Workshop of the Cool Chain Association

Temperature measurements

– when, where and how? -

Knivsta, Sweden, 13th and 14th November 2006

‘Project Intelligent Container’

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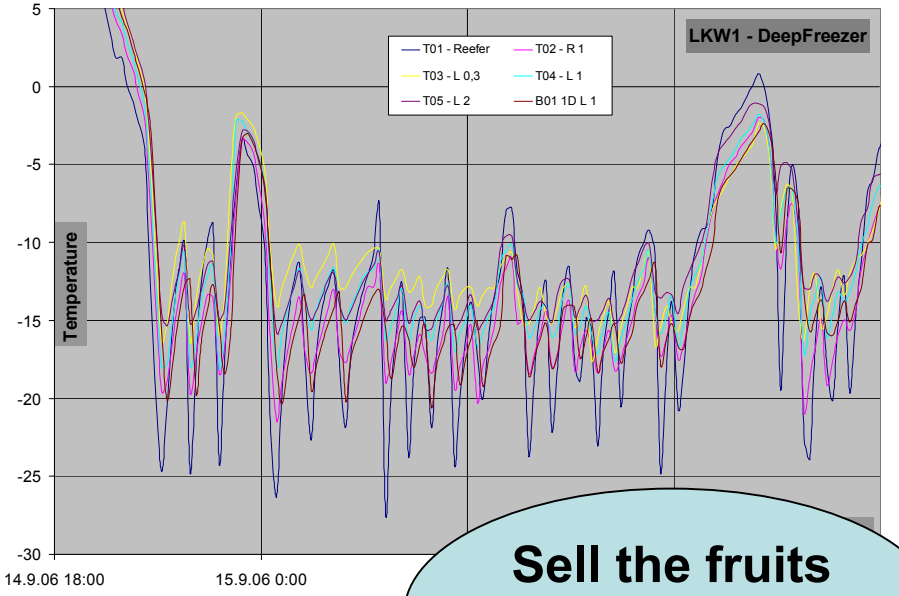
Project Intelligent Container

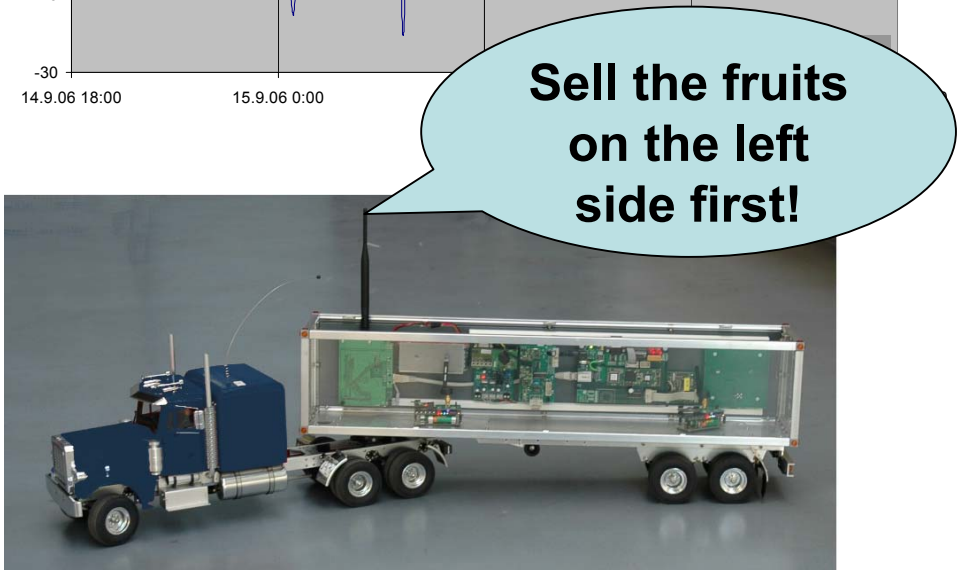
- Current study on spatial temperature distribution
- 3 different logger types

- Automated supervision system for transports of perishable goods
- Concept, software and prototype

Aim of the project

- Concise supervision
- Study on spatial temperature profiles
- Precise and individual shelf life prediction
- Automated temperature data evaluation and on-the-road access





Literature survey

- Articles on spatial temperature profiles
  - 5 Groups found (2004-2006)
  - 1 Simulation, 2 laboratory, 2 sea transports
  - Focus on containers / sea transports
  - Used wired temperature probes and recording unit (50 to 100 sensors)

- Results
  - Spatial deviations of 5 °C or more
  - Effects on freight quality:
    Firmness of Kiwis differs by factor 2 ...3

Literature references

- [Mou04] Moureh, J. ; Flick, D.: Airflow pattern and temperature distribution in a typical refrigerated truck configuration loaded with pallets In: International journal of refrigeration, Bd. 27 (2004), 5, S. 464-474
- [Punt05] Punt, H. ; Huysamer, M.: Supply Chain Technology and Assessment - Temperature Variances in a 12 m Integral Reefer Container Carrying Plums under a Dual Temperature Shipping Regime. In: Acta horticulturae, (2005), 687, S. 289-296.
- [Rod06] Rodriguez-Bermejo, J. et al., Thermal study of a transport container, Journal of Food Engineering (2006), http://dx.doi.org/10.1016/j.jfoodeng.2006.06.010
- [Tan03] Tanner, D.J.; Amos, N.D.: Heat and Mass Transfer - Temperature Variability during Shipment of Fresh Produce. In: Acta horticulturae, (2003), 599, S. 193-204.
- [Tan04] Tanner, D. and Amos, N.D.: Modelling product quality changes as a result of temperature variability in shipping systems. International Congress of Refrigeration 2003, Washington, D.C.
- [Wild05] Y. Wild, R. Scharnow and M. Rühmann, Containerhandbook, Vol. 3, Gesamtverband der Deutschen Versicherungswirtschaft e.V. (GDV), Berlin, 2005

Own measurements

- Goals
  - Verify magnitude of temperature deviations
  - Investigate temperature profiles for trucks
  - Extended data base for layout of autonomous supervision system
  - 'Quick to install' toolbox for measurements at partner companies
- Questions
  - How can we achieve precise supervision of individual goods with the minimal number of sensors?
  - How many measurement points are needed and where to place them?

Measurement of temperature profiles

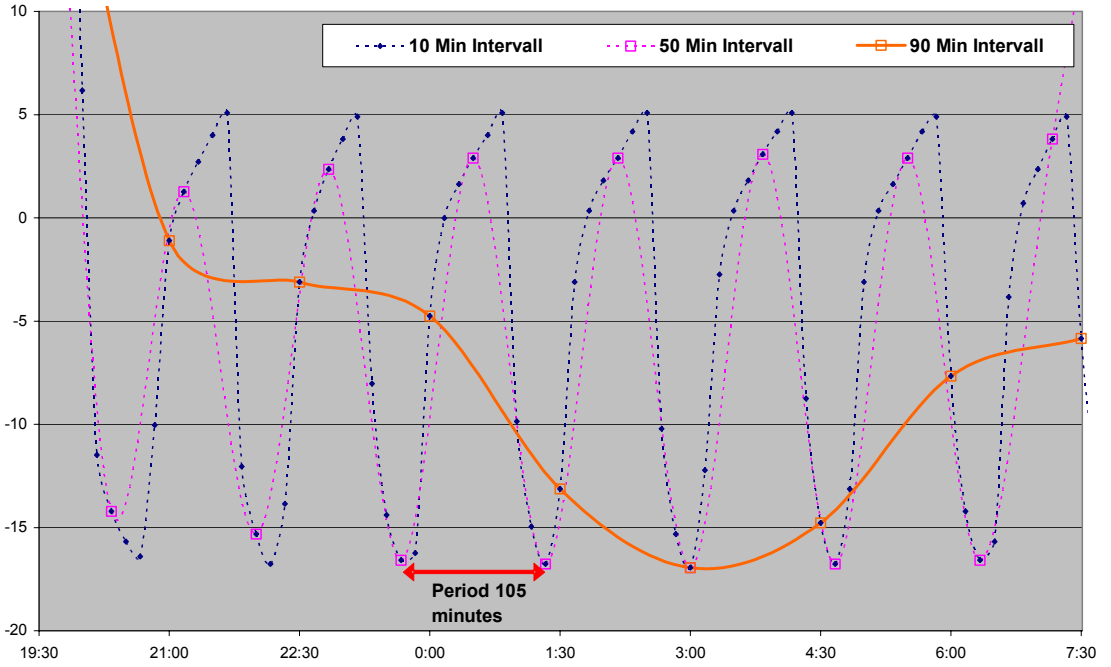
- Miniaturized data loggers
  - 2 RFID loggers and 1 with electrical interface under evaluation
  - Tests in climatic chamber
- Accuracy:
  - High accuracy required to detect spatial gradients and for accurate shelf life prediction (<< 0.5 °C)
  - Loggers often better than specified maximum error
  - standard deviation: 2/3 of all values are inside $\pm\delta$

Comparison of different data logger types

Type	KSW	TurboTag	iButton
Data points	700	700	4000
Battery	±	+	++
Resolution	~ 0.3 °C	~ 0.2 °C	0.0625 °C
Tested Accuracy	± 0.4 °C	± 0.18 °C	< ± 0.1 °C
Interface	RFID	RFID	One-Wire
Price	Low cost	Low cost	Middle
Handling	+	++	-
Software	±	++	±

Measurement intervals

- Take care of sampling theorem
  - Absolute minimum: 2 data points per oscillation period
- Time constants and influence of walls
- Typical Interval
  - 10 minutes in our experiments



