Artifact-driven Process Monitoring

Giovanni Meroni (supervisor Dr. Pierluigi Plebani)

Milan – June 26, 2018

Introduction

- **Business process**: “chain of events, activities and decisions” [A], “a set of activities that are performed in coordination in an organizational and technical environment” [B]
- **Business process monitoring**: tools and techniques to determine:
  - If activities are correctly executed
  - If dependencies among activities are respected
- **Artifact-driven process monitoring**: a novel technique for business process monitoring, that allows to:
  - Autonomously collect information
  - Determine violations at runtime
  - Without human intervention

[A] Dumas, M., La Rosa, M., Mendling, J., Reijers, H.: Fundamentals of Business Process Management
[B] Weske, M.: Business Process Management

Agenda

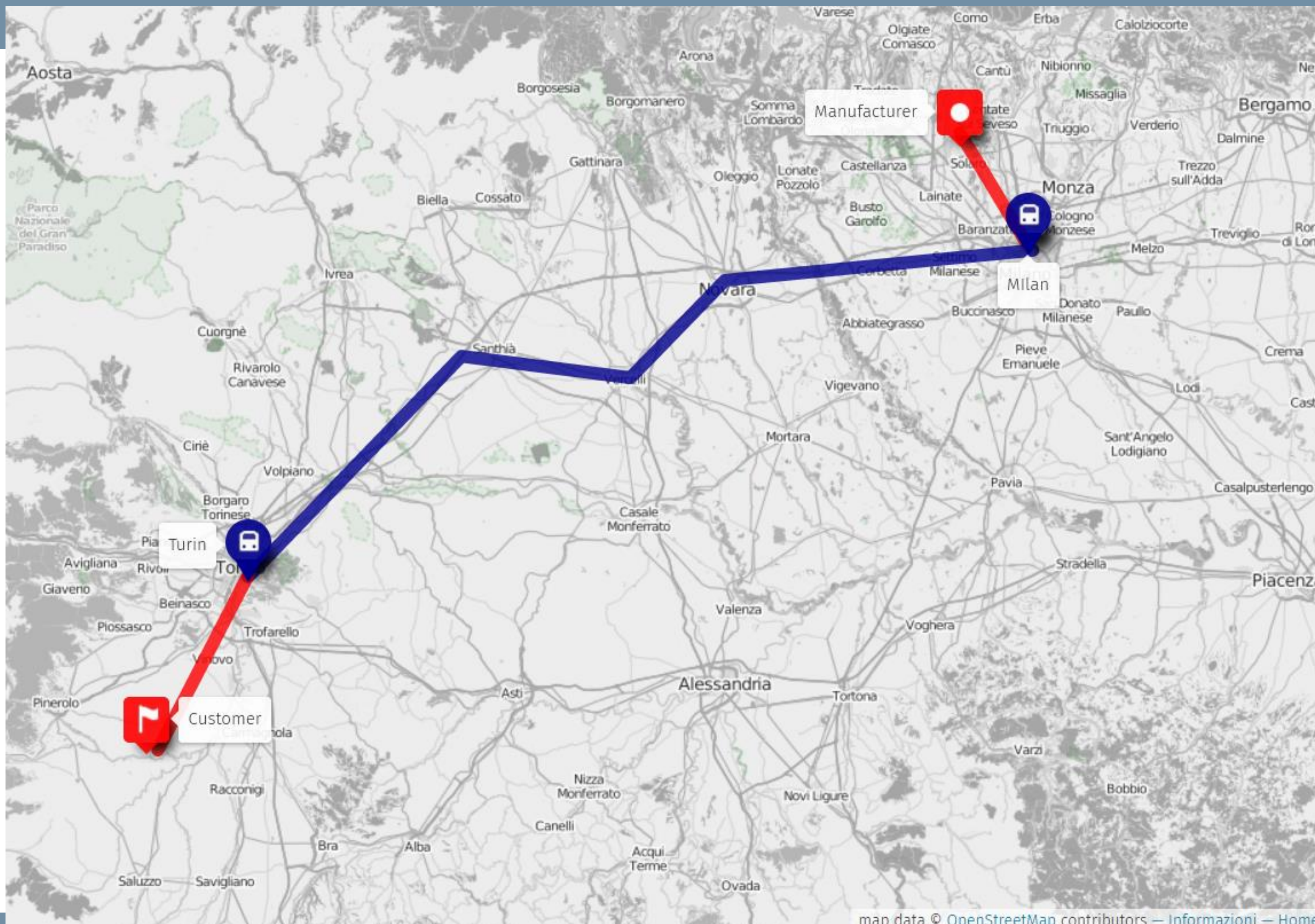
- Motivations
- Idea: artifact-driven process monitoring
- Contributions:
  - E-GSM modeling language
  - Method to configure smart objects
  - Monitorabilty assessment and improvement
  - SMARTifact monitoring platform
- Dissemination
- Validation
- Conclusion & future work

Motivations

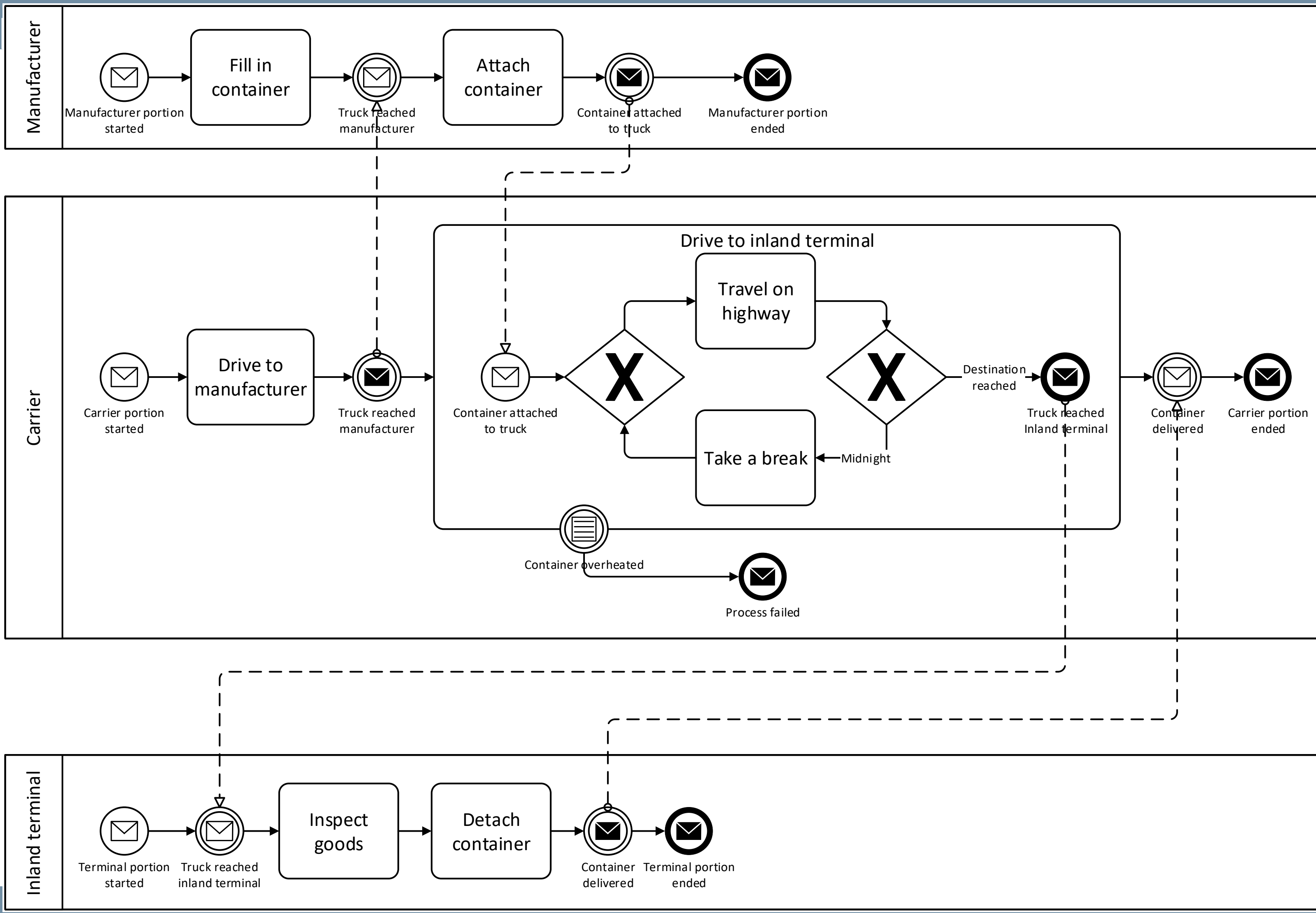
Context

- Many intra-organizational processes are becoming multi-party:
  - Portions of a process are outsourced to external organizations
  - Companies interact with goods without owning them
- Organizations are interested in monitoring the execution of multi-party processes as a whole
  - No guarantee that outsourced activities are performed as agreed
  - No guarantee that goods given to other companies are manipulated as agreed

