# Simulating fresh food supply chains by integrating product quality

Magdalena Leithner and Christian Fikar

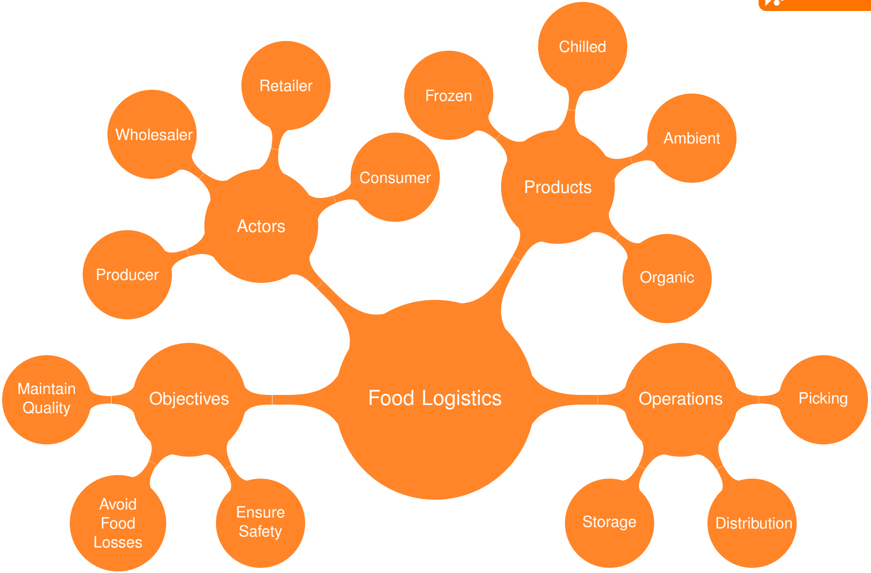
Institute of Production and Logistics
BOKU - University of Natural Resources and Life Sciences, Vienna

OR2017 - Berlin, September 2017

# Introduction

- In Europe, nearly one third of produced fresh fruits and vegetables (FFVs) gets lost along postharvest handling (Jedermann et al., 2014).
- Supply chain management has gained importance to strengthen competitiveness in the fresh food sector and to reduce food and quality losses (van der Vorst et al., 2008).
- Supply chain management in food logistics is challenged by
  - rising world population
  - ongoing urbanization
  - a shift to more fresh diets (Lundqvist et al., 2008)

# Introduction



# Background

**The logistics of perishables differs significantly from non-perishable items**

- Limited shelf life
- Various sources of uncertainties
  - Biological variance
  - Unpredictable weather conditions
  - Seasonable fluctuating supply and demand
- Quality decrease over time, mostly depending on temperature and environmental conditions.

# Background

**Operational research methods present powerful tools to handle the complexity of food logistics**

- Linear programming is the predominant modelling technique (Soto-Silva et al., 2016)
- Various works use simulation methods (Borodin et al., 2016)
  - Incorporate uncertainties
  - Integration of food quality models
  - Supply and market uncertainties taken into account
- Lacking consideration of changes in product quality and interdependencies between quality and chain design (van der Vorst et al., 2008)

## Problem Description

- Dynamic problem with uncertain supply and demand
- Immediate pre-cooling after harvest needed
- Product qualities subject to storage & transport conditions
- Objective
  - minimize food losses
  - minimize travel durations
  - maximize service levels
- Decisions
  - Which retailer is delivered by whom?
  - Direct or indirect deliveries?
  - Which product should be assigned?

# Decision Support

**Decision Support System (DSS)**
Development of a DSS to reduce food waste along regional fresh fruit supply chains

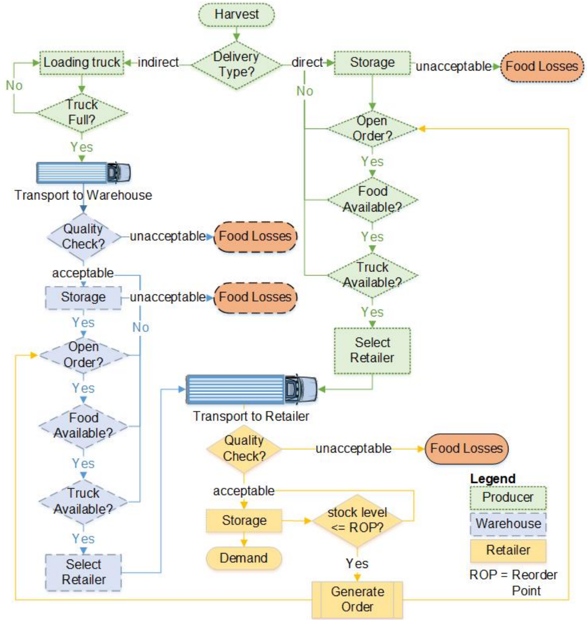
- Combining geographic network data with simulation and optimization methods
- Modelling food decay based on quality functions, storage and transport temperatures
- Simulating demand request based on Poisson-distributed arrival rates
- Integration of stock rotation schemes