Type	Ventilated Air	No ventilation
Turbo Tag	2	6
KSW	1	3
iButton	2	12

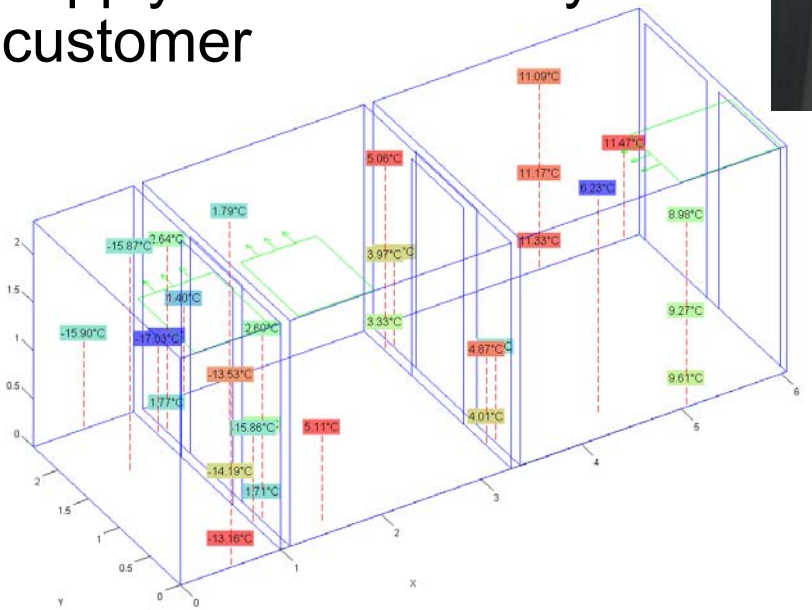
(Time constant in minutes, loggers mounted on plastic plate)

Partner Companies

- Rungis Express
- CCG Holding AG and CCG FRA
- Sealed Air Corporation
- Gildemeister
- Carl Schröter (Insurance company)
- Bremer Research Cluster for Dynamics in Logistics

Test at trucks for express delivery

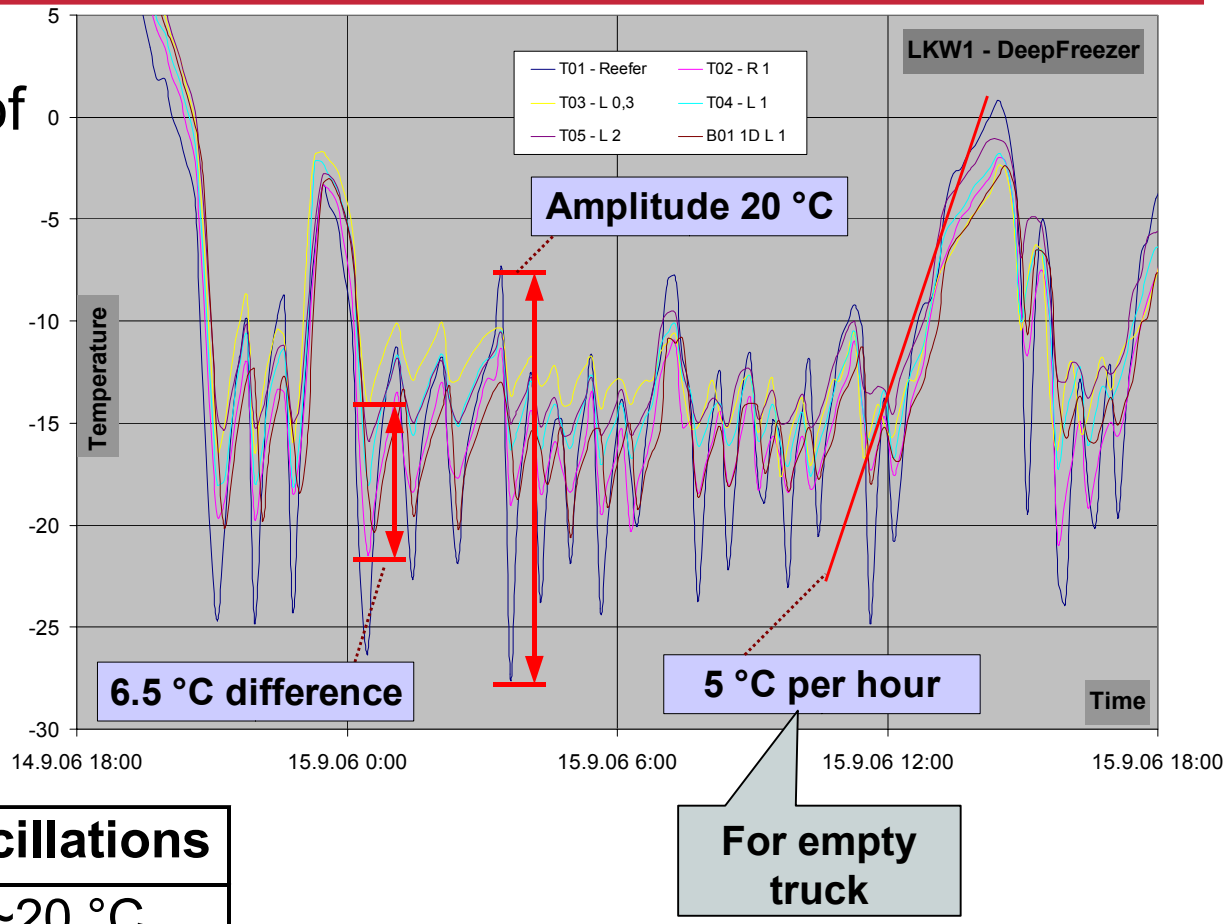
- First tests at Rungis Express (trading company for luxury and exclusive food)
- Focus on one part of the supply chain: Delivery to customer



- Trucks equipped with 40 loggers over 3 temperature zones
- Report of tendencies observed in our experiments

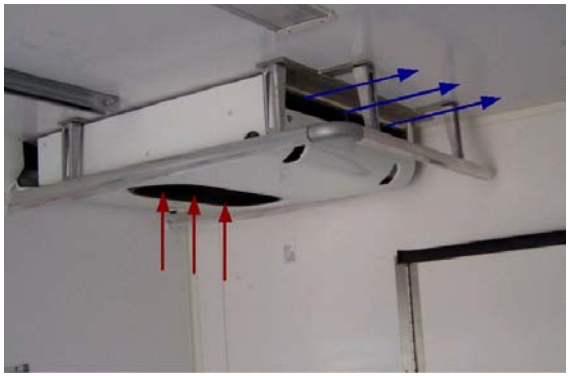
Oscillations by reefer cycles

- On/off-cycles of the reefer causes large fluctuations of temperature
- Oscillations almost everywhere present