Motivating example

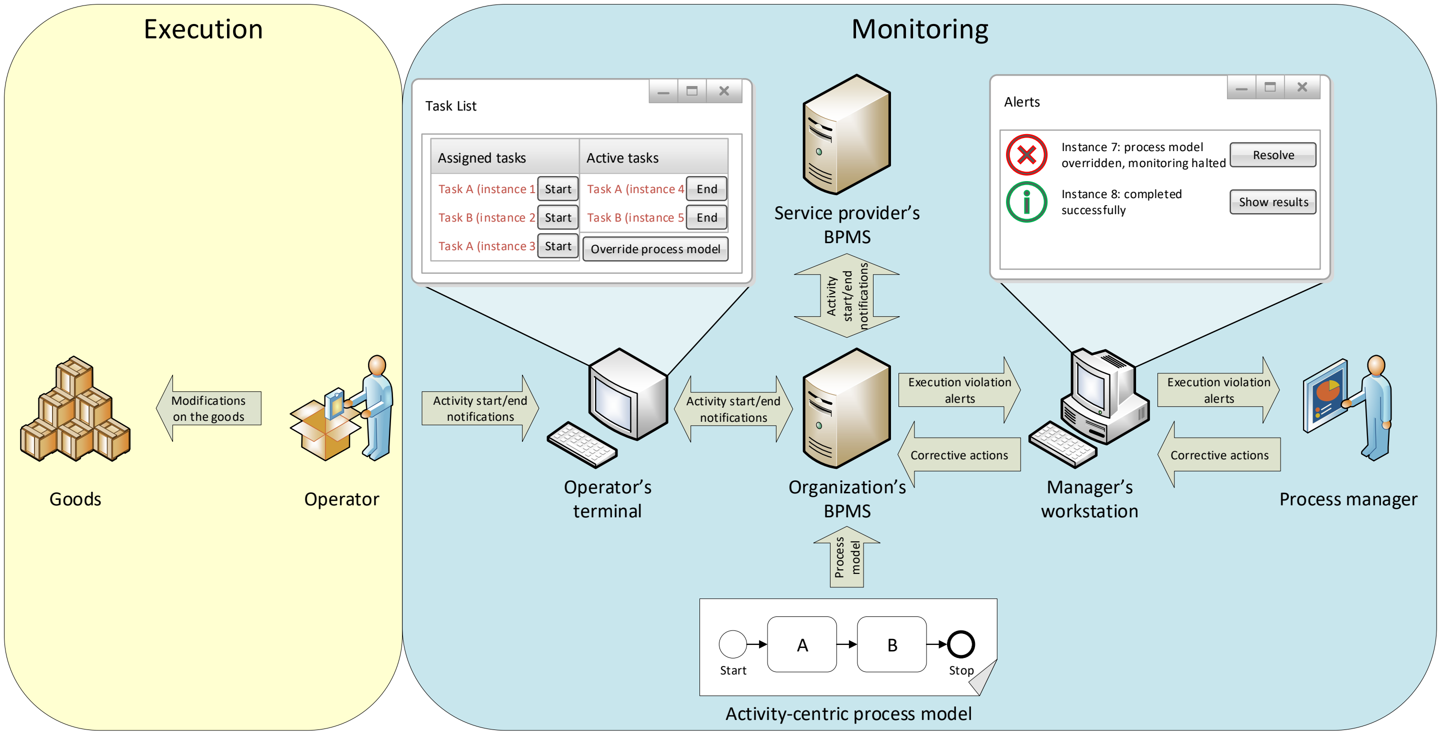


Motivating example



Problem statement

- Monitoring multi-party processes is challenging
  - The process cannot (always) be interrupted
  - Human operators may not provide feedback



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Idea: artifact-driven process monitoring

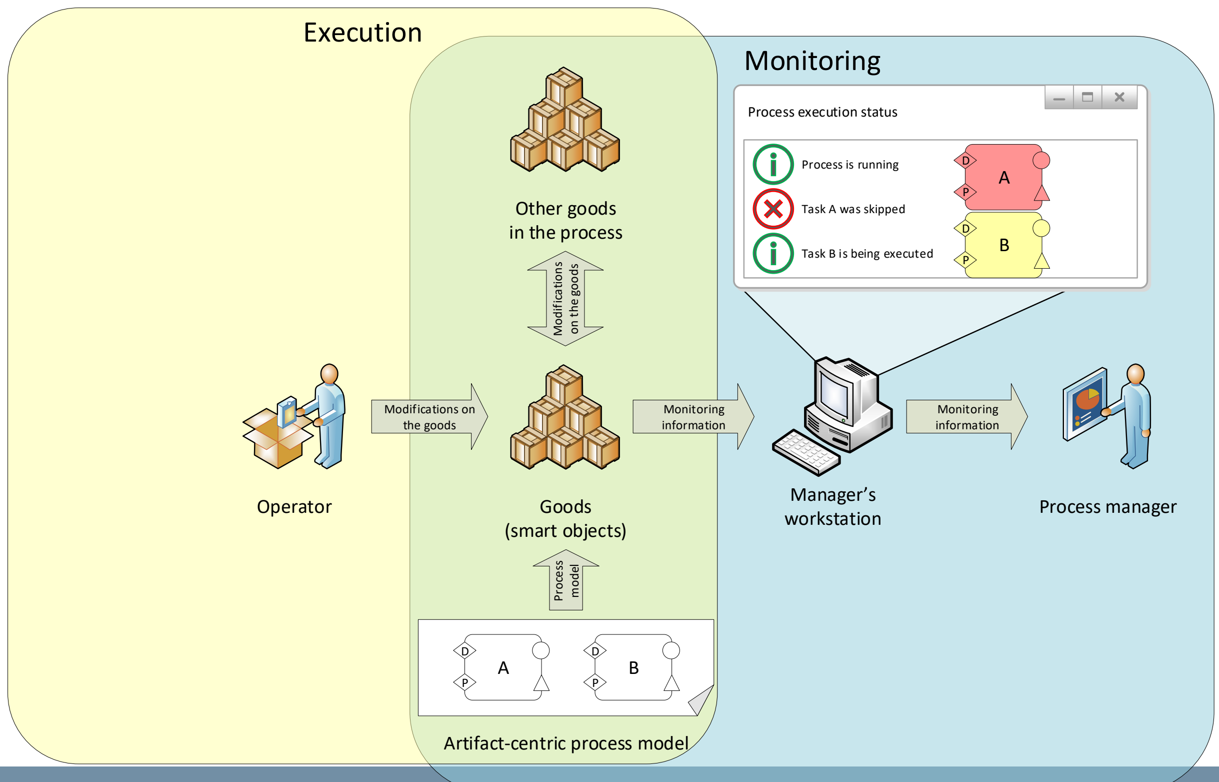
Idea: artifact-driven process monitoring

- Goods participate in multi-party processes
  - Goods belong to a specific organization
  - Goods have visibility on activities
  - The conditions of the goods can be altered by organizations
- Objects participating in a process are named **artifacts**
- Goods can be seen as artifacts
  - For our purposes, goods = artifacts
- Idea: Artifact-driven process monitoring [1]
  - Monitoring is directly performed on the artifacts
  - The artifact "knows" when its conditions change
  - The artifact "knows" when activities are executed

[1] Meroni, G.: Integrating the Internet of Things with Business Process Management: A Process-aware Framework for Smart Objects. In: CAiSE 2015 Doctoral Consortium

Objectives

- Exploit the Internet of Things to monitor processes
- Make objects aware of the process
- Perform monitoring transparently and autonomously



Contributions

- Extended-GSM (E-GSM), a declarative language to autonomously monitor business processes
- A method to configure smart objects for artifact-driven monitoring
- A technique to formalize, assess and improve the monitorability of a process
- SMARTifact, an artifact-driven monitoring platform prototype

Contributions

Extended-GSM modeling language

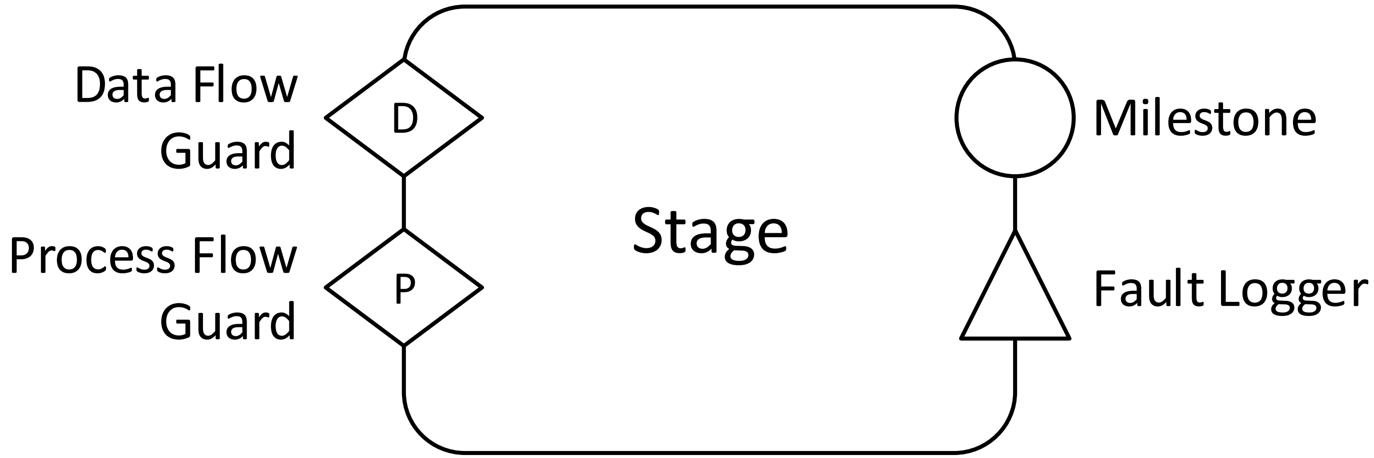
Limitations of activity-centric languages

- Activity-centric languages are unsuited for artifact-driven process monitoring:
  - Execution order must strictly adhere to the process definition
  - An orchestrator must explicitly starts or ends activities
- Artifact-centric languages overcome these limitations [2]
  - Only what is explicitly stated in the model is constrained
  - Everything else is allowed
  - Guard-Stage-Milestone is a good starting point

[2] Baresi, L., Meroni, G., Plebani, P.: A GSM-based approach for Monitoring Cross-Organization Business Processes using Smart Objects. In: BPM 2015 Workshops.

