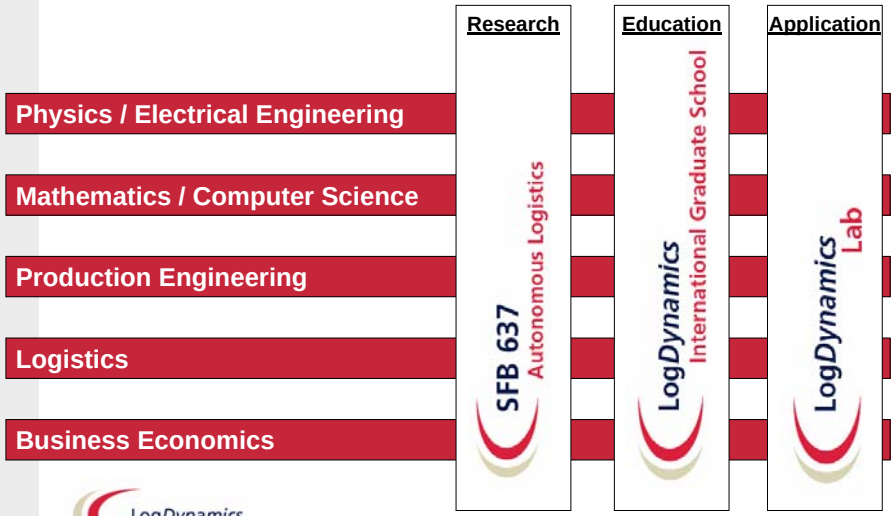
Reiner Jedermann, Adam Sklorz, Walter Lang, Institute for Microsensors, -Actuators and -Systems (IMSAS), University of Bremen

Dieter Uckelmann, Log*Dynamics* Lab, University of Bremen

The intelligent container:

Combining RFID with sensor networks, dynamic quality models and software agents

- Founded in 1971
- First principles are
  - interdisciplinary as well as
  - practice-oriented project studies
  - known as the „Bremen Model“
- 80 courses of studies, many of them are bachelor- or master degrees
- Scientific research centre in the northwest of germany
- Laboratories for 1,400 scientists
- A place to study for nearly
  - 22,000 students,
  - thereof nearly 3,000 foreign students
- A workplace for more than 1,160 employees
- 12 faculties representing various sciences



Long:

“Autonomous Control describes processes of decentralized decision-making in heterarchical structures. It presumes interacting elements in non-deterministic systems, which possess the capability and possibility to render decisions independently. The objective of Autonomous Control is the achievement of increased robustness and positive emergence of the total system due to distributed and flexible coping with dynamics and complexity.”

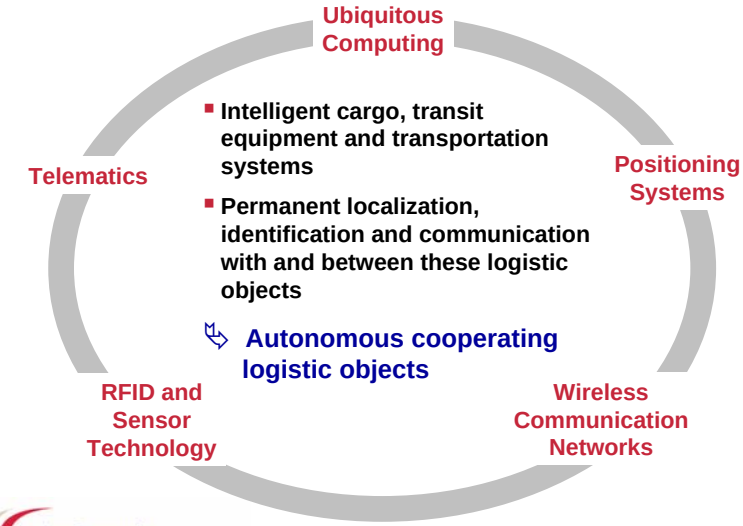
Short:

“Autonomous control in logistics systems is characterised by the ability of logistic objects to process information, to render and to execute decisions on their own.”

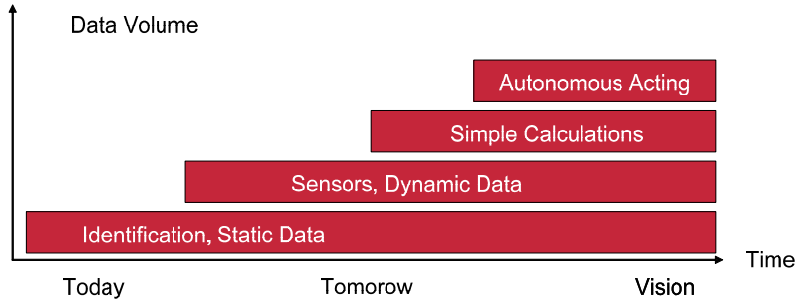
Autonomous Control – Opportunities and Risks

- Autonomous control is a paradigm to manage complexity, dynamics and uncertainty within logistic processes
- It is based on autonomy & decentralization for decision making
- Autonomous control designs emergent synergies & infrastructures in complex systems (chances):
  - Increase of decision capacities
  - Reduction of decision complexity
  - Transition to flexible strategies, structures, processes and resources
  - By adopting dynamic requirements the system robustness increases
- Autonomous controlled systems contain redundancies (risks)
  - Redundant tasks, structures and resources
  - Overall performance is endangered by egoism of subsystems
  - Missing central control might lead to instability

Technological Basis



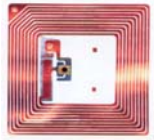
Roadmap from RFID to Autonomous Control



Sensors Extending Tracking & Tracing

„We do not only want to know at any point of time where the fright item is but also in which state it is"

- Supply Chain Control by Radio Frequency Identification

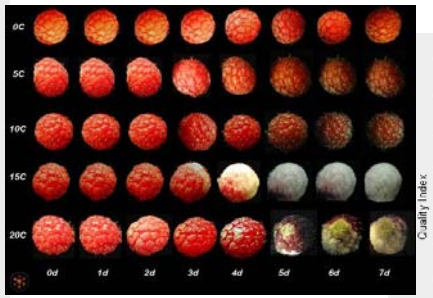


Application in Fruit Logistics

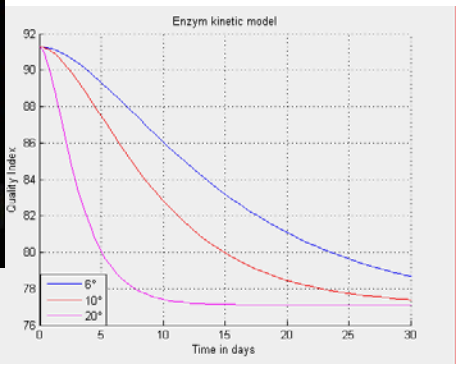
- Agricultural products are still "alive" after harvest

Maritime reefer transports total	**57 million tons**
Bananas	29 %
Citrus	10 %
Other Fruits	17 %

Dynamic Data have an Impact!



Source: Dr.Jean-Pierre Emond, University of Florida



Compare: Bobelyn, 2005

Inactive —exp(Temperature) / Arrihinus Law→ **Oxidase**

Colour + Oxidase —exp(Temperature) / Arrhenius' Law→ **Colourless**

Mobile Sensors

Three generations of sensor systems

1. **Standard data loggers:**
   Reading of measurement protocol at end of transport
   Might be to late for appropriate reactions
2. **Radio data loggers:**
   Allow permanent access
   Extensive configuration work and information overhead
3. **Third generation sensor system:**
   a) Autonomous configuration
   b) On-the-road sensor access
   c) Autonomous data interpretation and decision-making

The Sensor System

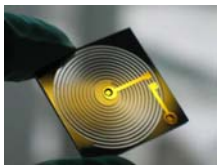
Ultra low power design

Power consumption per month

- Temperature, humidity 1 mAh
- Acceleration 72 mAh
- µController MSP430 1 mAh
- Wireless IEEE 802.15.4 2,5 mAh
  One Message per minute