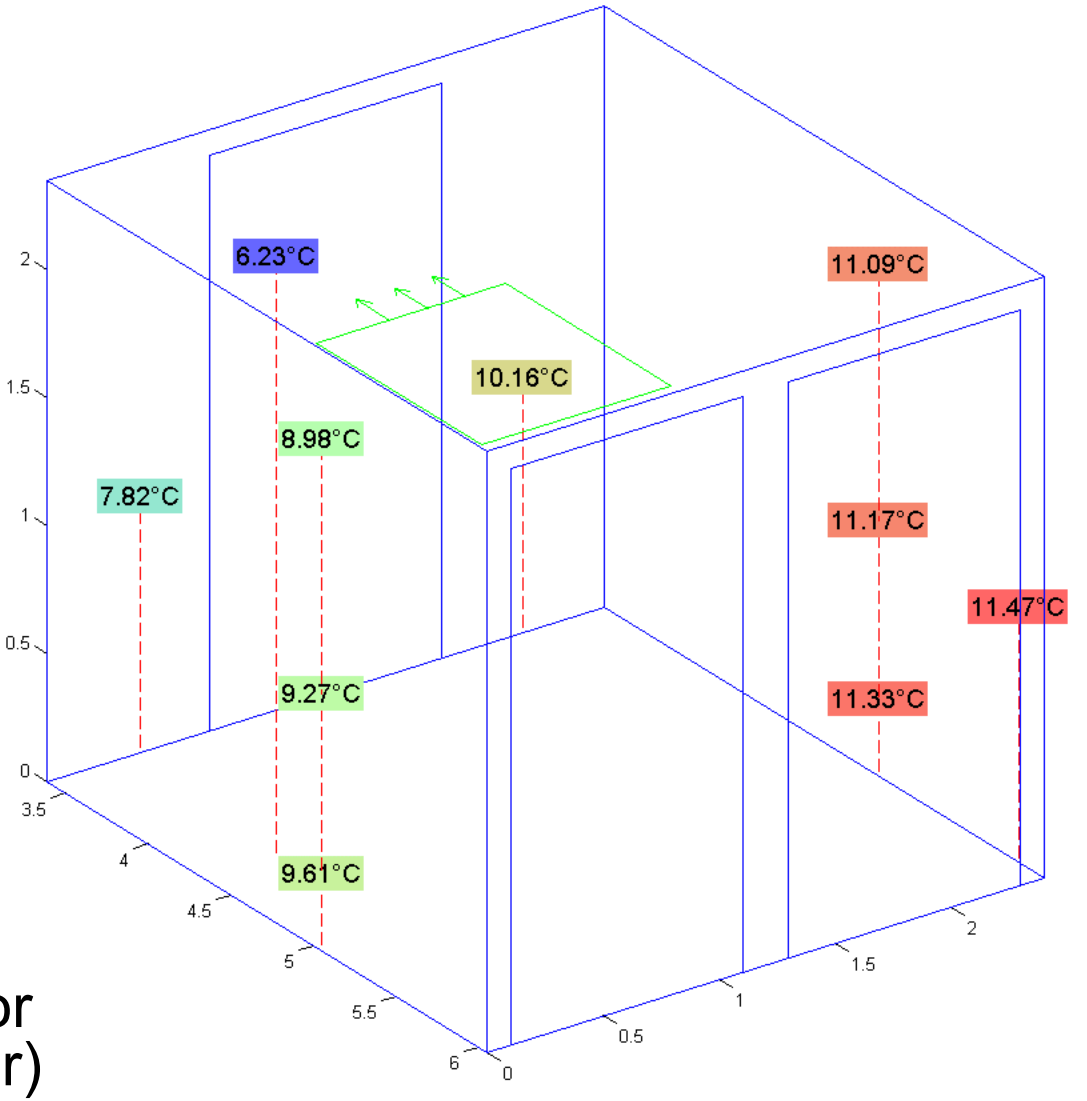


Point	Oscillations
Reefer Air	~20 °C
Walls	3°C to 15 °C
Inside Freight	1 °C

Influence of reefer position

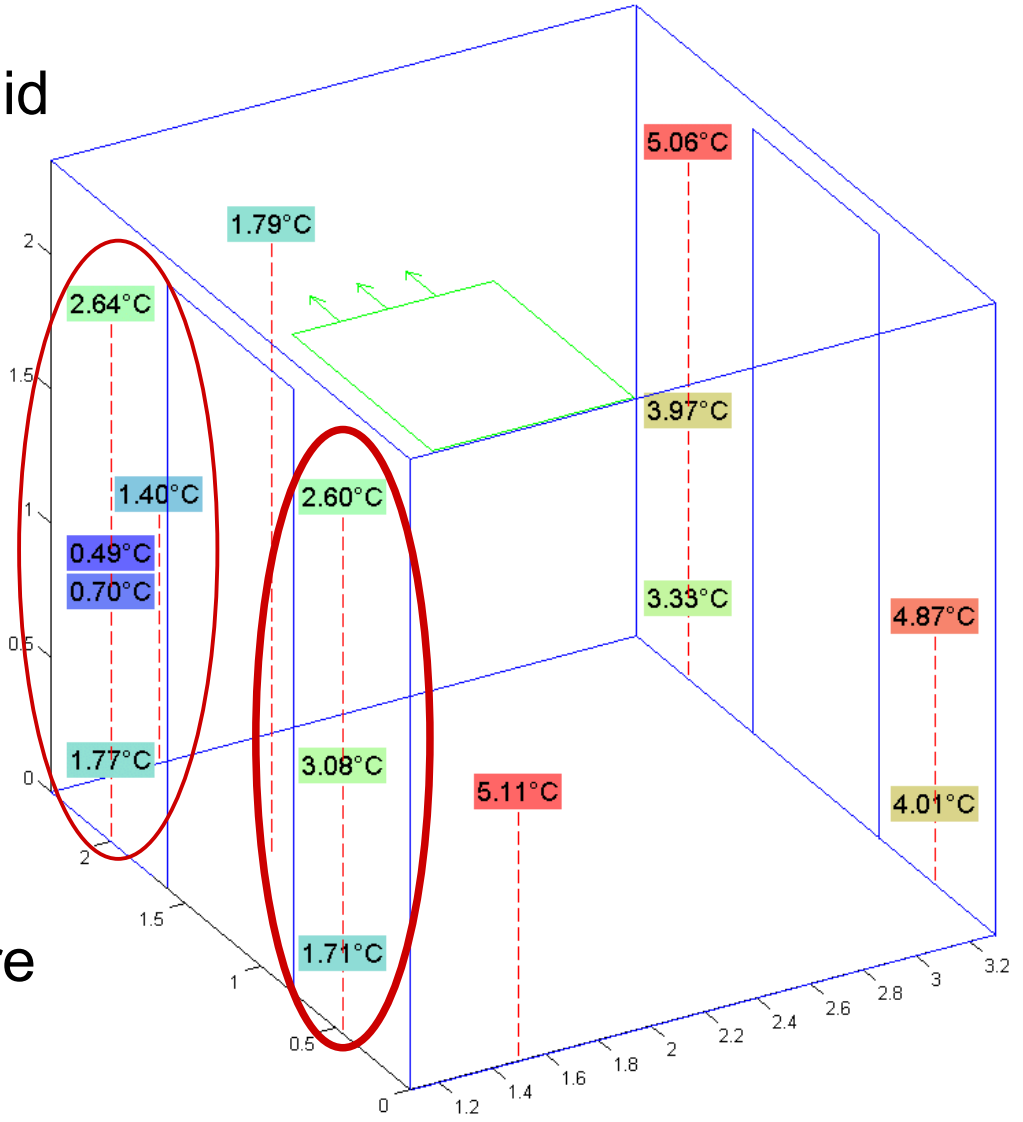


- Each compartment has a separate fan unit
- Plot of average value over 8 hours (separately for each logger)
- Reefer side 2 °C colder (mounted either left wall side or close to room divider)



Middle compartment

- 'Reefer rule' only valid for groups / average of loggers
- Single loggers behave 'chaotic'
- Replacing one sensor by averaging is neighbors not possible
- Afternoon: Temperature 0.4 °C to 1 °C higher (ambient temperature change of ~10 °C)



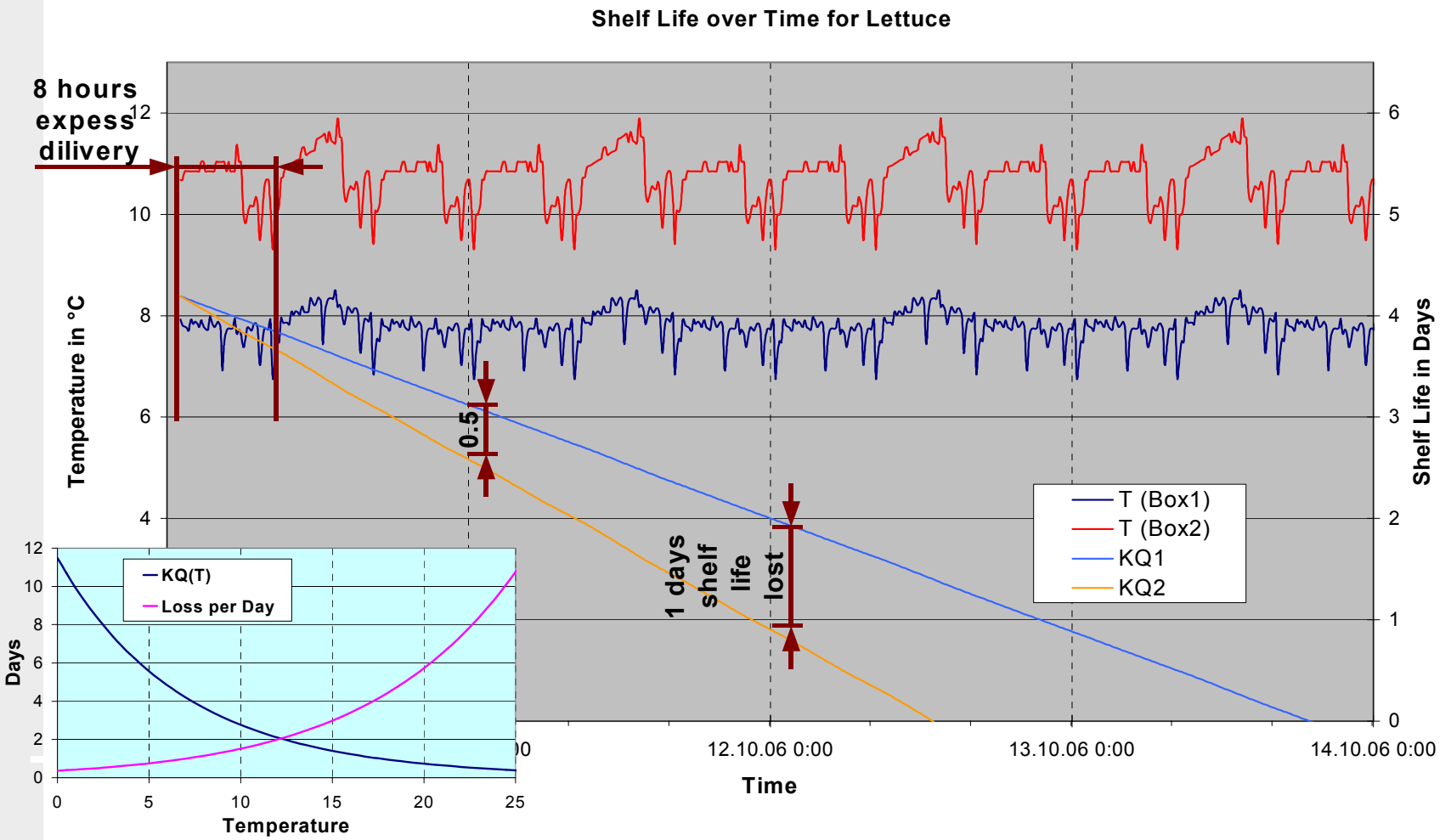
Effects on freight temperature

- Measurements inside freight boxes
  - Boxes / cartons equipped with 2 logger (wall / corridor side)
  - 5 boxes vegetables and 4 boxes in fish compartment
- Observed deviations
  - 3 °C difference between coldest and warmest position inside boxes
  - 0.5 ... 1.5 °C difference inside box

Vegetables	Temperature
Min	7.7 °C
Max	10.6 °C
Difference	2.9 °C

(Average over time for each logger separately calculated)

Effects on shelf life



Temperature profiles

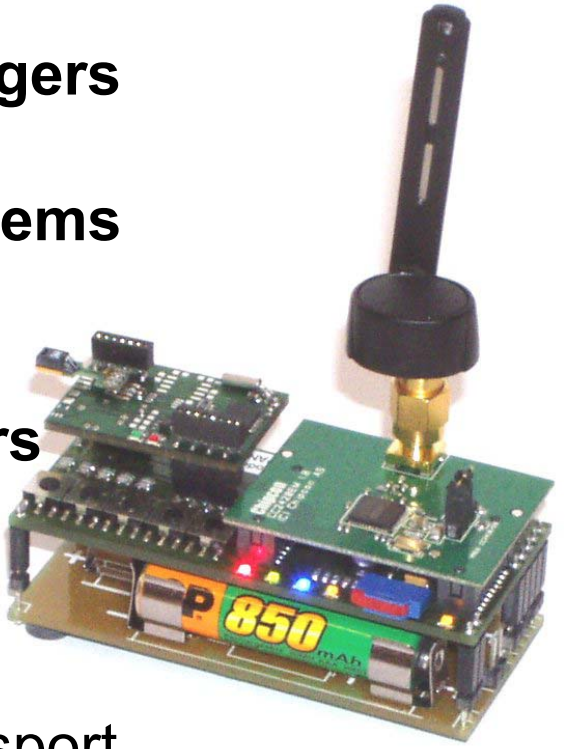
- Observations in first tests
  - Variance of temperature inside cargo hold verified
  - Difference between coldest and hottest point 2.5 ° ... 6 °C
  - Mayor influence factors
    - on/off cycles (peaks up to 15°C)
    - reefer position / air flow (2°C)
    - ambient temperature (0.4 °C ... 1 °C)
    - door opening
- Conclusions
  - Local temperature deviations cause differences in shelf life
  - Multi-point measurement required for concise supervision and correct shelf life prediction
  - Temperature profiles could not be reduced to a simple model
  - Very good data compression required to transfer 'chaotic' temperature data over mobile communication

Additional measurements

- Deeper analyses of spatial temperature profiles
  - Still necessary
  - More measurements with focus on core temperature required
  - Cover complete supply chain
- Questions for future measurements
  - Are wall measurements sufficient to predict freight core temperature?
    - (Wall sensors = multiple use, freight sensors get frequently lost)
  - How many measurement points are needed and where to place them?
    - Is it possible to subsume the temperature profiles of single boxes into groups or clusters for joint use of sensor facilities and shelf life calculation?