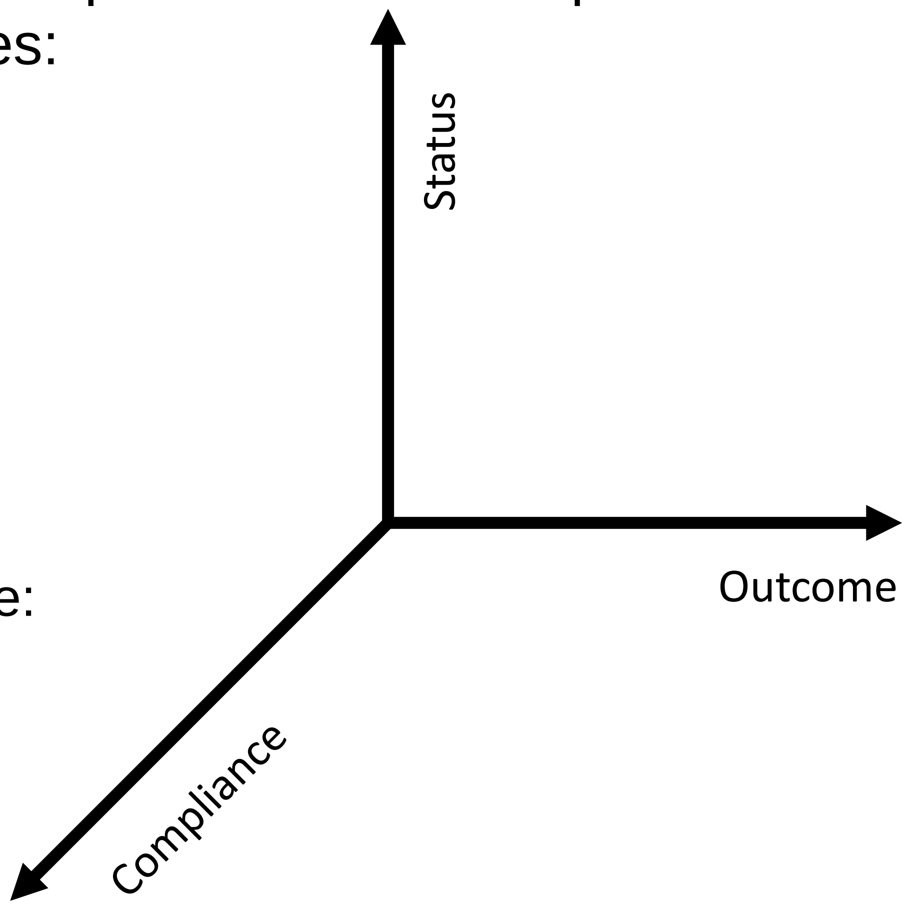
Extended-GSM overview

- GSM provides the following constructs:
  - **Data Flow Guards** to determine task activation
  - **Milestones** to determine task termination
- E-GSM adds these additional constructs:
  - **Process Flow Guards** to define the expected process flow
  - **Fault Loggers** to determine if a task is unsuccessfully executed



Process monitoring perspectives

- E-GSM allows to monitor processes with respect to three orthogonal perspectives:
  – Execution status:
    - unopened
    - opened
    - closed
  – Execution outcome:
    - regular
    - faulty
  – Execution compliance:
    - on time
    - out of order
    - skipped



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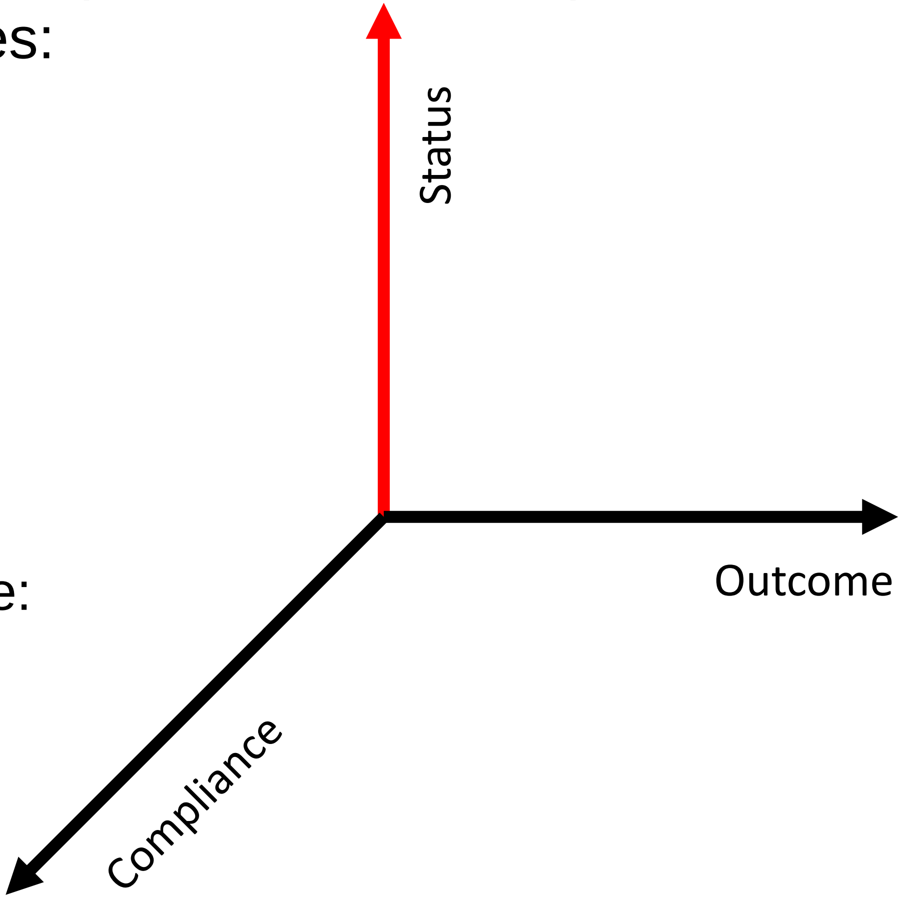

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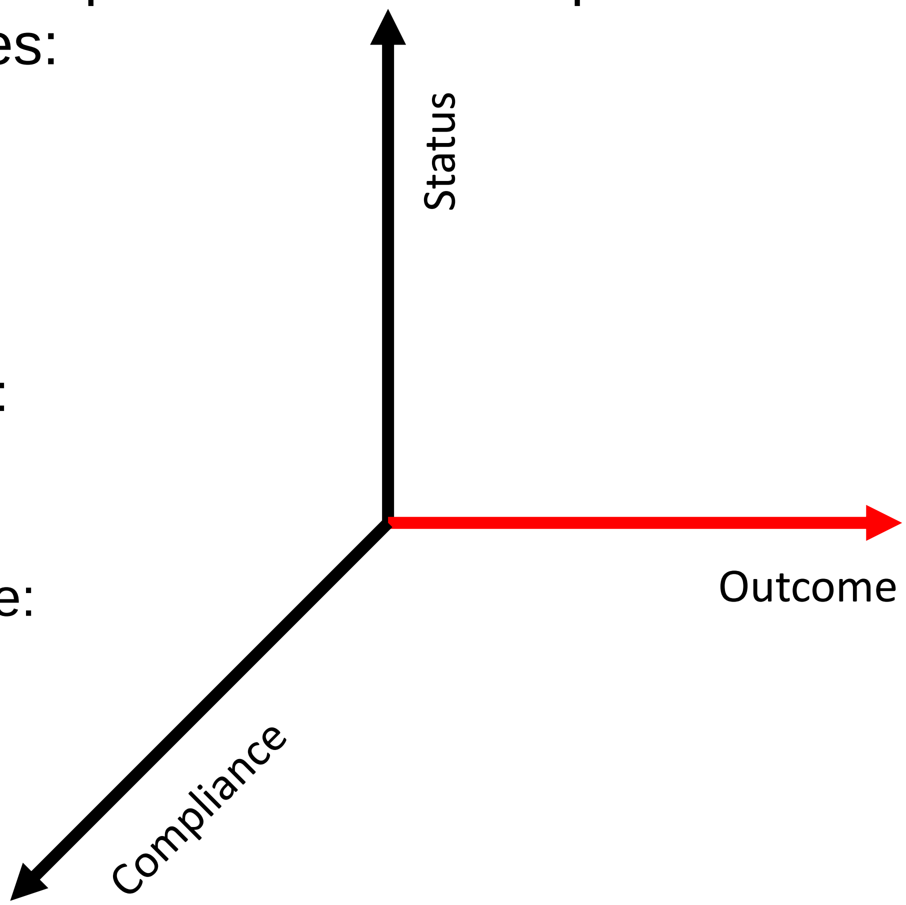