Miniaturized Ethylene Chromatography

- Development based on existing device for volatile aromatic components

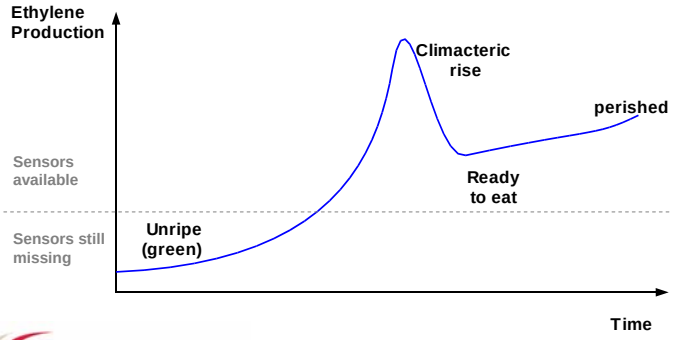


MCB
Microsystems Center Bremen
Zentrum für Mikrosystemtechnik

The Importance of Ethylene

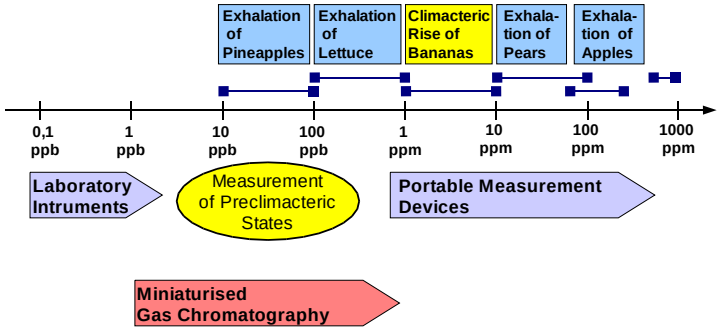
The gaseous hormone ethylene

- Indicator: Typical peak in ethylene exhalation at start of ripening
- Catalyst: Ripening of Bananas is forced by exposure to high concentrations
  One overripe Banana can spoil a hole transport



The Ethylene Scale

Typical concentrations and measurement instruments



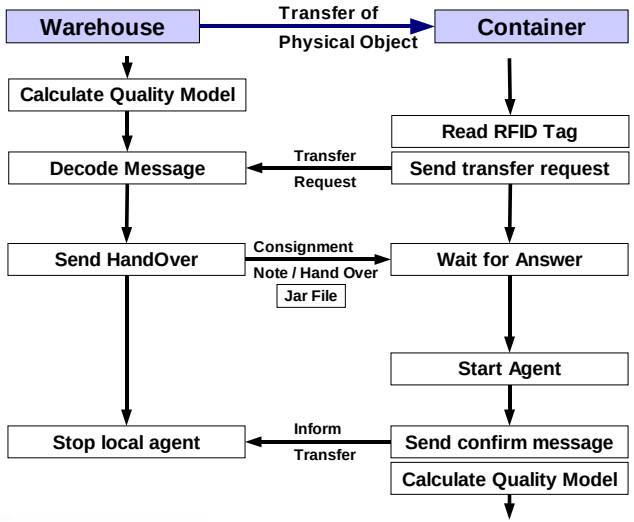
Mobile Agents

Linking sensor data into an electronic consignment note

- Extended Software concept (Mobile Agents)
- Each fright item is represented by an agent
- Accompanies the freight along the transport chain
- Performs actively supervision task per item

- **Agent knows how to handle their corresponding fright item:**
  - Which parameters need supervision
  - Whom to inform at dysfunction
  - Which actions to trigger

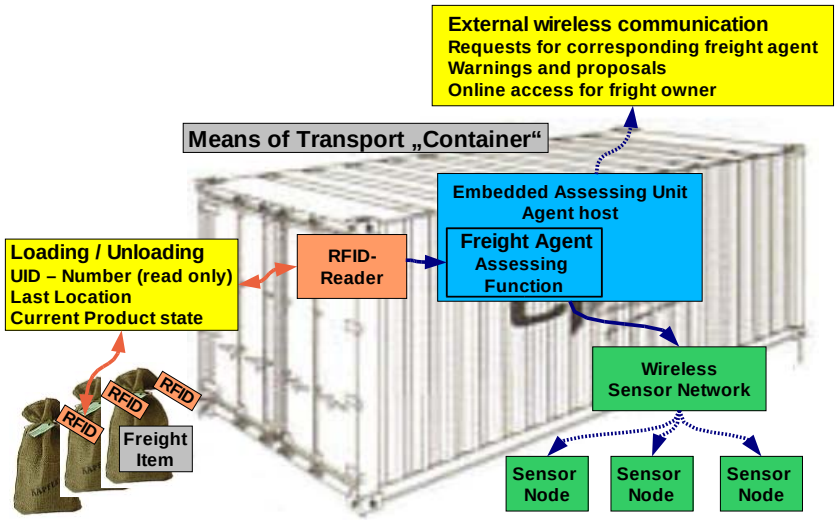
Protocol Level



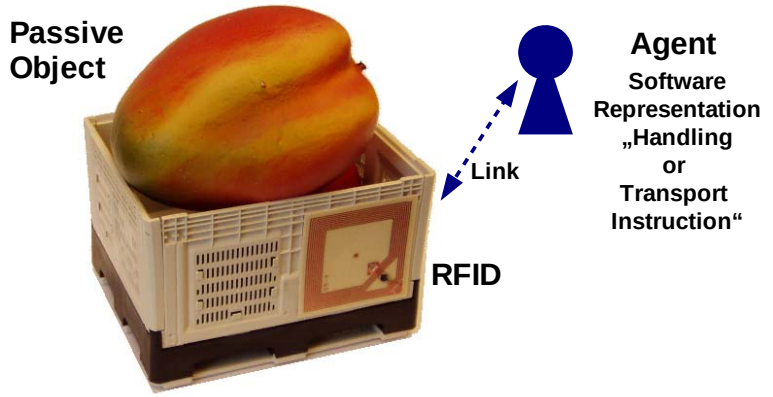
Agents on RFID Tags

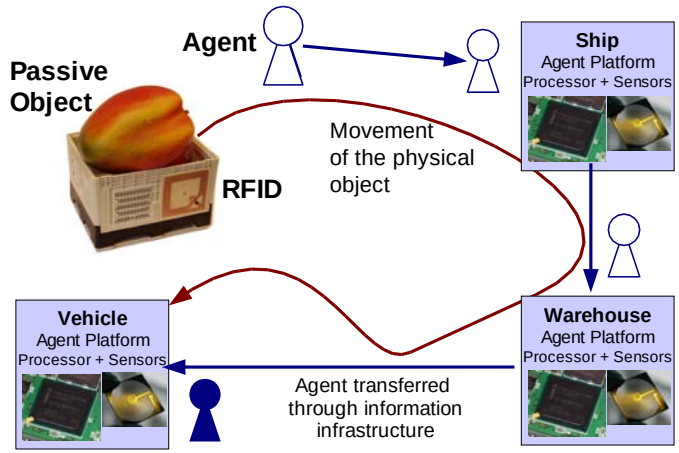
- Code size
  - Base Agent 20 k Byte
  - Dynamic extensions 4 k Byte
- Transfer rate of 13 MHz RFID-Tags
  - Overhead by Anti collision and protocols
  - Effective rate ~ 1 k Bit / sec
  - Memory typically 1 k Bit
- UHF Tags
  - limited by bandwidth of 200 kHz
  - A few hundreds identification numbers per second
- Our approach
  - Identification number
  - Quality state information
  - Address of the agent (IP of last vehicle)