On- and offline supervision

'Cheap' RFID-loggers versus telemetric systems



Data loggers

- Cheap, single use might be possible
- Only offline, manual reading at transshipment points
- Limited storage

Wireless sensors

- Must be returned to owner / stay in means of transport
- Online / On-road-access to current freight conditions
- Development of partner institute

ITEM
Institut für Theoretische Elektrotechnik und Mikroelektronik

The need for online information

- If there is a quality problem, early information is of very high worth
  - Inform customer
  - Order replacement
    - The more time available, the less expensive gets a replacement purchase
  - Offer only goods to customer that will arrive in proper quality
  - Redirect truck as long as they are on the road
    - Example: 3 out of 10 trucks with strawberry from Spain have a quality problem, redirect the reaming 7 to satisfy each customer at least partly

Concept of the intelligent container

- Entirely automated system for transport supervision
  - Reduced scale prototype
  - Online access over mobile communication
  - Miniaturized sensor notes to capture spatial temperature profile
  - Configuration by RFID
  - Electronic consignment note as software agent
  - Shelf life modelling / data compression inside the truck
  - Gas sensors for agricultural products planned (Ethylene)

The framework of the CRC637

Faculty 1 – Physics / Electrical Engineering

ComNets
Kommunikationsnetze

IMSAS
Institut für Mikrosensoren, Aktuatoren und -Systeme

ITEM
Institut für Theoretische Elektrotechnik und Mikroelektronik

Faculty 3 – Mathematics / Computer Science

Zentrum für Technomathematik

TZI Technologie-Zentrum Informatik

Faculty 4 – Production Engineering and Technology

Universität Bremen
PSPS Planung und Steuerung produktionstechnischer Systeme

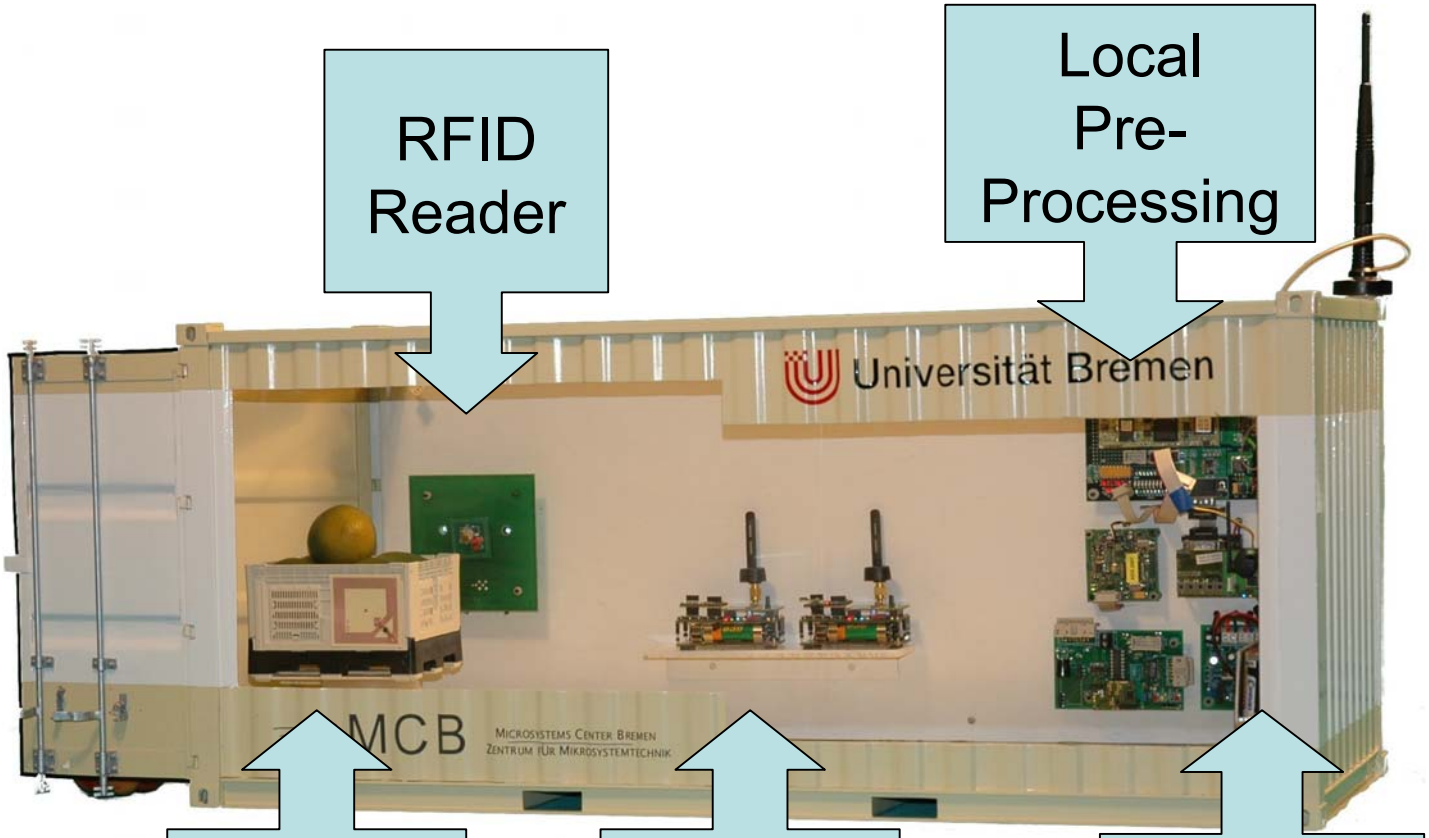
IT-applications in the production technology

Faculty 7 – Business Studies and Economics

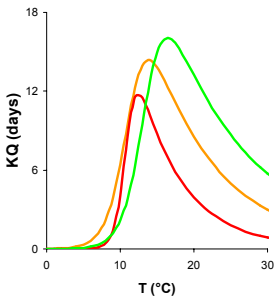
LfL HB

Prof. Dr. Michael Hülsmann
Management Nachhaltiger Systementwicklung

Hardware


RFID Reader
Local Pre-Processing
Universität Bremen
MCB
Microsystems Center Bremen
Zentrum für Mikrosystemtechnik
Freight Object (RFID)
Sensor Nodes
External Commu-nication