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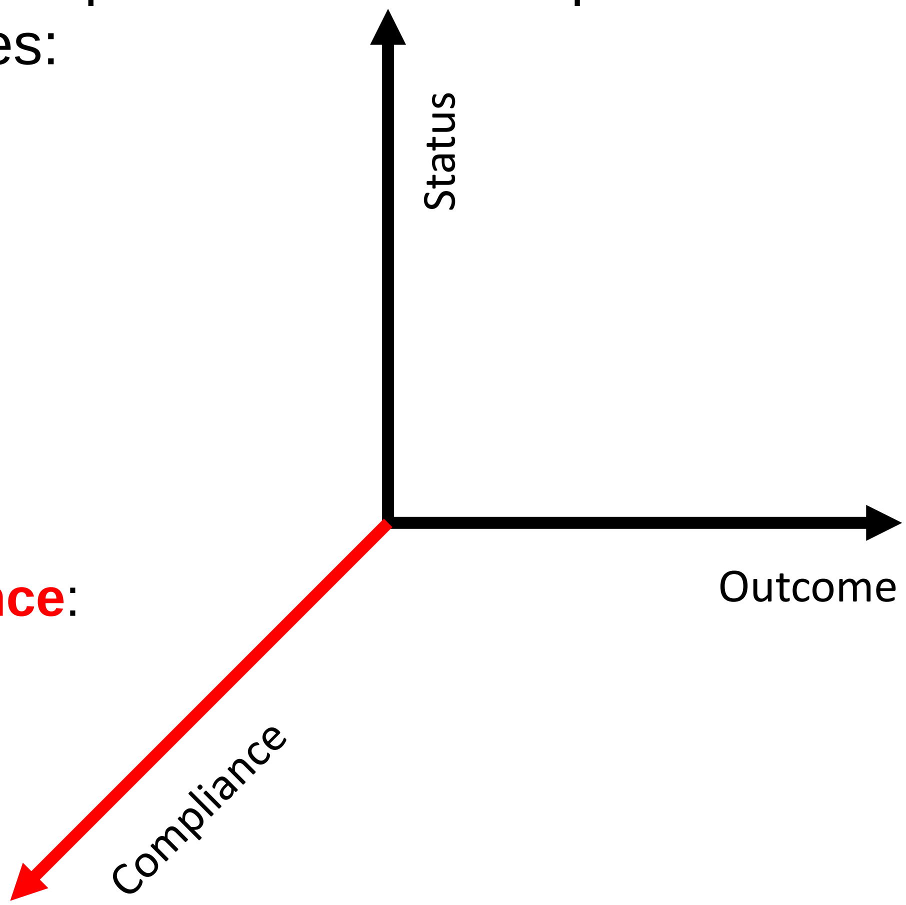


Contributions

Method for configuring smart objects

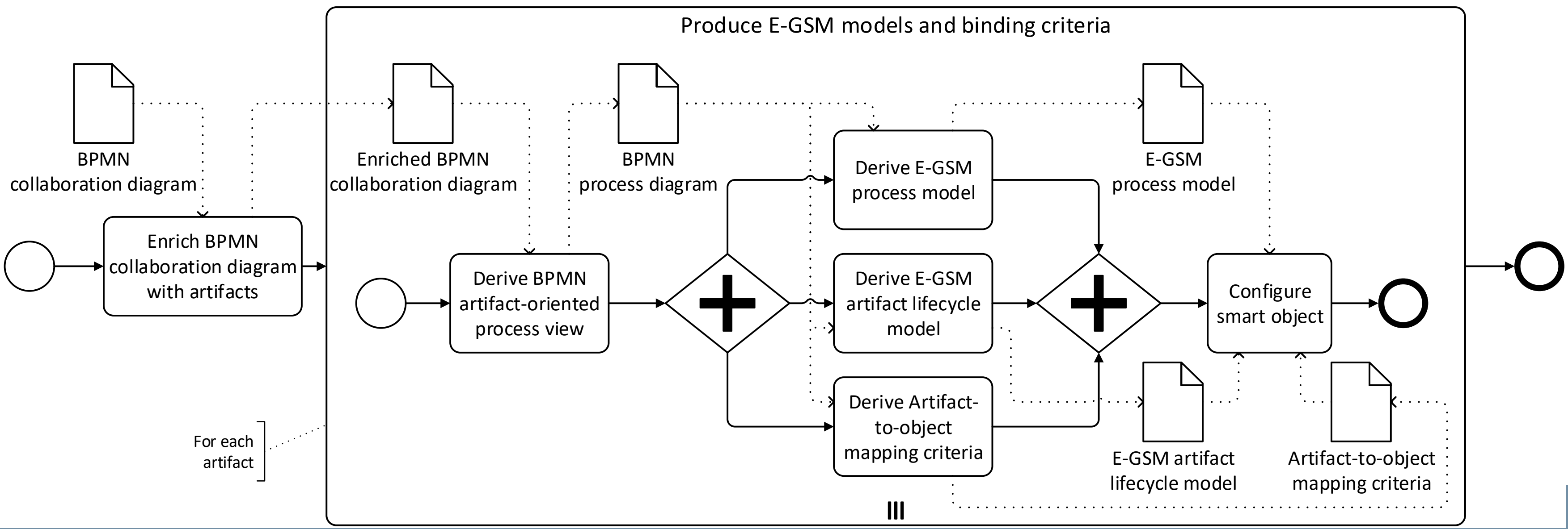
Configuring smart objects for artifact-driven monitoring

- The adoption of E-GSM is not straightforward
  - Artifact-centric languages are difficult to model
  - Processes may already be modeled in BPMN
  - Modelers don’t want to do the same task twice
- Multiple Smart Objects required to monitor the process
- Smart Objects may participate in a portion of the process
  - Information exchanged before/after that portion is useless
- We propose a method to easily configure smart objects [3] [4] [5]

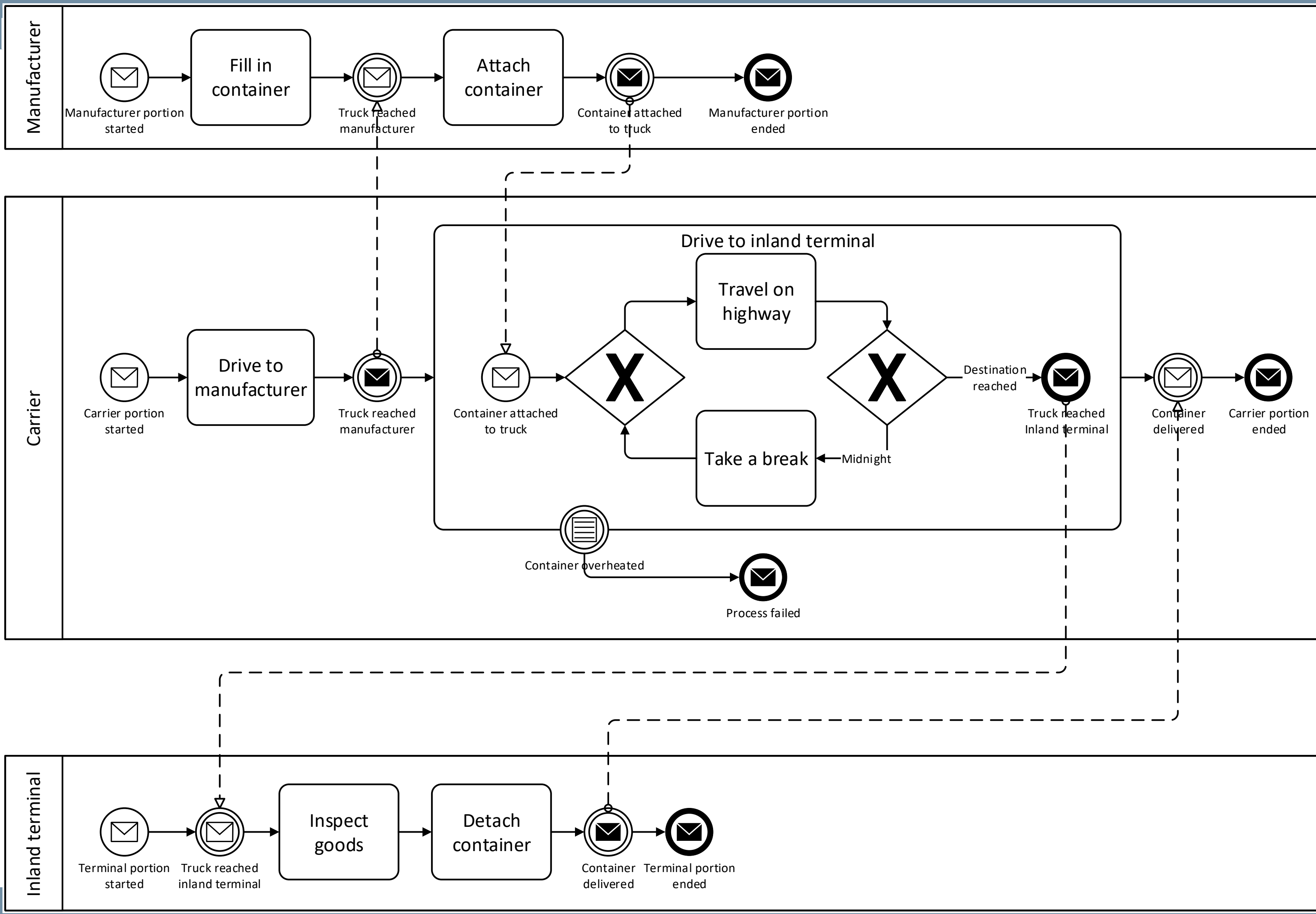
[3] Baresi, L., Meroni, G., Plebani, P.: Using the Guard-Stage-Milestone Notation for Monitoring BPMN-based Processes. In: Enterprise, Business-Process and Information Systems Modeling 2016
[4] Meroni, G., Di Ciccio, C., Mendling, J.: Artifact-driven process monitoring: Dynamically binding real-world objects to running processes. In: CAiSE-Forum-DC 2017
[5] Meroni, G., Baresi, L., Montali, M., Plebani, P.: Multi-party business process compliance monitoring through IoT-enabled artifacts. In: Information Systems. Volume 73 (2018)