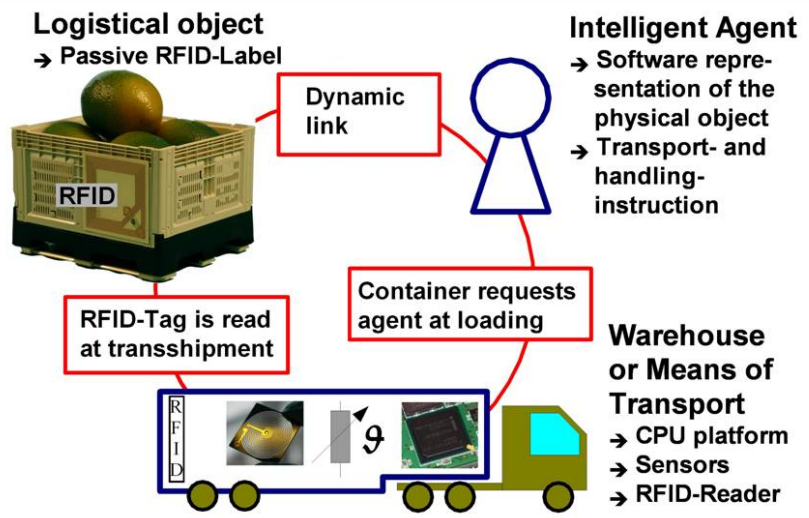
System Concept



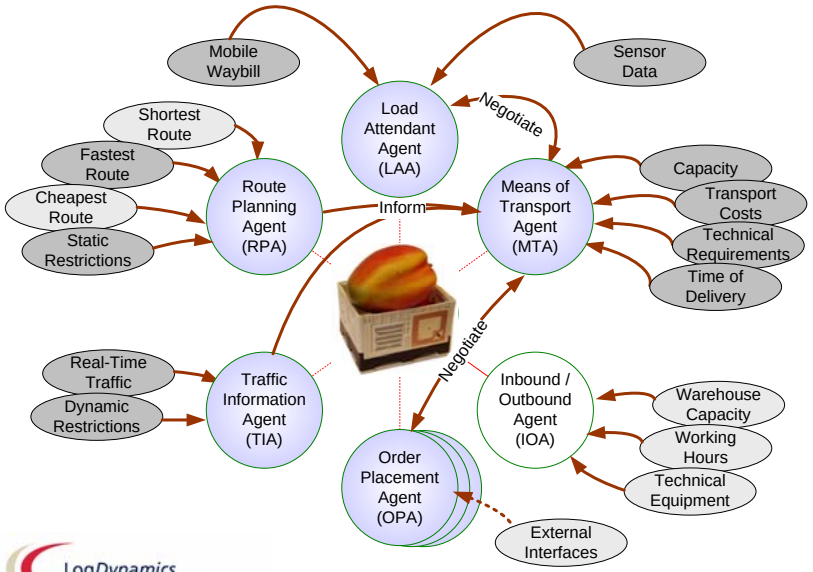
Passive Tags Within an Intelligent Environment





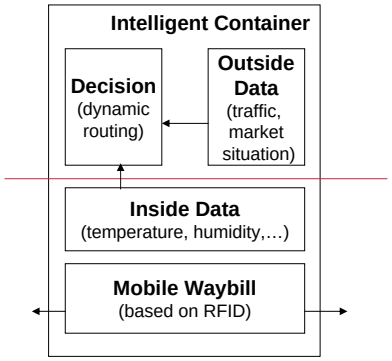


Interacting Agents

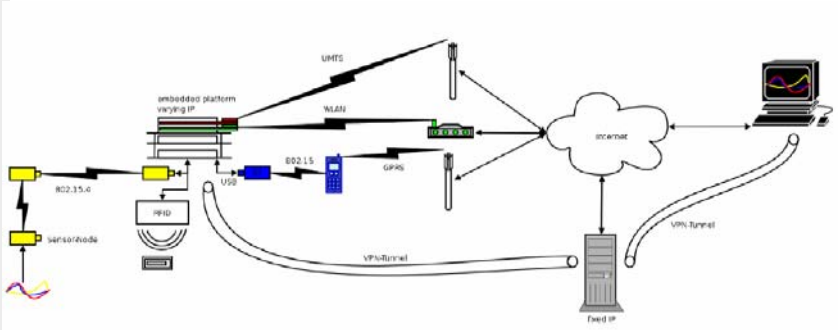


Inside and Outside Dynamic Data

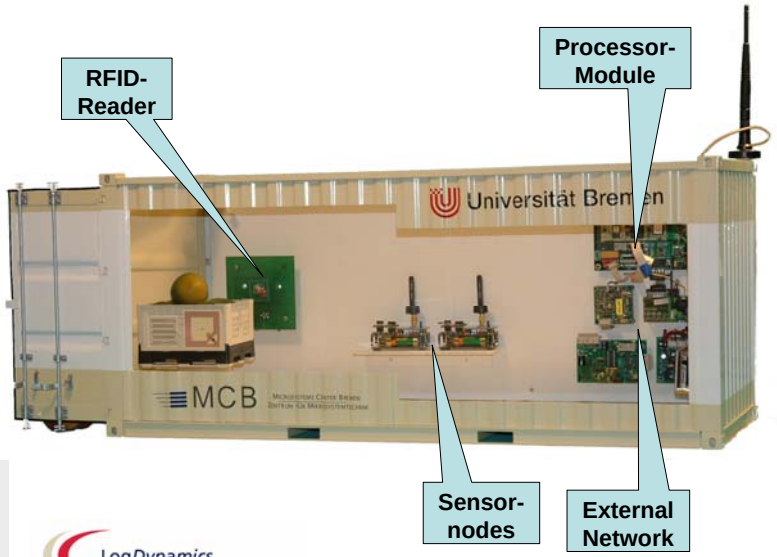
- Environment perception and information processing are basic requirements to autonomous controlled systems
- Individual interpretation of sensor data in relation to monitored goods is necessary
- Dynamic data related to smart container should be devided into inside and outside data



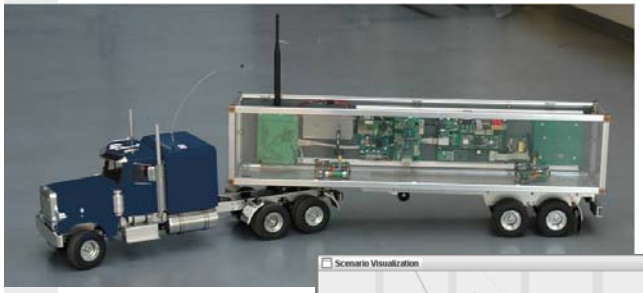
Communication Infrastructure

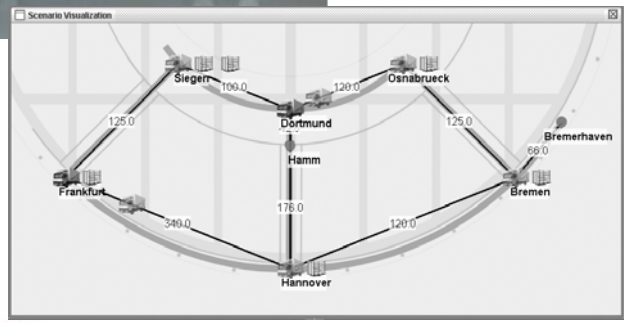


Second Prototype (Model 1:8)