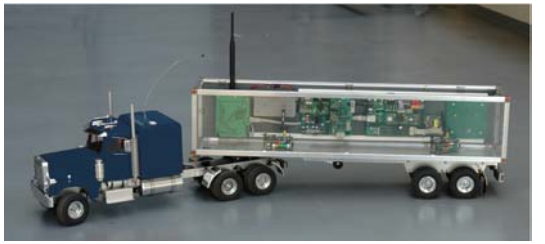
Local processing



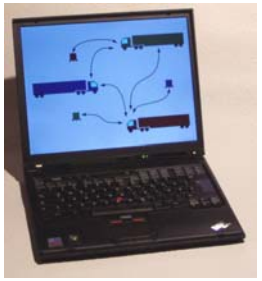
Quality Modelling

Transport Operator

Sensor raw data

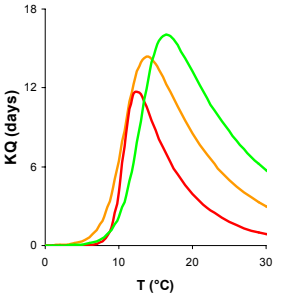


Standard T&T

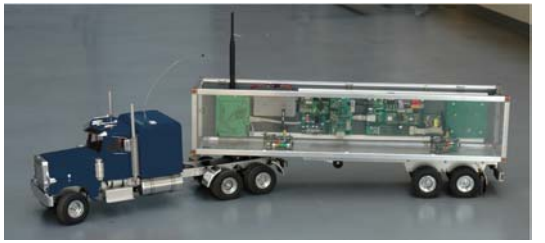


Transport Operator

Quality Information



Quality Modelling



Standard T&T + Processor

RFID and information flow

Logistical object

➔ Passive RFID-Label

Dynamic link

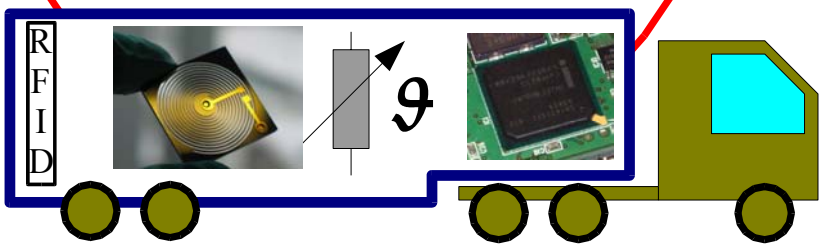
Intelligent Agent

➔ Software repre-sentation of the physical object

➔ Transport- and handling-instruction

RFID-Tag is read at transshipment

Container requests agent at loading



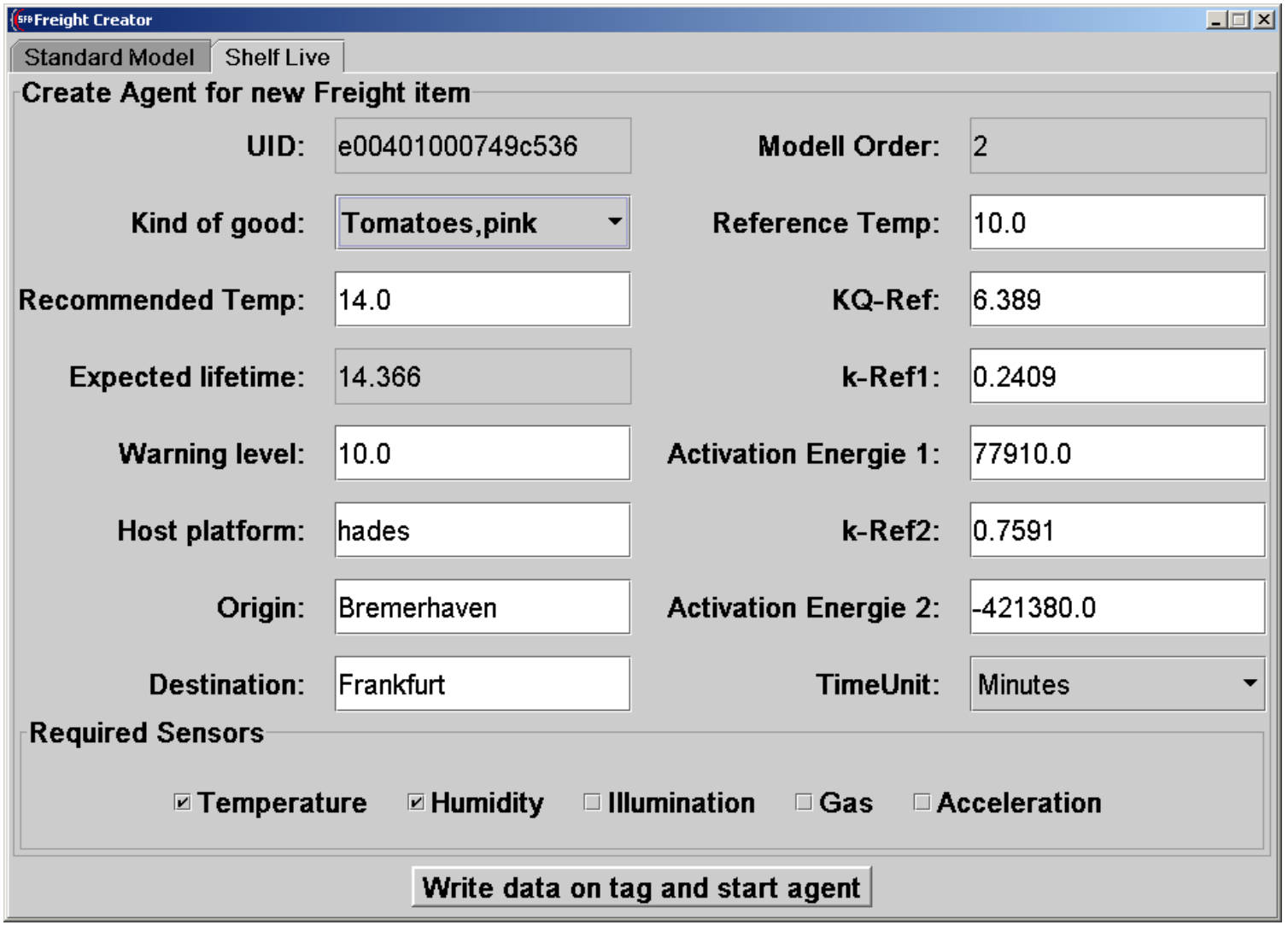
Warehouse or Means of Transport

➔ CPU platform

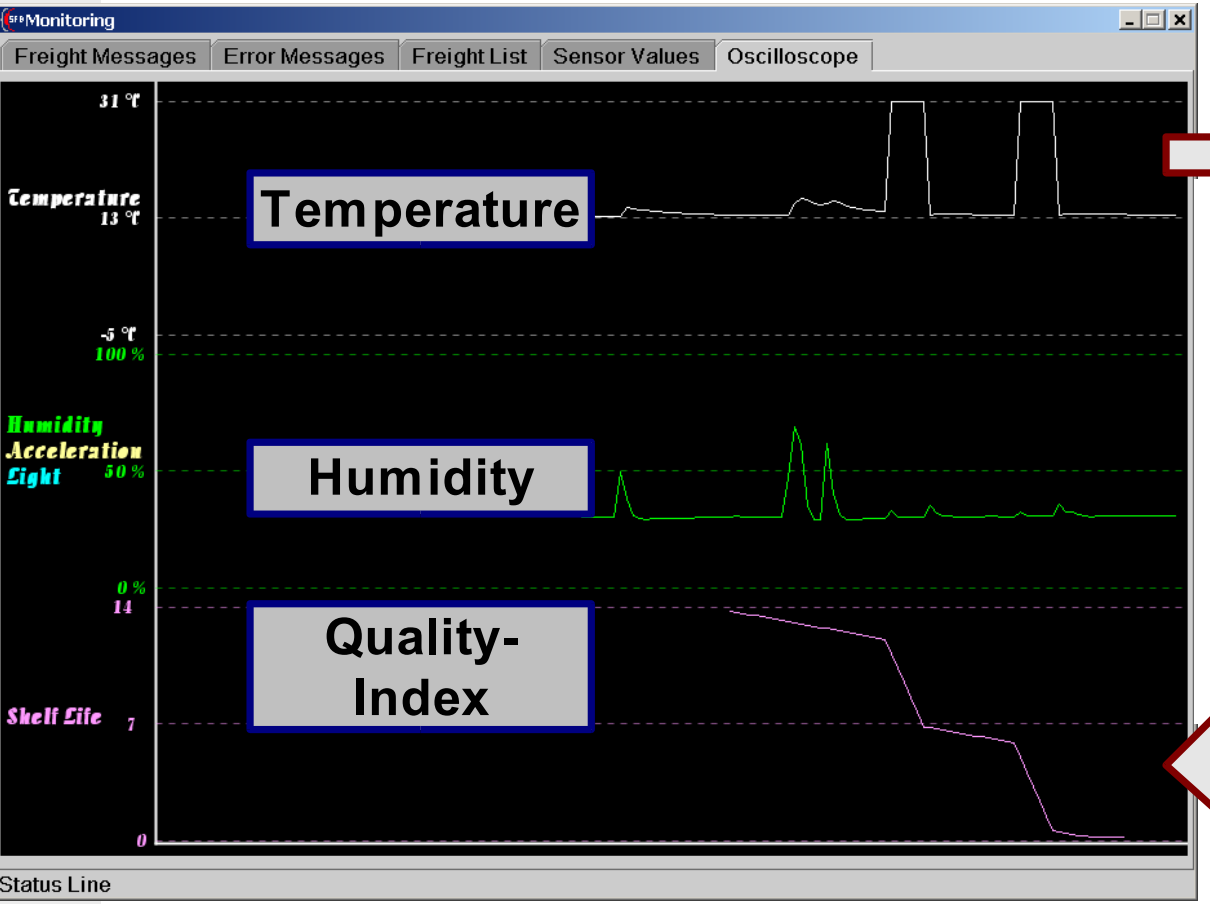
➔ Sensors

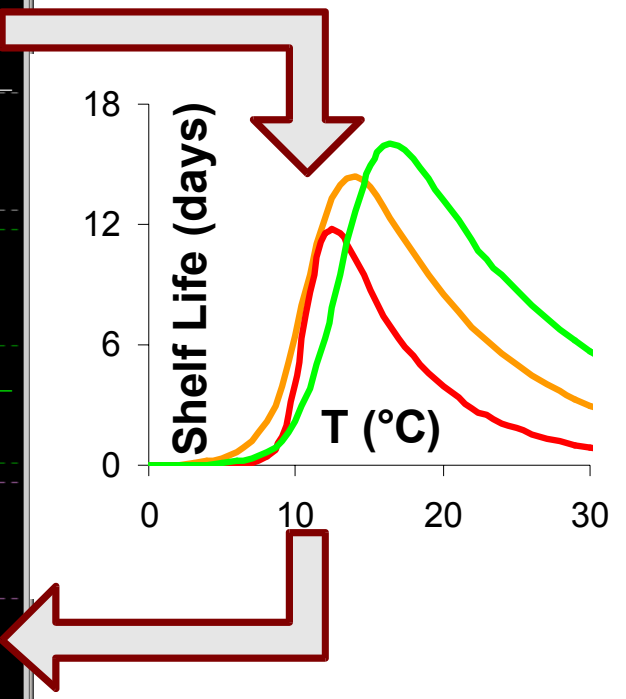
➔ RFID-Reader

Creation of transport order

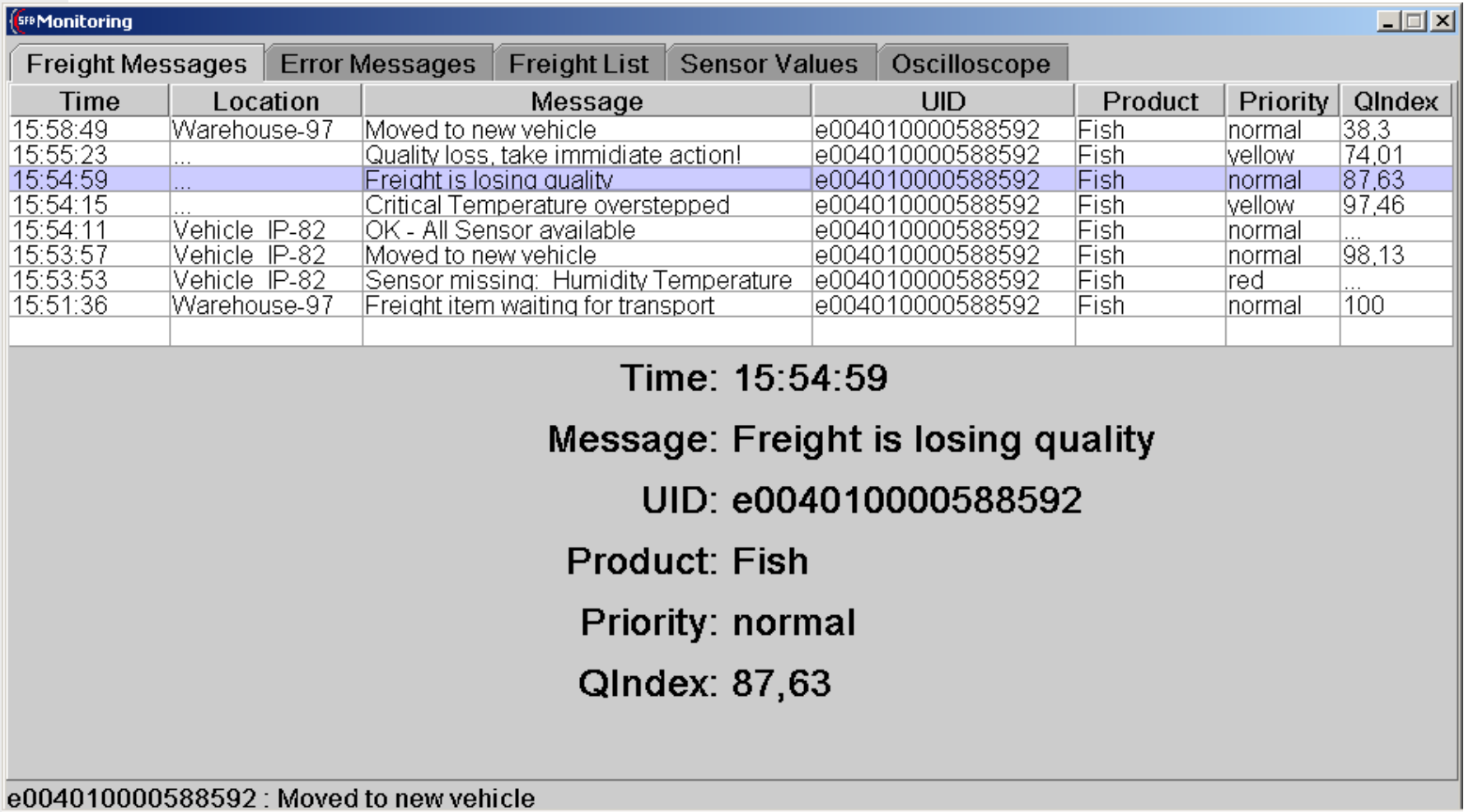


Oscilloscope view

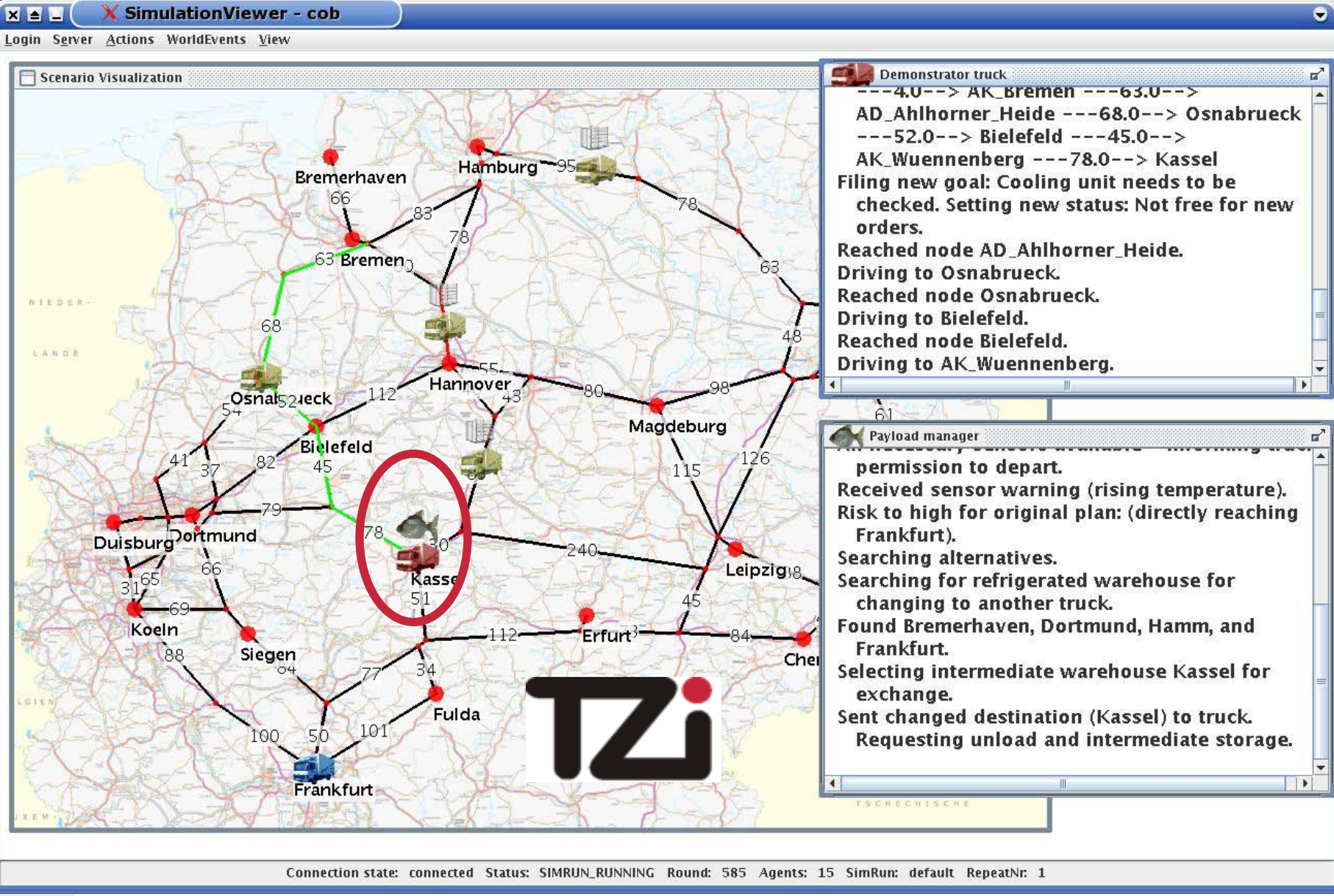




Message screen

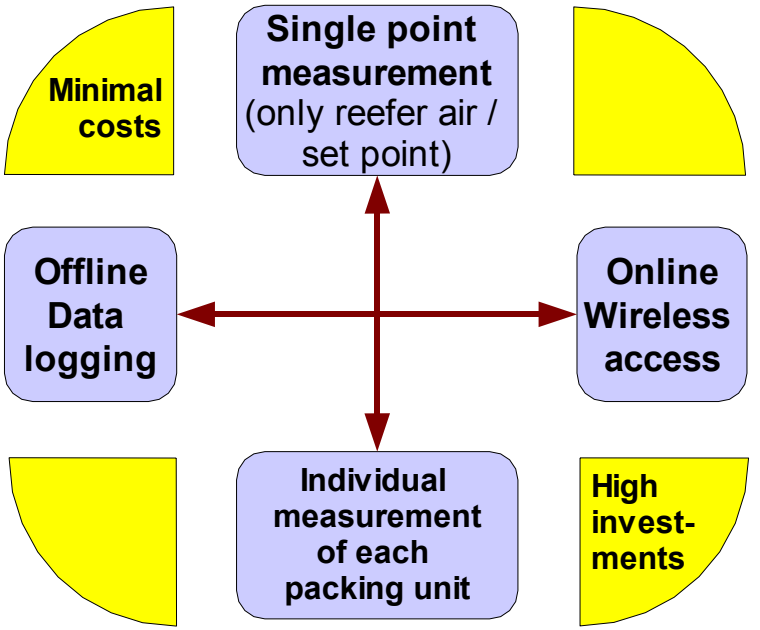


Time	Location	Message	UID	Product	Priority	QIndex
15:58:49	Warehouse-97	Moved to new vehicle	e004010000588592	Fish	normal	38,3
15:55:23	...	Quality loss, take immidiate action!	e004010000588592	Fish	yellow	74,01
15:54:59	...	Freight is losing quality	e004010000588592	Fish	normal	87,63
15:54:15	...	Critical Temperature overstepped	e004010000588592	Fish	yellow	97,46
15:54:11	Vehicle IP-82	OK - All Sensor available	e004010000588592	Fish	normal	...
15:53:57	Vehicle IP-82	Moved to new vehicle	e004010000588592	Fish	normal	98,13
15:53:53	Vehicle IP-82	Sensor missing: Humidity Temperature	e004010000588592	Fish	red	...
15:51:36	Warehouse-97	Freight item waiting for transport	e004010000588592	Fish	normal	100


SimulationViewer - cob
Login Server Actions WorldEvents View
Scenario Visualization
Bremerhaven
Hamburg
Bremen
Hannover
Osnabrueck