Configuring smart objects for artifact-driven monitoring

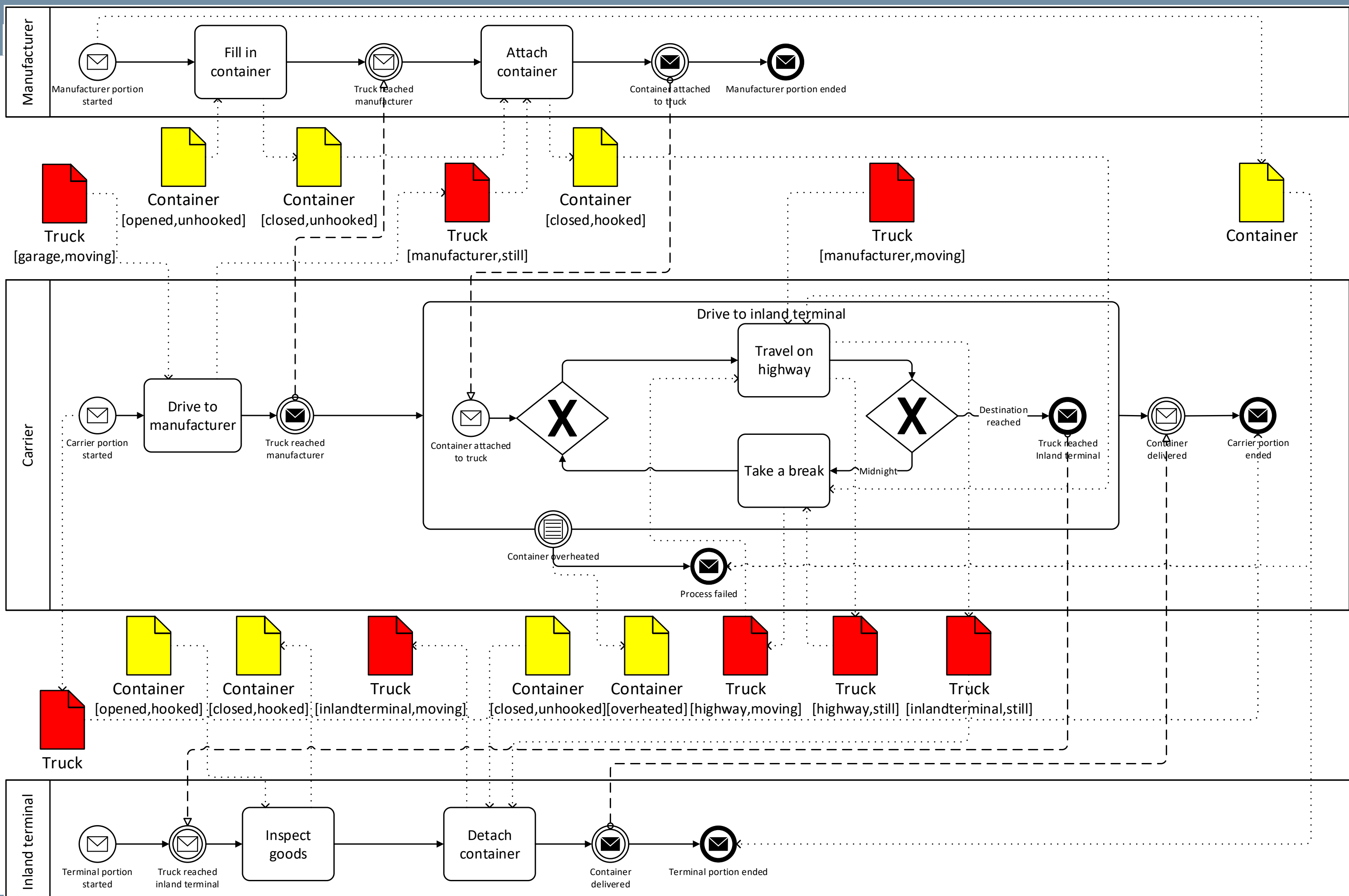
- Input: BPMN collaboration diagram
- Output:
  - rules to dynamically bind and unbind smart objects
  - E-GSM models to monitor:
    - When activities composing the process are performed
    - If the conditions of the smart object evolve as expected



Back to the motivating example



Step 1 – Enrich BPMN collaboration diagram



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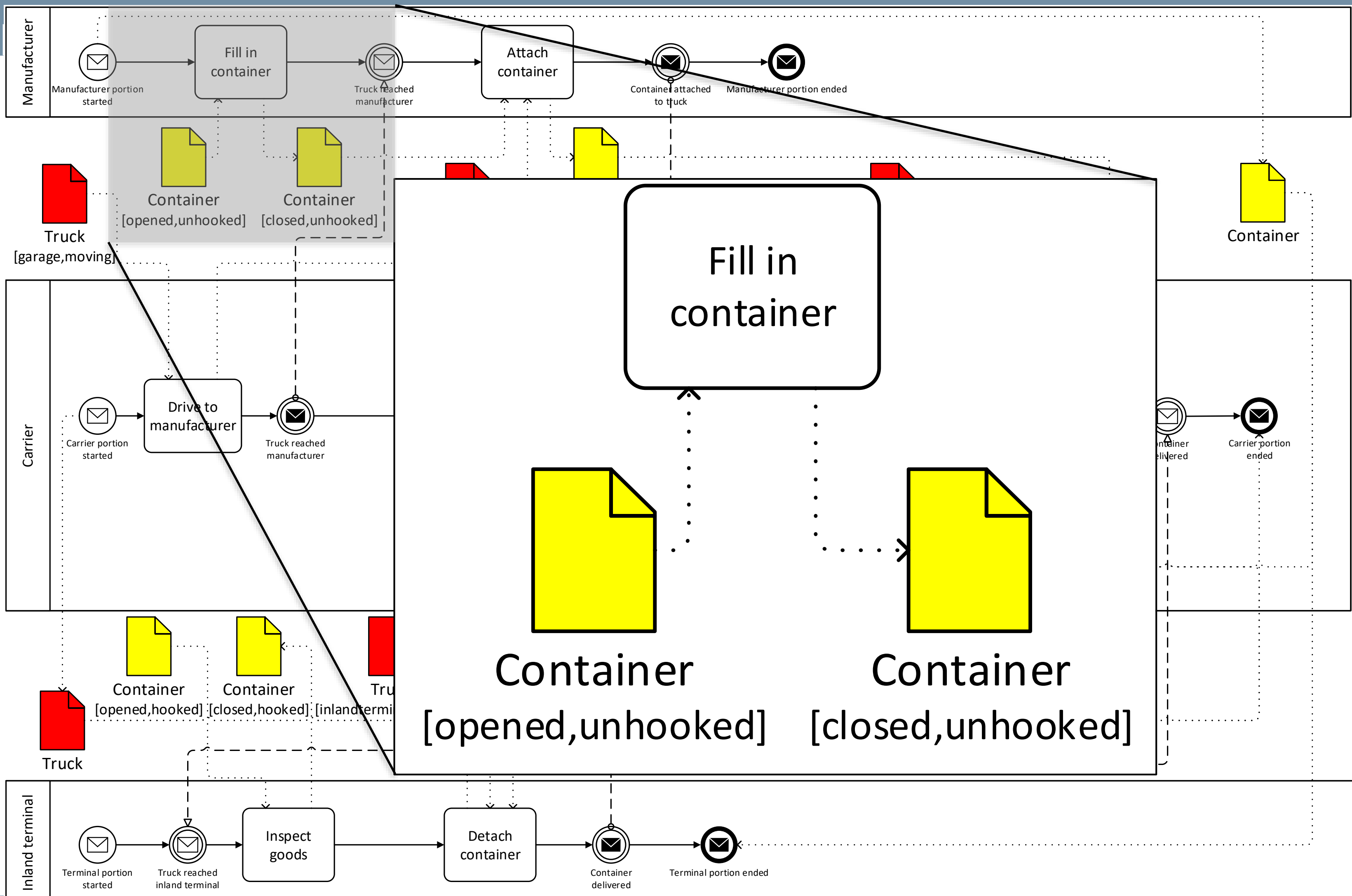