## Discrete Event Simulation

- Regional fresh fruit supply chain
  - Direct deliveries (producers to retailers)
  - Indirect deliveries (producers to warehouse to retailers)
- Various temperatures along supply chain
- Quality updated continuously

| **Components** | **Representation** |
|---|---|
| Perishable Item | perishable product with implemented specific quality attribute |
| Producer | produces perishable product with biological variations in quality |
| Batch | implemented to collect perishable items for one truck load |
| Truck | climate controlled truck (producers) |
| Warehouse | cooled warehouse |
| Warehouse Truck | climate controlled truck (warehouse) |
| Retailer | end destination of perishable items where consumers meet their demand |

# Decision Support



# Decision Support

**Modelling the quality of fresh fruits and vegetables**
Generic Keeping Quality Model implemented (Tijskens and Polderdijk, 1996)

- Calculates keeping quality as a function of time, temperature, reaction rate and initial quality.
- 'Keeping Quality' is the time until a commodity becomes unacceptable.
- Limit of acceptance depends on
  - initial quality
  - intrinsic characteristics
  - consumer's perceptions
- At constant environmental conditions, known initial quality and a defined quality limit, always the same quality attribute hits the acceptance limit first.

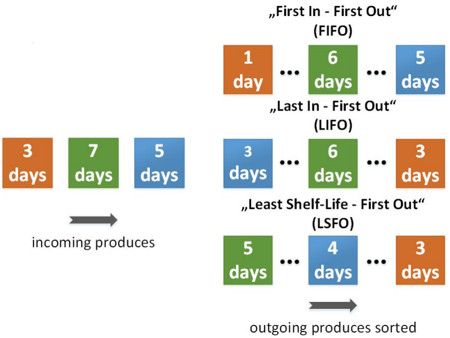
**Distribution Strategies**

- Three strategies are compared on how to fulfil incoming replenishment orders
  - serving orders in accordance to arrival time
  - by distance to the retailer's location
  - randomly
- Full truckloads are assumed

# Decision Support

## Stock Rotation Schemes (SRS)

- SRS aim to limit food losses
- Need to be adapted to product characteristics and requirements
- Implemented schemes




magdalena.leithner@boku.ac.at

# Computational Experiments

### Test Settings

- Investigation of the impact of (i) delivery strategies, (ii) distribution strategies and (iii) stock rotation schemes on
  - Food losses (items)
  - Travel durations (h)
  - Cycle service level (%)
- 100 replications per setting and averages are reported
- Developed with AnyLogic 8.1.0 facilitating GraphHopper and OpenStreetMap for real-world routing network

# Computational Experiments

**Study Area**

A regional strawberry supply chain in Lower Austria is modelled.

- 10 strawberry farmers in Lower Austria (GLOBALG.A.P database)
- 1 warehouse in the South of Vienna
- 23 retail stores in the biggest cities in Lower Austria
- Simulation horizon: 2 weeks

# Computational Experiments

## Study Area

# Computational Experiments

## Quality Losses of Strawberries

- Short shelf life (5-7 days)
- Generic Keeping Quality Model of Tijskens and Polderdijk (1996)
  - Keeping Quality limited by spoilage rate (Schouten et al., 2002)
  - Batch Keeping Quality

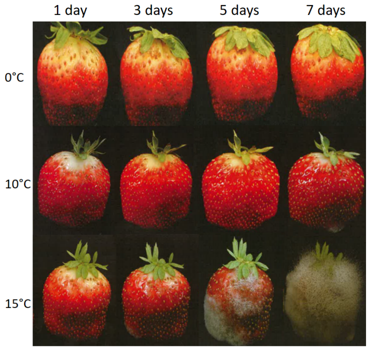



Figure based on Nunes, M.C. do N., 2008. Color atlas of postharvest quality of fruits and vegetables, 1.edn. Blackwell Publ, Ames, Iowa.