Bielefeld
Magdeburg
Duisburg
Dortmund
Koeln
Siegen
Kassel
Leipzig
Erfurt
Fulda
Frankfurt
Demonstrator truck
AD_Ahlhorner_Heide ---68.0--> Osnabrueck
---52.0--> Bielefeld ---45.0-->
AK_Wuennenberg ---78.0--> Kassel
Filing new goal: Cooling unit needs to be checked. Setting new status: Not free for new orders.
Reached node AD_Ahlhorner_Heide.
Driving to Osnabrueck.
Reached node Osnabrueck.
Driving to Bielefeld.
Reached node Bielefeld.
Driving to AK_Wuennenberg.
Payload manager
permission to depart.
Received sensor warning (rising temperature).
Risk to high for original plan: (directly reaching Frankfurt).
Searching alternatives.
Searching for refrigerated warehouse for changing to another truck.
Found Bremerhaven, Dortmund, Hamm, and Frankfurt.
Selecting intermediate warehouse Kassel for exchange.
Sent changed destination (Kassel) to truck.
Requesting unload and intermediate storage.
Connection state: connected Status: SIMRUN_RUNNING Round: 585 Agents: 15 SimRun: default RepeatNr: 1

Coasts and accuracy

- Maximum solution
  - Separate sensor for each freight item
  - Wireless access to each measurement point
- Cost reduction
  - Clusters of freight objects share sensor
  - Online access only to selected points, others only data logging
- Concept for mixed solution



Example for combination

- Equipment
  - High number of data loggers to monitor freight core temperature (access only at transhipments)
  - Reduced number of wireless sensors to capture ambient temperature profile (always accessible)
- Automated shelf life correction
  - **During transport:** Ambient sensors provide a (inaccurate) estimation of shelf life (offset towards freight core temperature)
  - **Unloading / Transhipment:** Reading temperature history from core loggers / Consolidation of temperature data
  - **Correction:** Shelf life prediction corrected by the history of the core temperature