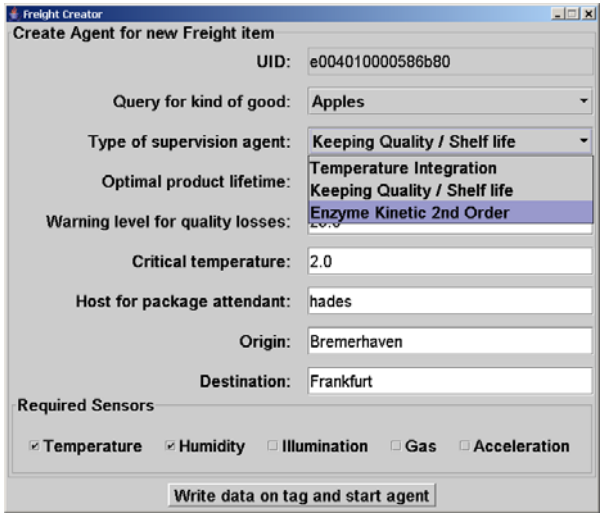


On the Road again…





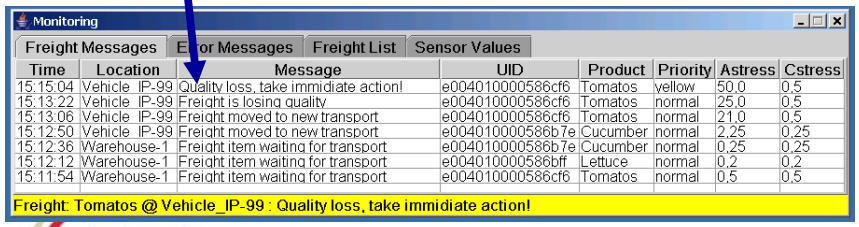
Composing the Consignment Note

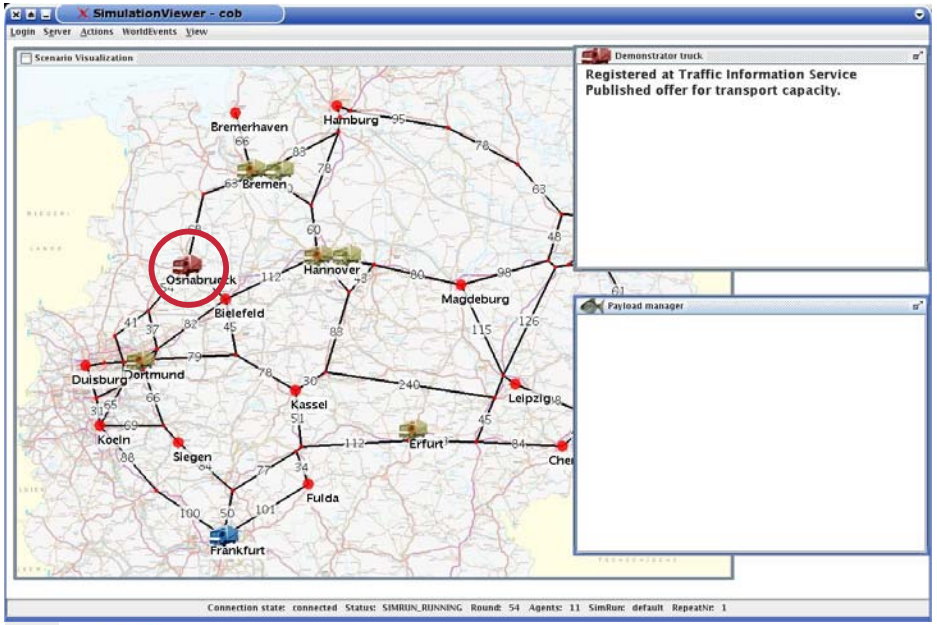


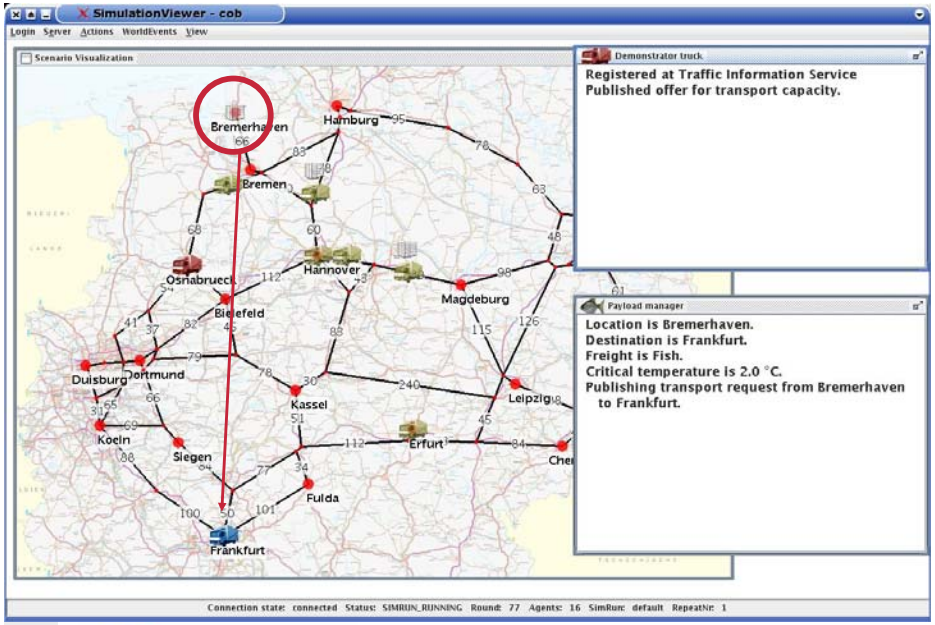
User Interface

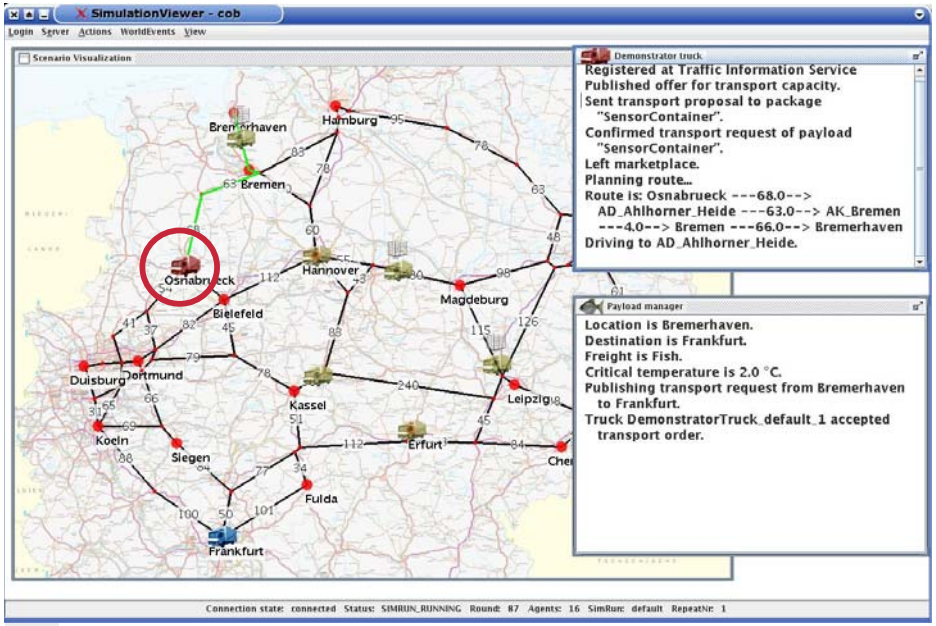
Warnings at quality changes

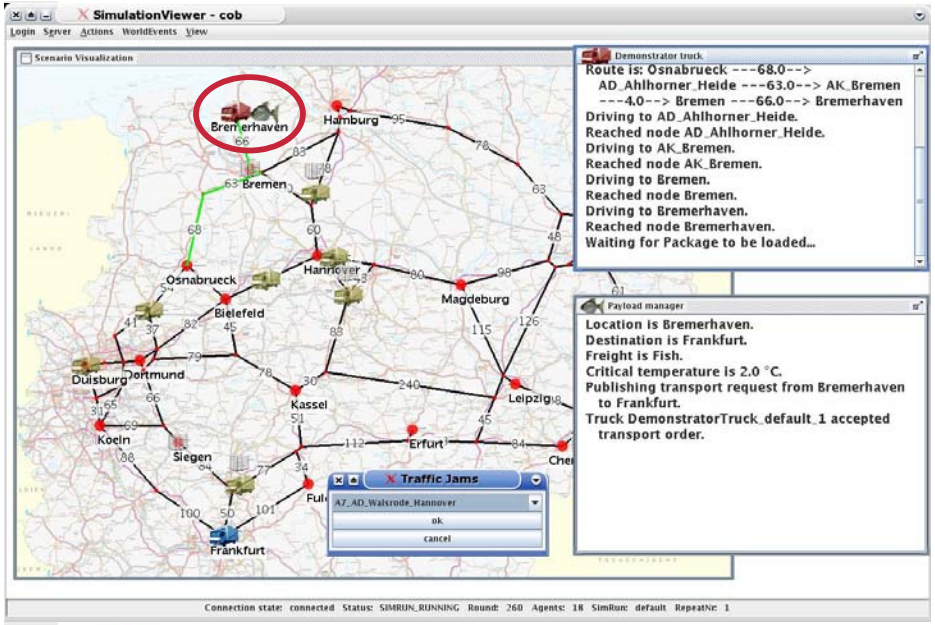
- Time: 15:15:04
- Location: Vehicle IP-99
- Message: Quality loss, take immediate action!
- UID: e0040100000586cf6
- Product Tomatoes
- Priority yellow
- Astress 50%