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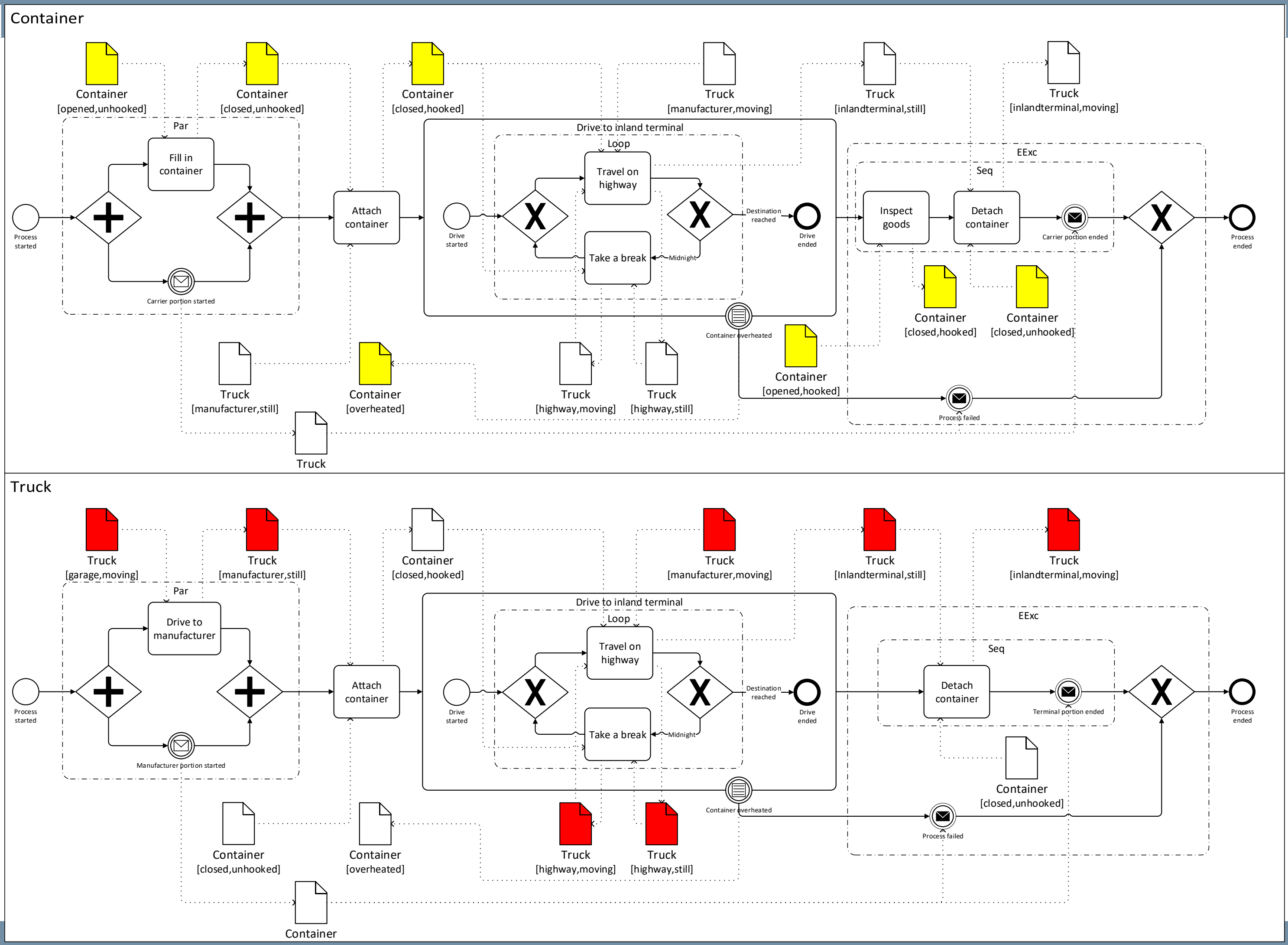
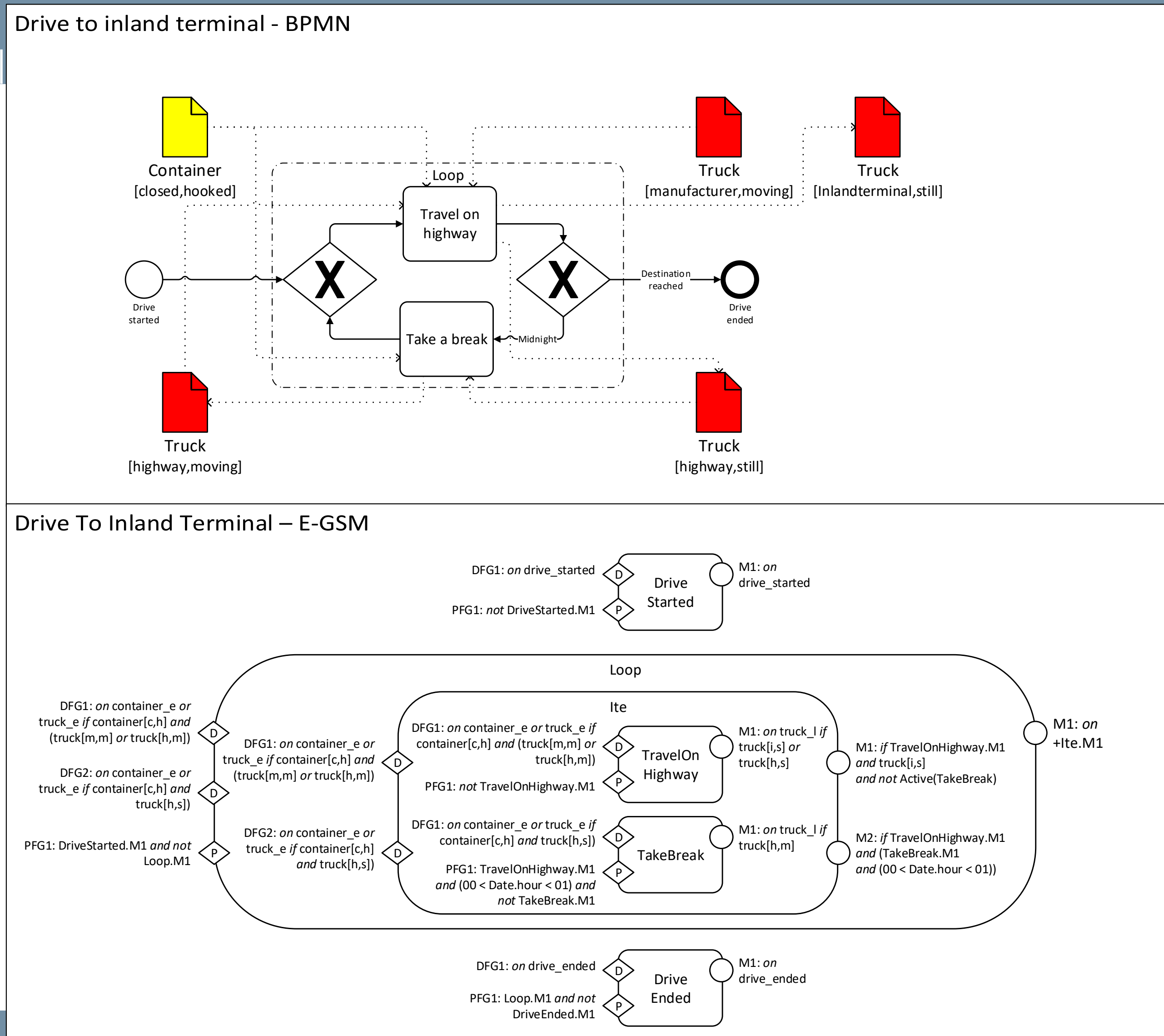
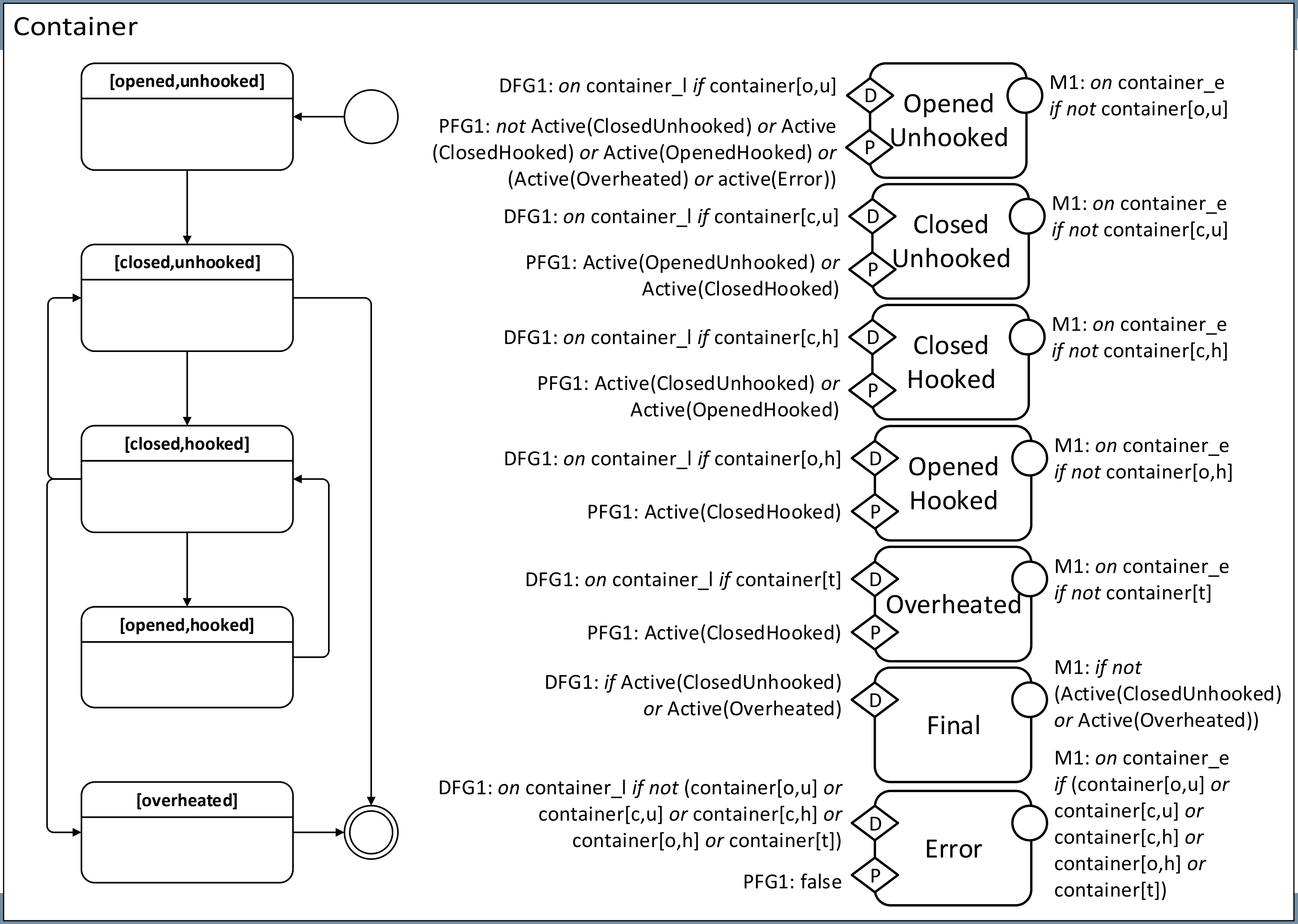
Step 2 – Derive BPMN process view