Summary

- Various effects cause local temperature deviations
  - Multi-point measurement required
  - Deeper analyses necessary
  - Differences in shelf life
- Autonomous supervision
  - Manuel reading and data evaluation of multiple loggers not feasible
  - Online supervision could prevent losses and improve transport planning
- Technical solution required combination of technologies
  - Wireless sensor noted for online access
  - Miniaturized data loggers to reduce costs
  - RFID for automated configuration
  - Embedded systems for local data processing

Thanks for your attention

- For more information and publications please visit
  www.intelligentcontainer.com
- Article in ScanRef Journal planned (January 2007)

- Contact address and copyright

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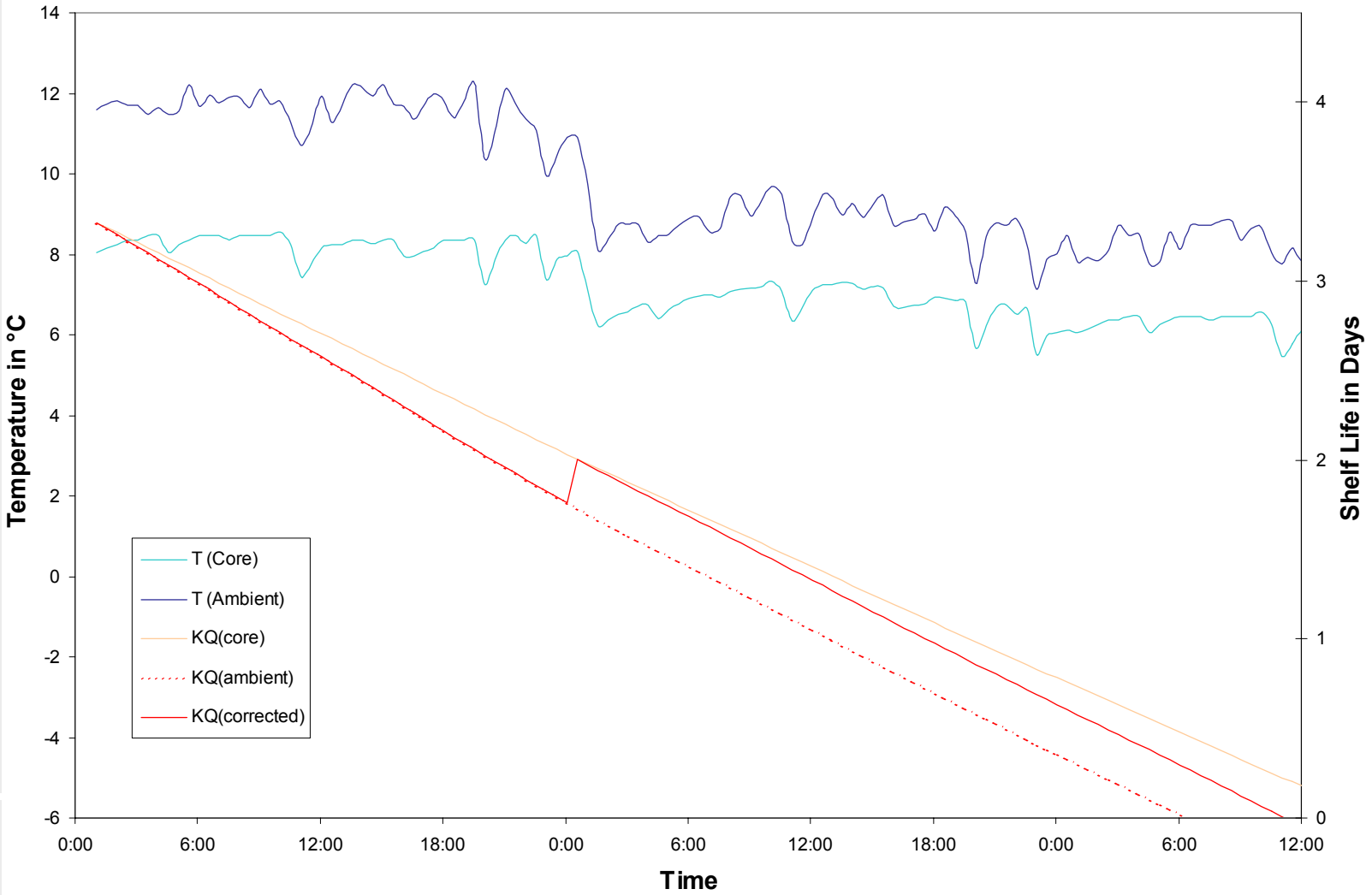
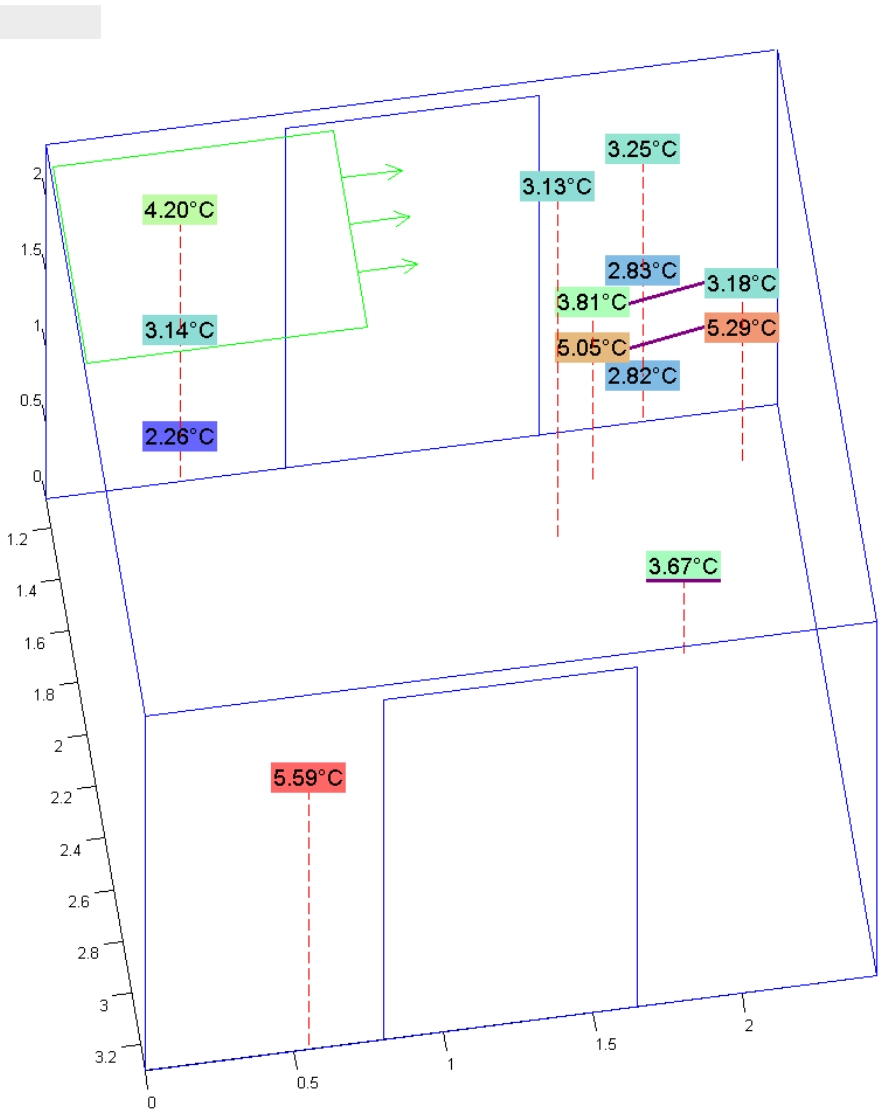
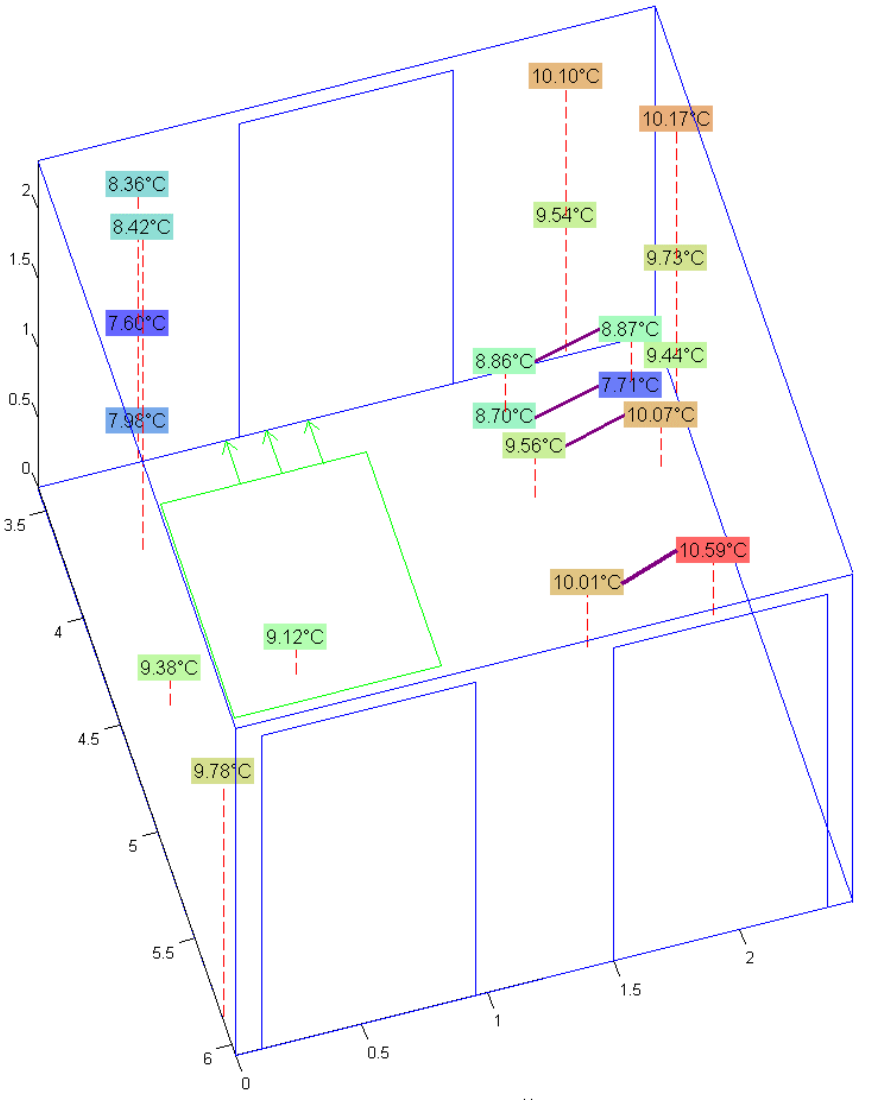
Example for combination