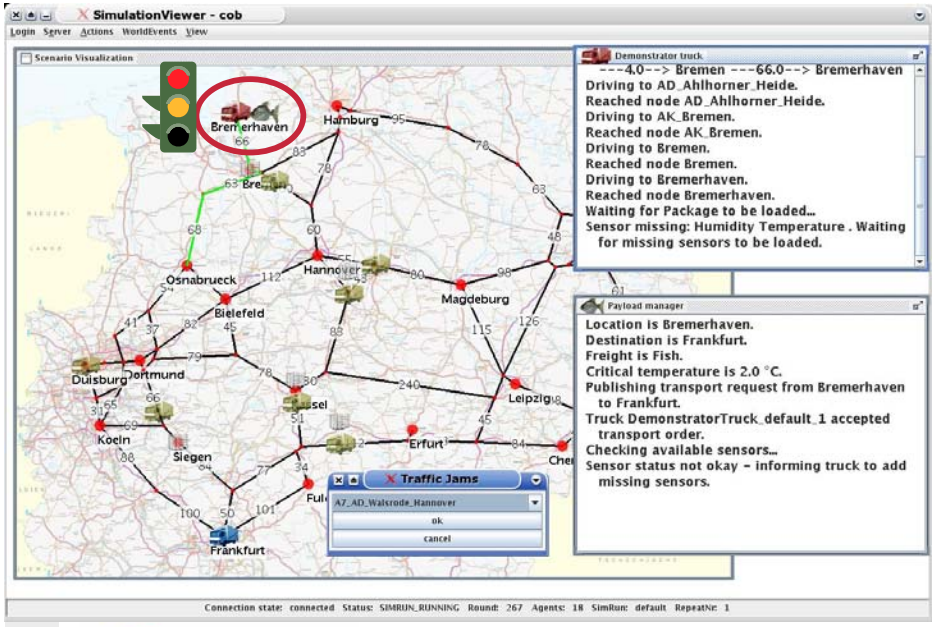


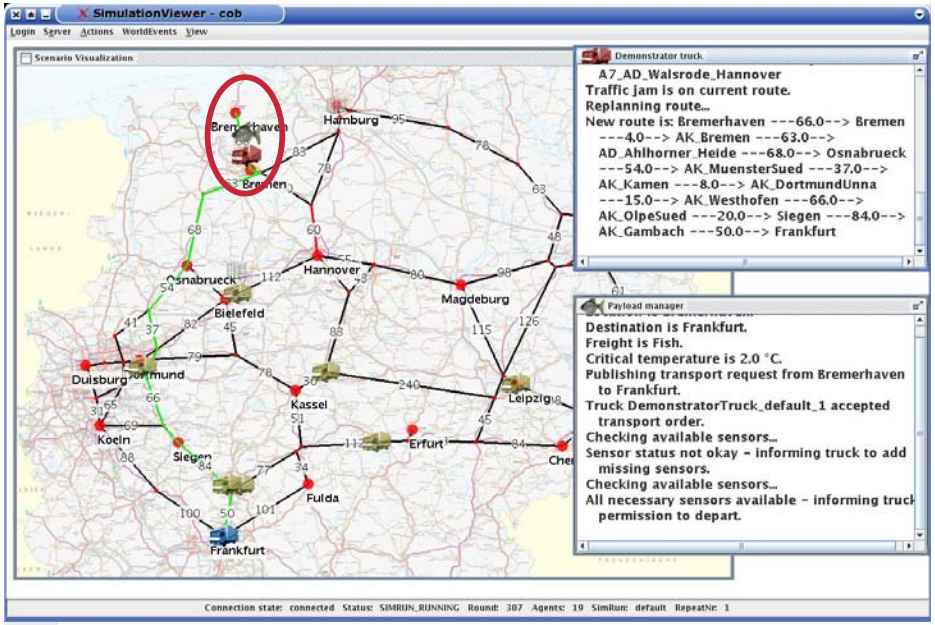


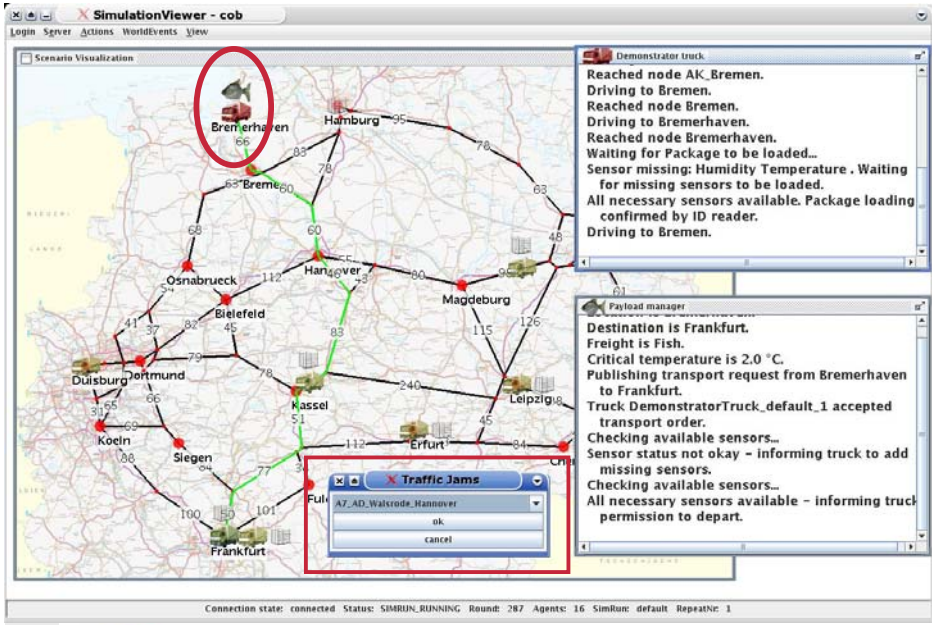

SimulationViewer - cob
Login Server Actions WorldEvents View
Scenario Visualization
Demonstrator truck
Registered at Traffic Information Service
Published offer for transport capacity.
Payload manager
Location is Bremerhaven.
Destination is Frankfurt.
Freight is Fish.
Critical temperature is 2.0 °C.
Publishing transport request from Bremerhaven to Frankfurt.
Bremerhaven
Hamburg
Bremen
Osnabrueck
Hannover
Magdeburg
Bielefeld
Duisburg
Dortmund
Kassel
Leipzig
Koeln
Siegen
Erfurt
Fulda
Frankfurt
Connection state: connected Status: SIMRUN_RUNNING Round: 77 Agents: 16 SimRun: default RepeatNr: 1

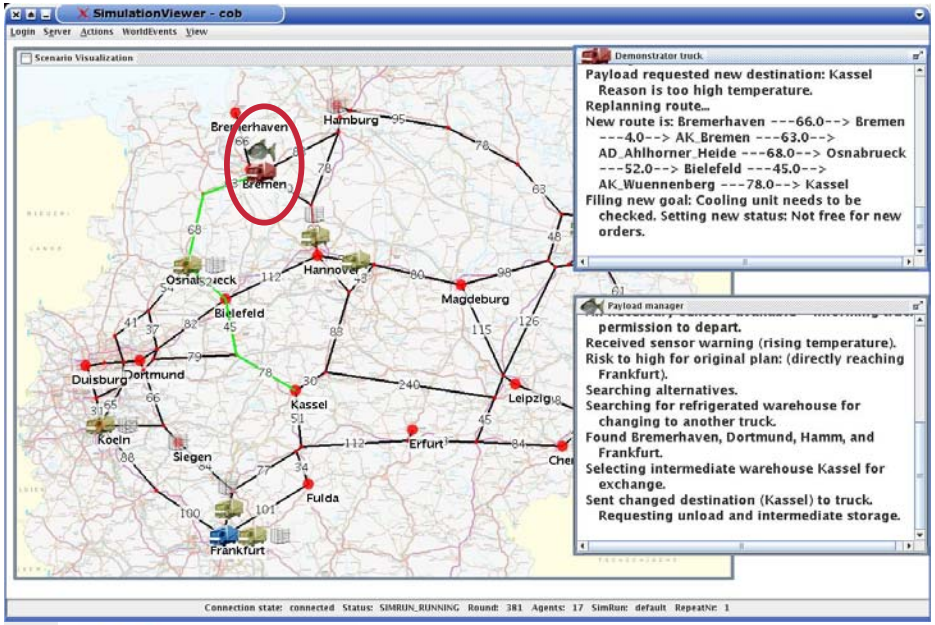

SimulationViewer - cob
Login Server Actions WorldEvents View
Scenario Visualization
Demonstrator truck
Registered at Traffic Information Service
Published offer for transport capacity.
Sent transport proposal to package "SensorContainer".
Confirmed transport request of payload "SensorContainer".
Left marketplace.
Planning route...
Route is: Osnabrueck ---68.0--> AD_Ahlhorner_Heide ---63.0--> AK_Bremen ---4.0--> Bremen ---66.0--> Bremerhaven
Driving to AD_Ahlhorner_Heide.
Payload manager
Location is Bremerhaven.
Destination is Frankfurt.
Freight is Fish.
Critical temperature is 2.0 °C.
Publishing transport request from Bremerhaven to Frankfurt.
Truck DemonstratorTruck_default_1 accepted transport order.
Bremerhaven
Hamburg
Bremen
Osnabrueck
Hannover
Magdeburg
Bielefeld
Duisburg
Dortmund
Kassel
Leipzig
Koeln
Siegen
Erfurt
Fulda
Frankfurt
Connection state: connected Status: SIMRUN_RUNNING Round: 87 Agents: 16 SimRun: default RepeatNr: 1