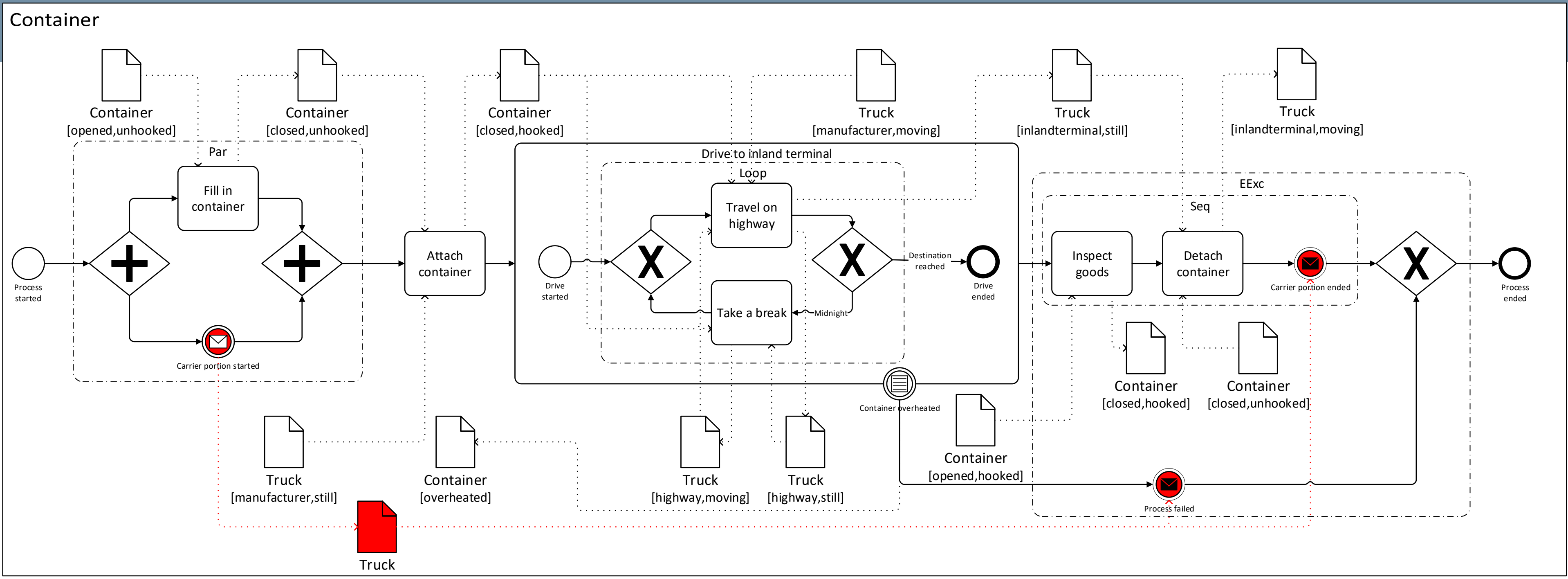
Step 3a – Derive the E-GSM process model



Step 3b – Derive E-GSM artifact lifecycle model



Step 3c – Derive mapping criteria



<LocalArtifact name="Container"/>
<Mapping><Artifact name="Truck">
<BindingEvent id="Carrier_portion_started"/>
<UnbindingEvent id="Carrier_portion_ended"/>
<UnbindingEvent id="Process_failed"/>
</Artifact></Mapping>

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Contributions

Monitorability assessment and improvement

Monitorability of a process

- Not all smart objects are suited to monitor a process
- The **monitorability** of a process indicates how many activities in a process can be monitored by smart objects [6]
- The capabilities of the Smart Objects affect monitorability
  - The execution of activities is determined by the state of the smart objects
  - The state of a smart object is inferred from its physical properties
  - The physical properties of a smart object are measured by sensors

[6] Meroni, G., Plebani, P.: Artifact-Driven Monitoring for Human-Centric Business Processes with Smart Devices: Assessment and Improvement. In: BPM Forum 2017

Assessing and improving monitorability

- We exploit ontologies to formalize:
  - Sensor data provided by smart objects
  - Rules to derive the state of an artifact from sensor data
- We then query the ontologies to:
  - Compute the monitorability of activities
  - Derive the monitorability of the process
  - Suggest modifications to improve monitorability:
    - Which sensors should be added to smart objects
    - Which rules can be easily altered to exploit other sensor data

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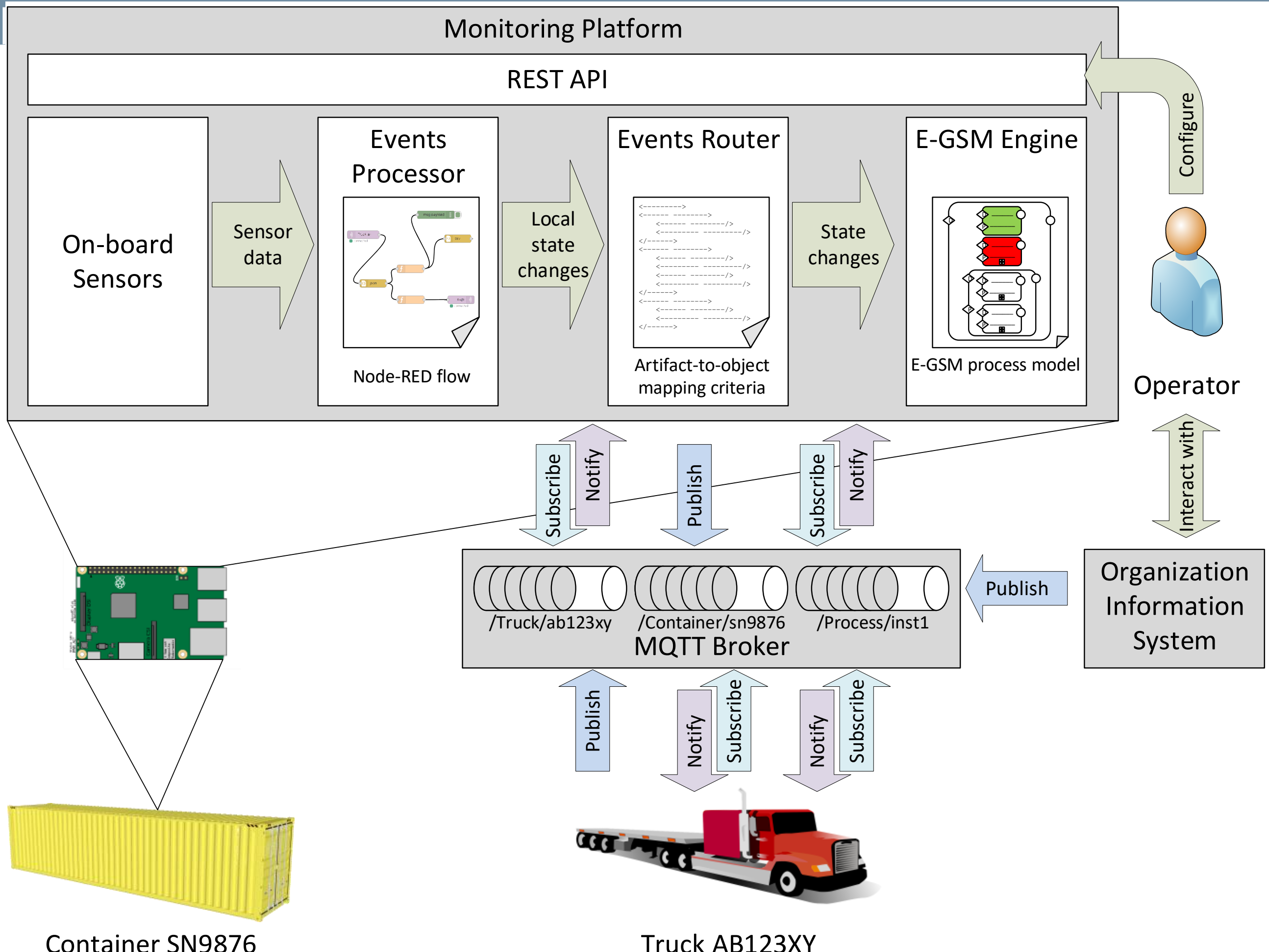
Contributions