## Handling temperatures along Strawberry Supply chain

| | **Temperature (°C)** | | | | |
|---|---|---|---|---|---|
| **Location** | Hertog et al., 1999 | Hertog et al., 1999 (closed cold chain) | Nunes et al., 2014 (blackberries) | Nunes et al., 2003 | **in this work** |
| Field | — | — | **23.9** | — | 23.9 |
| Producer | 12 | **4** | — | 3 | 4 |
| Warehouse | 4 | 4 | 1.1 | **3** | 3 |
| Transport | 10 | **4** | 0.6-0.7 | 3 | 4 |
| Retailer | 16 | 4 | 6.7 | 20 | 10 |

# Preliminary Results

## Experiment: Stock Rotation Schemes

Impact of distribution strategy and stock rotation schemes on food losses (indirect deliveries - 2 warehouse trucks).

| **Delivery** / **SRS** | FirstOrder | NearestRetailer (FoodLosses) | RANDOM |
|---|---|---|---|
| LSFO | 0 | 0 | 0 |
| FIFO | 595 | 0 | 620 |
| LIFO | 18532 | 11925 | 18567 |

- Four warehouse trucks substantially reduce food losses under LSFO and FIFO whereas higher amounts of food losses occur under LIFO.
- If less trucks are available, the LSFO approach produces less food losses than the FIFO approach.

# Preliminary Results

## Experiment: Distribution strategy

Impact of distribution strategy on service level, travel duration and food losses (indirect deliveries - 4 warehouse trucks).

| **Delivery** | FirstOrder | NearestRetailer | RANDOM |
|---|---|---|---|
| ServiceLevel (%) | 86 | 92 | 85 |
| TravelDuration (h) | 919 | 894 | 921 |
| FoodLosses (items) | 2164 | 1013 | 2292 |

Regional deliveries (NearestRetailer) positively influence travel duration, the amount of food losses and service levels.

- Drawback: stores unevenly served

## Conclusion

- Integration of food quality with delivery strategies in food supply chain simulations are of importance
- Applying the LSFO substantially reduces food losses
- Regional deliveries reduce travel distances, food losses and improve product availability

## Future Work

- Integration of replenishment strategies
- The assignment of low quality products to shorter routes
- Expending the product range to consider interactions among various FFVs
- Improve vehicle routing algorithms

**University of Natural Resources and Life Sciences, Vienna**

Department of Economics and Social Sciences
Institute of Production and Logistics

Magdalena Leithner

Feistmantelstraße 4, A-1180 Vienna
magdalena.leithner@boku.ac.at

This work was funded by the Austrian security research programme MdZ of the Federal Ministry for Transport, Innovation and Technology (bmvit).

# References


- Borodin, V., Bourtembourg, J., Hnaien, F., Labadie, N., 2016. Handling uncertainty in agricultural supply chain management: A state of the art. European Journal of Operational Research 254, 348-359.
- Fredriksson, A., Liljestrand, K., 2015. Capturing food logistics: a literature review and research agenda. Int. J. Logist. Res. Appl. 18, 16-34.
- Hertog, M., Boerrigter, H.A.M., van den Boogaard, G.J.P.M., Tijskens, L.M.M., van Schaik, A.C.R., 1999. Predicting Keeping Quality of strawberries (cv. 'Elsanta') packed under modified atmospheres. an integrated model approach. Postharvest Biology and Technology 15, 1-12.
- Jedermann, R., Nunes, M.C.N., Uysal, I., Lang, W., 2014. Reducing food losses by intelligent food logistics. Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Angineering Sciences 372, 20130302.
- Lundqvist, J., de Faiture, C., Model, D., 2008. Saving Water: From Field to Fork - Curbing Losses and Wastage in the Food Chain. SIWI Policy Brief, Stockholm.
- Nunes, M.C.N.,Nicomento, M., Emond, J.P., Melis, R.B., Uysal, I., 2014. Improvement in fresh fruit and vegetable logistics quality: berry logistics field studies. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 372, 20130307.
- Nunes, M.C.N., 2008. Color atlas of postharvest quality fruits and vegetables, 1. ed. Blackwell Publ. Ames, Iowa.
- Nunes, M.C.N., Emond, J.P., Brecht, J.K., 2003. Quality of strawberries as affected by temperature abuse during ground and in-flight and retail handling operations, Acta Horticulturae.
- Schouten, R.E., Kessler, D., Orcaray, L., van Kooten, O., 2002. Predictability of keeping quality of strawberry batches. Postharvest Biology and Technology 26, 35-47.
- Soto-Silva, W.E., Nadal-Roig, E., González-Araya, M.C., Pla-Aragones, L.M., 2015. Operational research models applied to the fresh fruit supply chain. Eur. J. Oper. Res. 251, 345-355.
- Tijskens, L.M.M., Polderdijk, J.J., 1996, A generic model for keeping quality of vegetable produce during storage and distribution. Agric. Syst. 51, 431-452.
- van der Vorst, J., Tromp, S.O., van der Zee, D.J., 2009. Simulation modelling for food supply chain redesign: integrated decision making on product quality, sustainabiity and logistics. International Journal of Production Research 47, 6611-6631.