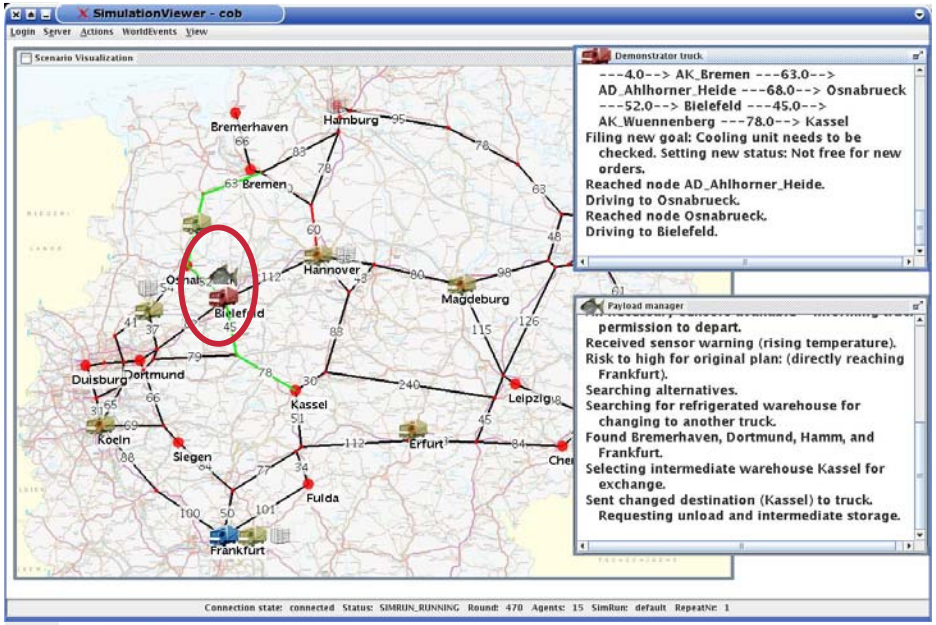

SimulationViewer - cob
Login Server Actions WorldEvents View
Scenario Visualization
Demonstrator truck
Route is: Osnabrueck ---68.0--> AD_Ahlhorner_Heide ---63.0--> AK_Bremen ---4.0--> Bremen ---66.0--> Bremerhaven
Driving to AD_Ahlhorner_Heide.
Reached node AD_Ahlhorner_Heide.
Driving to AK_Bremen.
Reached node AK_Bremen.
Driving to Bremen.
Reached node Bremen.
Driving to Bremerhaven.
Reached node Bremerhaven.
Waiting for Package to be loaded...
Payload manager
Location is Bremerhaven.
Destination is Frankfurt.
Freight is Fish.
Critical temperature is 2.0 °C.
Publishing transport request from Bremerhaven to Frankfurt.
Truck DemonstratorTruck_default_1 accepted transport order.
Traffic Jams
A7_AD_Walsrode_Hannover
ok
cancel
Bremerhaven
Hamburg
Bremen
Osnabrueck
Hannover
Magdeburg
Bielefeld
Duisburg
Dortmund
Kassel
Leipzig
Koeln
Siegen
Erfurt
Frankfurt
Connection state: connected Status: SIMRUN_RUNNING Round: 260 Agents: 18 SimRun: default RepeatNr: 1

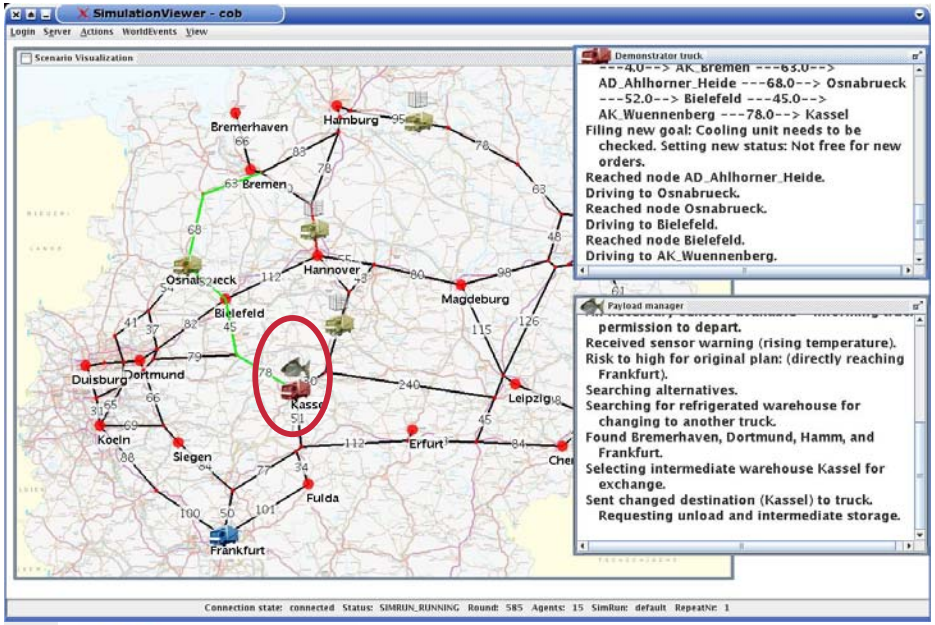

SimulationViewer - cob
Login Server Actions WorldEvents View
Scenario Visualization
Demonstrator truck
---4.0--> Bremen ---66.0--> Bremerhaven
Driving to AD_Ahlhorner_Heide.
Reached node AD_Ahlhorner_Heide.
Driving to AK_Bremen.
Reached node AK_Bremen.
Driving to Bremen.
Reached node Bremen.
Driving to Bremerhaven.
Reached node Bremerhaven.
Waiting for Package to be loaded...
Sensor missing: Humidity Temperature . Waiting for missing sensors to be loaded.
Payload manager
Location is Bremerhaven.
Destination is Frankfurt.
Freight is Fish.
Critical temperature is 2.0 °C.
Publishing transport request from Bremerhaven to Frankfurt.
Truck DemonstratorTruck_default_1 accepted transport order.
Checking available sensors...
Sensor status not okay - informing truck to add missing sensors.
Traffic Jams
A7_AD_Walsrode_Hannover
ok
cancel
Bremerhaven
Hamburg
Bremen
Osnabrueck
Hannover
Magdeburg
Bielefeld
Duisburg
Dortmund
Kassel
Leipzig
Koeln
Siegen
Erfurt
Frankfurt
Connection state: connected Status: SIMRUN_RUNNING Round: 267 Agents: 18 SimRun: default RepeatNr: 1

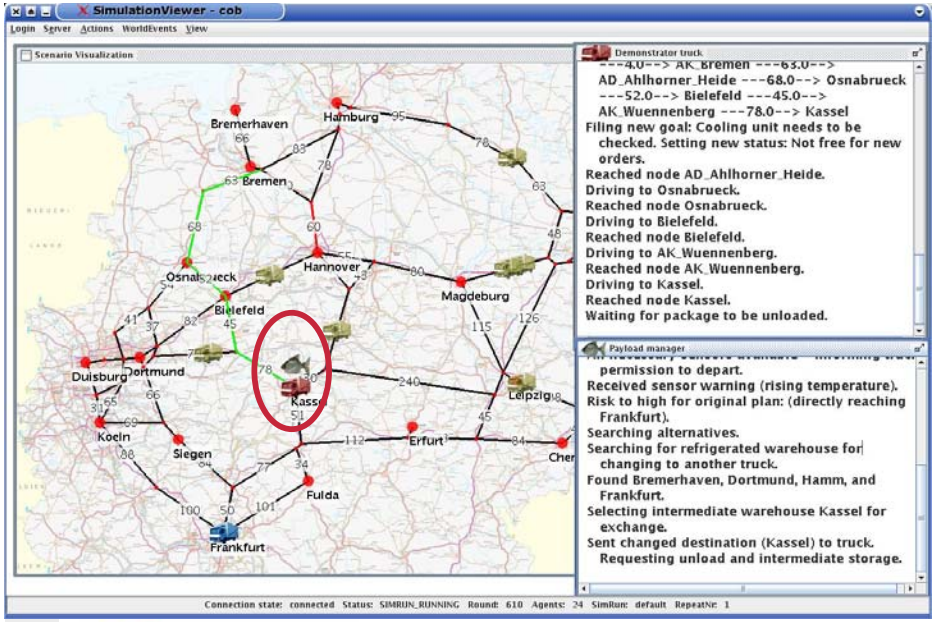

SimulationViewer - cob
Login Server Actions WorldEvents View
Scenario Visualization
Demonstrator truck
A7_AD_Walsrode_Hannover
Traffic jam is on current route.
Replanning route...
New route is: Bremerhaven ---66.0--> Bremen ---4.0--> AK_Bremen ---63.0--> AD_Ahlhorner_Heide ---68.0--> Osnabrueck ---54.0--> AK_MuensterSued ---37.0--> AK_Kamen ---8.0--> AK_DortmundUnna ---15.0--> AK_Westhofen ---66.0--> AK_OlpeSued ---20.0--> Siegen ---84.0--> AK_Gambach ---50.0--> Frankfurt
Payload manager
Destination is Frankfurt.
Freight is Fish.
Critical temperature is 2.0 °C.
Publishing transport request from Bremerhaven to Frankfurt.
Truck DemonstratorTruck_default_1 accepted transport order.
Checking available sensors...
Sensor status not okay - informing truck to add missing sensors.
Checking available sensors...
All necessary sensors available - informing truck permission to depart.
Bremerhaven
Hamburg
Bremen
Osnabrueck
Hannover
Magdeburg
Bielefeld
Duisburg
Dortmund
Kassel
Leipzig
Koeln
Siegen
Erfurt
Fulda
Frankfurt
Connection state: connected Status: SIMRUN_RUNNING Round: 307 Agents: 19 SimRun: default RepeatNr: 1