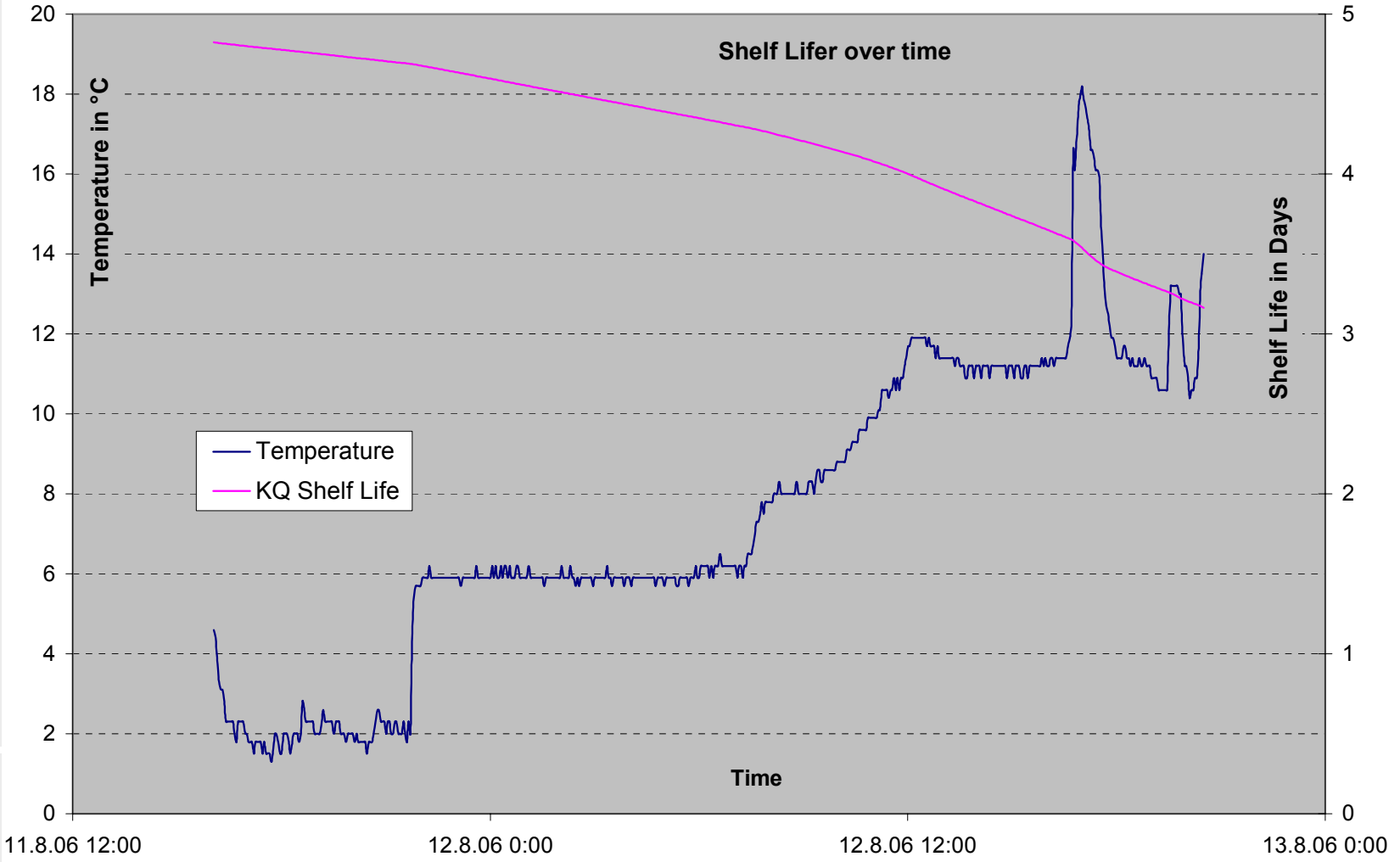


Loggers in fish compartment and vegetable boxes

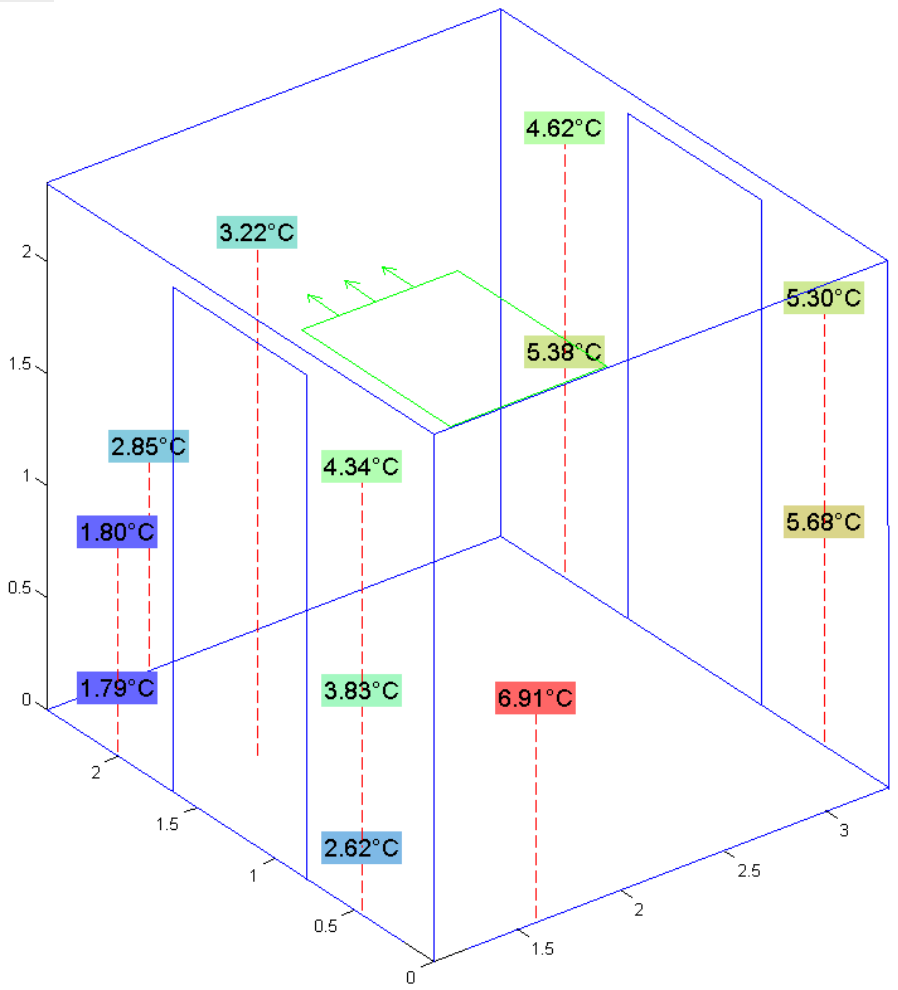


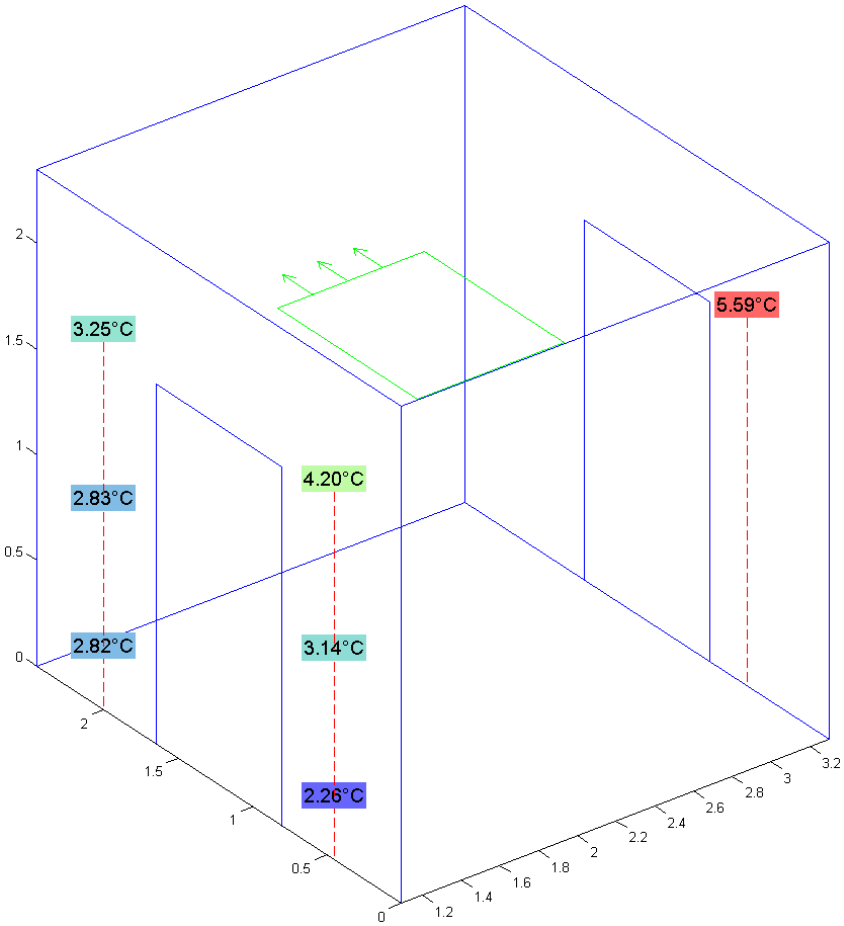


Air transport



Fish Compartment September and October





Vegetables Compartment September and October