation for Artificial Intelligence
  ISI impact factor(2009): 3.036

- R. Rossi, "Augmenting the lot sizing quantity for perishable items", research note, Wageningen University, 2010
Related Works


Conclusions

• We discussed a **discrete event simulation model** for **microbiological risk assessment** in food chains.

• Our model builds upon the work of Rijgersberg et al. by introducing **advanced inventory control policies** in a simulation environment and by assessing the **impact** of these rules on some selected **KPIs**.

• Our model is based on an open source DES library (SSJ) and on an inventory optimization algorithm for perishable stocks.

• To the best of our knowledge, our approach **integrates simulation and optimization in a novel way**.

• We also discussed four case studies that will employ the model discussed for conducting a quantitative microbial risk assessment at trade/company level.
A final remark…

Thank you!
Discussion