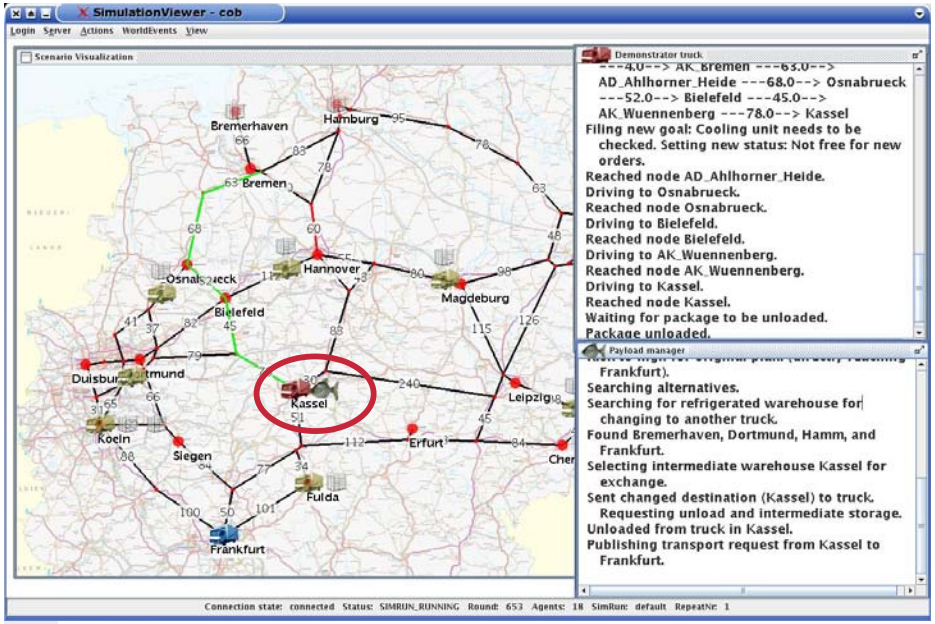

SimulationViewer - cob
Login Server Actions WorldEvents View
Scenario Visualization
Demonstrator truck
Reached node AK_Bremen.
Driving to Bremen.
Reached node Bremen.
Driving to Bremerhaven.
Reached node Bremerhaven.
Waiting for Package to be loaded...
Sensor missing: Humidity Temperature . Waiting for missing sensors to be loaded.
All necessary sensors available. Package loading confirmed by ID reader.
Driving to Bremen.
Payload manager
Destination is Frankfurt.
Freight is Fish.
Critical temperature is 2.0 °C.
Publishing transport request from Bremerhaven to Frankfurt.
Truck DemonstratorTruck_default_1 accepted transport order.
Checking available sensors...
Sensor status not okay - informing truck to add missing sensors.
Checking available sensors...
All necessary sensors available - informing truck permission to depart.
Traffic Jams
A7_AD_Walsrode_Hannover
ok
cancel
Bremerhaven
Hamburg
Bremen
Osnabrueck
Hannover
Magdeburg
Bielefeld
Duisburg
Dortmund
Kassel
Leipzig
Koeln
Siegen
Erfurt
Fulda
Frankfurt
Connection state: connected Status: SIMRUN_RUNNING Round: 287 Agents: 16 SimRun: default RepeatNr: 1

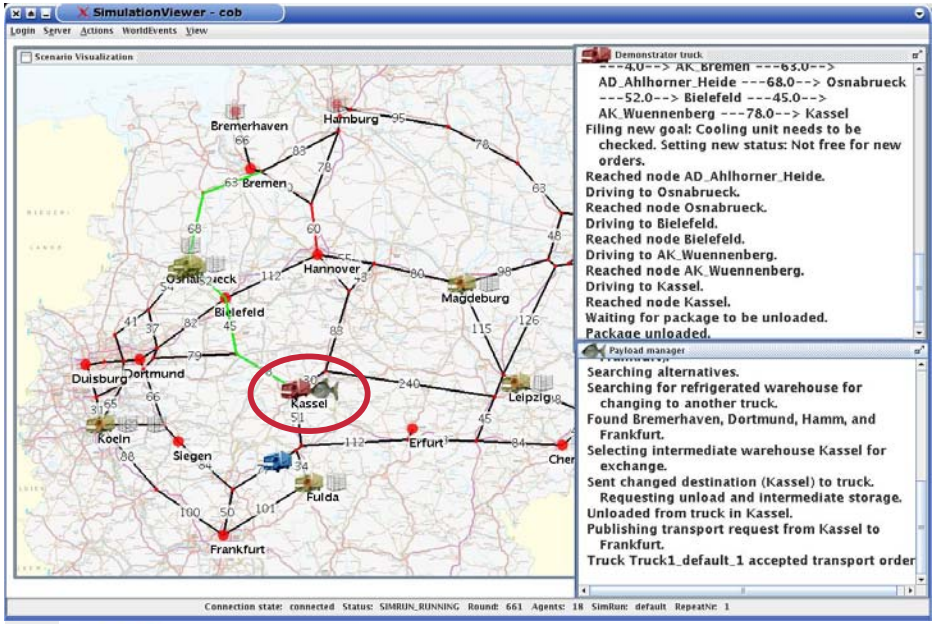

SimulationViewer - cob
Login Server Actions WorldEvents View
Scenario Visualization
Demonstrator truck
Payload requested new destination: Kassel
Reason is too high temperature.
Replanning route...
New route is: Bremerhaven ---66.0--> Bremen ---4.0--> AK_Bremen ---63.0--> AD_Ahlhorner_Heide ---68.0--> 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.
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.
Bremerhaven
Hamburg
Bremen
Hannover
Magdeburg
Bielefeld
Duisburg
Dortmund
Kassel
Leipzig
Koeln
Siegen
Erfurt
Fulda
Frankfurt
Connection state: connected Status: SIMRUN_RUNNING Round: 381 Agents: 17 SimRun: default RepeatNr: 1

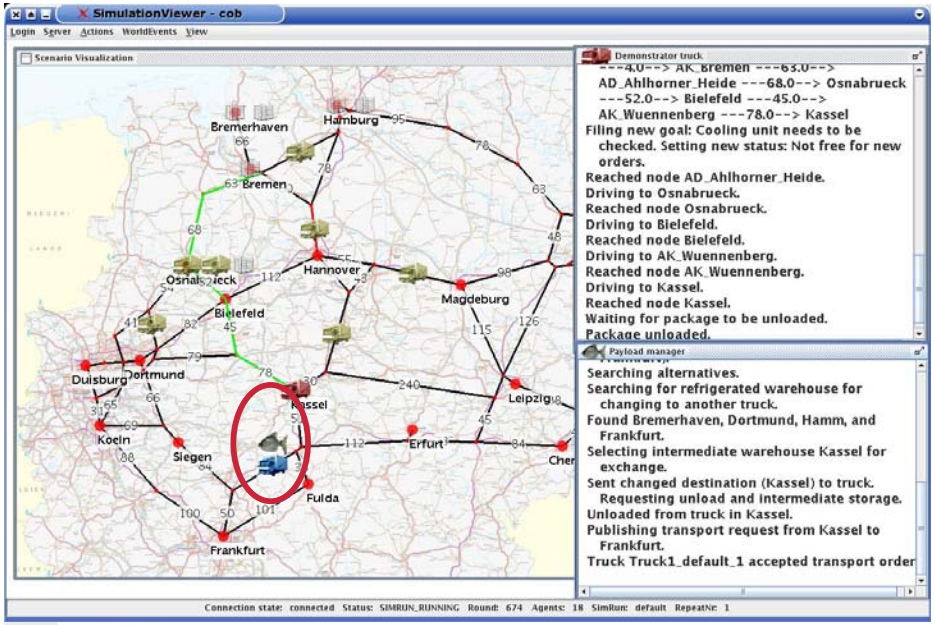

SimulationViewer - cob
Login Server Actions WorldEvents View
Scenario Visualization
Demonstrator truck
---4.0--> AK_Bremen ---63.0--> AD_Ahlhorner_Heide ---68.0--> Osnabrueck ---52.0--> Bielefeld ---45.0--> AK_Wuennenberg ---78.0--> Kassel
Filing new goal: Cooling unit needs to be checked. Setting new status: Not free for new orders.
Reached node AD_Ahlhorner_Heide.
Driving to Osnabrueck.
Reached node Osnabrueck.
Driving to Bielefeld.
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.
Bremerhaven
Hamburg
Bremen
Hannover
Magdeburg
Bielefeld
Duisburg
Dortmund
Kassel
Leipzig
Koeln
Siegen
Erfurt
Fulda
Frankfurt
Connection state: connected Status: SIMRUN_RUNNING Round: 470 Agents: 15 SimRun: default RepeatNr: 1

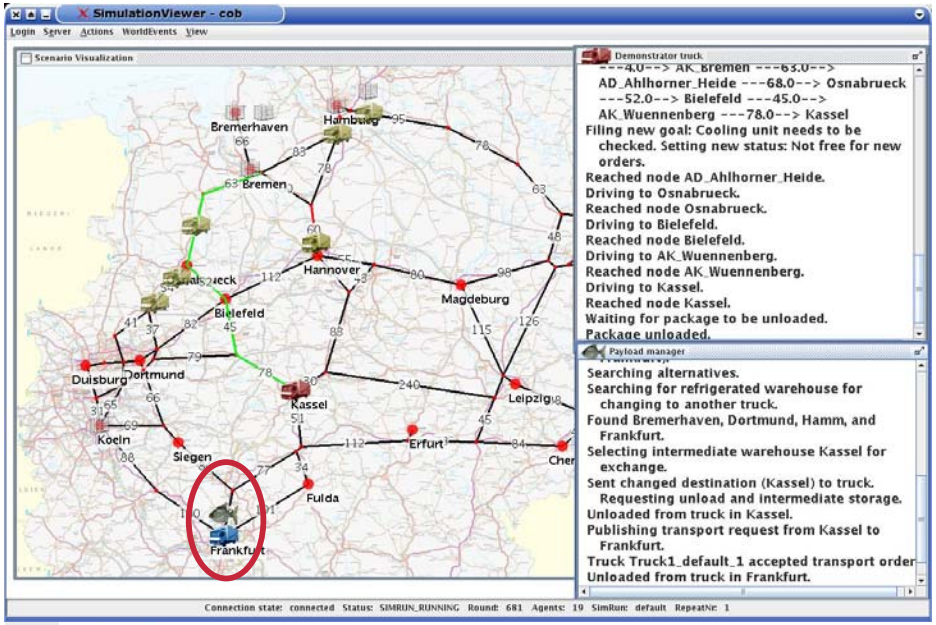

SimulationViewer - cob
Login Server Actions WorldEvents View
Scenario Visualization
Demonstrator truck
AD_Ahlhorner_Heide ---68.0--> Osnabrueck
---52.0--> Bielefeld ---45.0-->
AK_Wuennenberg ---78.0--> Kassel
Filing new goal: Cooling unit needs to be checked. Setting new status: Not free for new orders.
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.
Bremerhaven
Hamburg
Bremen
Hannover
Magdeburg
Osnabrueck
Bielefeld
Duisburg
Dortmund
Kassel
Leipzig
Koeln
Siegen
Erfurt
Fulda
Frankfurt
Connection state: connected Status: SIMRUN_RUNNING Round: 585 Agents: 15 SimRun: default RepeatNr: 1

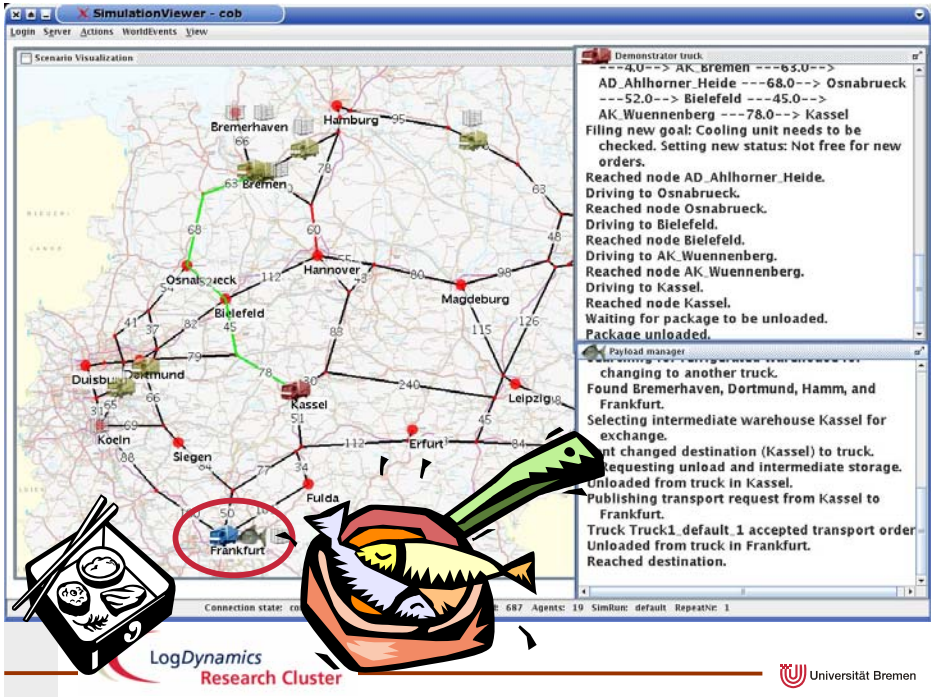

SimulationViewer - cob
Login Server Actions WorldEvents View
Scenario Visualization
Demonstrator truck
AD_Ahlhorner_Heide ---68.0--> Osnabrueck
---52.0--> Bielefeld ---45.0-->
AK_Wuennenberg ---78.0--> Kassel
Filing new goal: Cooling unit needs to be checked. Setting new status: Not free for new orders.
Reached node AD_Ahlhorner_Heide.
Driving to Osnabrueck.
Reached node Osnabrueck.
Driving to Bielefeld.
Reached node Bielefeld.
Driving to AK_Wuennenberg.
Reached node AK_Wuennenberg.
Driving to Kassel.
Reached node Kassel.
Waiting for package to be unloaded.
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.
Bremerhaven
Hamburg
Bremen
Hannover
Magdeburg
Osnabrueck
Bielefeld
Duisburg
Dortmund
Kassel
Leipzig
Koeln
Siegen
Erfurt
Fulda
Frankfurt
Connection state: connected Status: SIMRUN_RUNNING Round: 610 Agents: 24 SimRun: default RepeatNr: 1


SimulationViewer - cob
Login Server Actions WorldEvents View
Scenario Visualization
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.
Reached node AK_Wuennenberg.
Driving to Kassel.
Reached node Kassel.
Waiting for package to be unloaded.
Package unloaded.
Payload manager
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.
Unloaded from truck in Kassel.
Publishing transport request from Kassel to Frankfurt.
Bremerhaven
Hamburg
Bremen
Hannover
Magdeburg
Osnabrueck
Bielefeld
Duisburg
Dortmund
Kassel
Leipzig
Koeln
Siegen
Erfurt
Fulda
Frankfurt
Connection state: connected Status: SIMRUN_RUNNING Round: 653 Agents: 18 SimRun: default RepeatNr: 1


SimulationViewer - cob
Login Server Actions WorldEvents View
Scenario Visualization
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.
Reached node AK_Wuennenberg.
Driving to Kassel.
Reached node Kassel.
Waiting for package to be unloaded.
Package unloaded.
Payload manager
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.
Unloaded from truck in Kassel.
Publishing transport request from Kassel to Frankfurt.
Truck Truck1_default_1 accepted transport order
Bremerhaven
Hamburg
Bremen
Hannover
Magdeburg
Osnabrueck
Bielefeld
Duisburg
Dortmund
Kassel
Leipzig
Koeln
Siegen
Erfurt
Fulda
Frankfurt
Connection state: connected Status: SIMRUN_RUNNING Round: 661 Agents: 18 SimRun: default RepeatNr: 1







Conclusion

Costs

- One time investment for embedded computer and sensor equipment

Advantages

- Use 15 cent RFID-Tags for data logging with full sensor utilization
- Online accessibility
- Option for intelligent decentralized decisions

Thank you for your attention

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