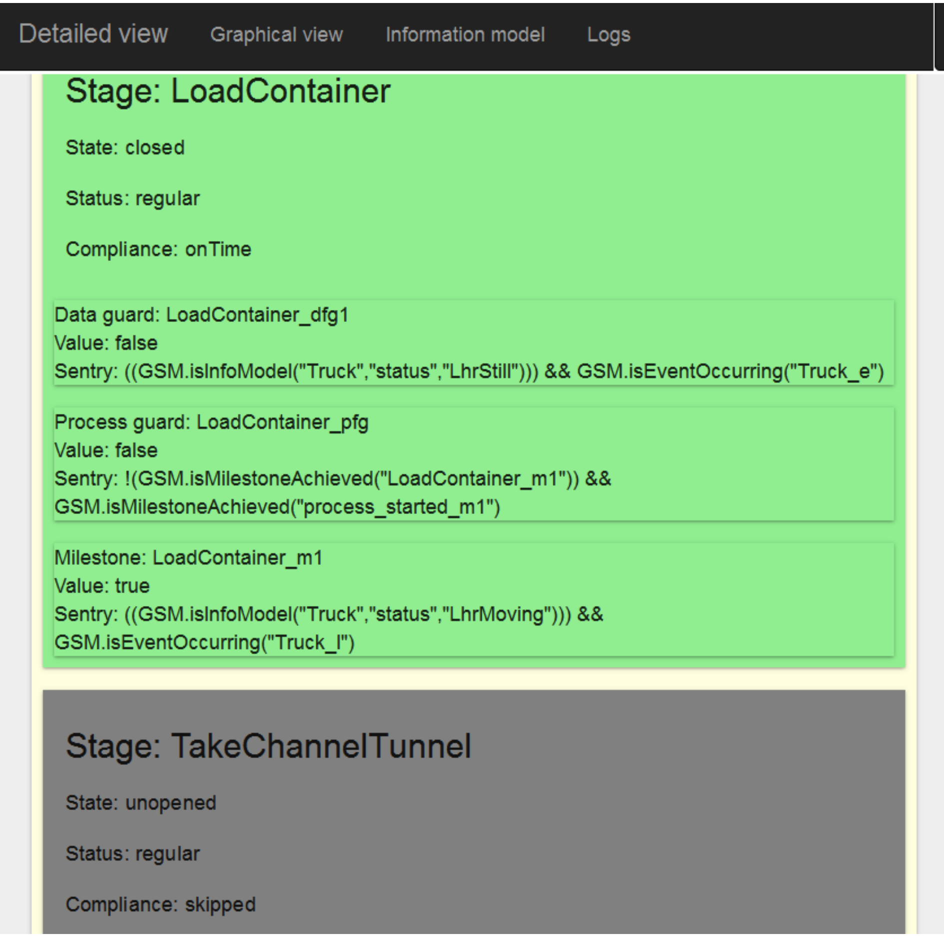
SMARTifact monitoring platform prototype

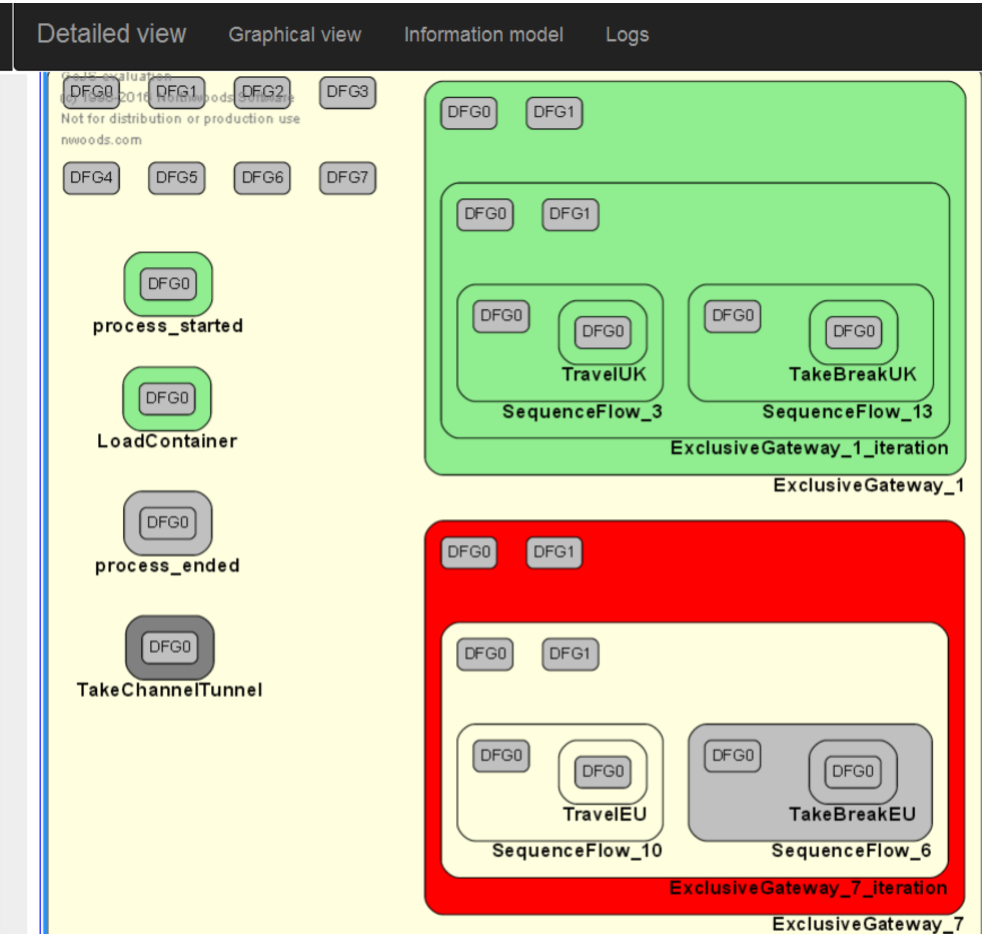
SMARTifact – An artifact-driven monitoring platform



[7] Baresi, L., Di Ciccio, C., Mendling, J., Meroni, G., Plebani, P.: mArtifact: an Artifact-driven Process Monitoring Platform. In: BPM 2017 Demo Track and BPM Dissertation Award

SMARTifact – An artifact-driven monitoring platform





Validation

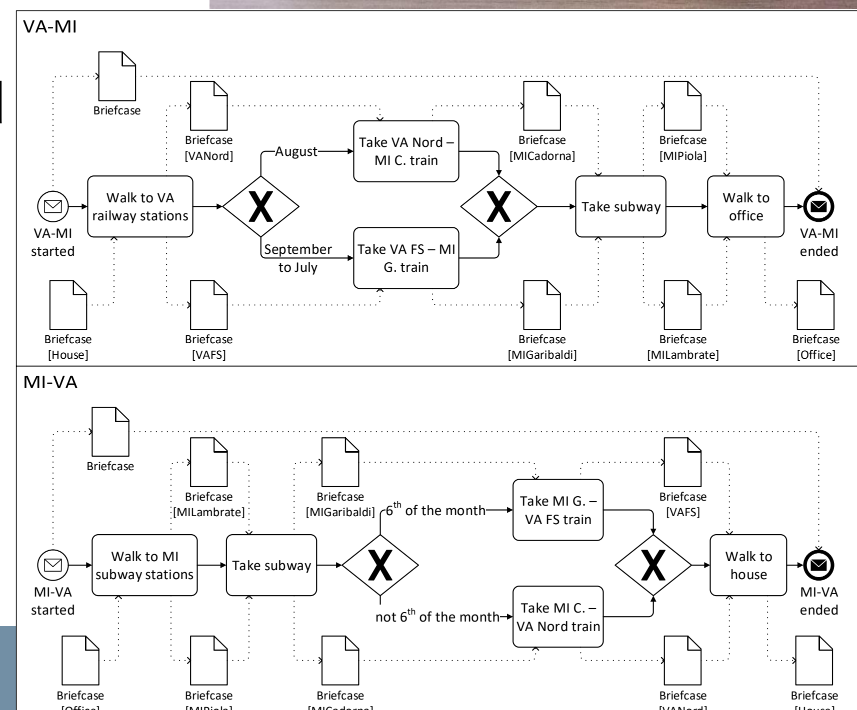
Validating SMARTifact – Simulated environment

- Eight shipment processes provided by a large European logistics company [8]
- Two datasets related to 77 shipments
  - Dataset 1: position and speed of trucks (19966 entries)
  - Dataset 2: activation and termination of activities in shipment processes, manually notified by truck drivers (815 entries)
- Dataset 1 was replayed on SMARTifact
- The results of the monitoring were compared with Dataset 2
  - Over 93% of the shipments were correctly monitored
  - SMARTifact detected more activities than manual notifications
  - Detection delay was less than 5 minutes w.r.t. 533 minutes uptime

[8] Meroni, G., Di Ciccio, C., Mendling, J.: An Artifact-Driven Approach to Monitor Business Processes Through Real-World Objects. In: ICSOC 2017

Validating SMARTifact – Field evaluation

- Equipped my briefcase with an Intel Galileo SBC and a GPS receiver
- Monitored for 4 months the process of going to work and back home
- Almost 95% of the process instances were correctly identified
- The median detection delay was less than 2 minutes, while the processes lasted on average 102 minutes



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Dissemination

Publications

- Meroni, G.: Integrating the Internet of Things with Business Process Management: A Process-aware Framework for Smart Objects. In: CAiSE 2015 Doctoral Consortium. CEUR Workshop Proceedings, pp 56-64. CEUR-WS.org (2015)
- Baresi, L., Meroni, G., Plebani, P.: A GSM-based approach for Monitoring Cross-Organization Business Processes using Smart Objects. In: BPM 2015 Workshops. LNBIP, pp 389-400. Springer International Publishing (2016)
- **Baresi, L., Meroni, G., Plebani, P.: Using the Guard-Stage-Milestone Notation for Monitoring BPMN-based Processes**. In: Enterprise, Business-Process and Information Systems Modeling 2016. LNBIP, pp.18-33. Springer International Publishing (2016)
- Baresi, L., Meroni, G., Plebani, P.: On Handling Business Process Anomalies through Artifact-based Modeling. In: CAiSE-Forum 2016. CEUR Workshop Proceedings, pp 9-16. CEUR-WS.org (2016)
- Meroni, G., Di Ciccio, C., Mendling, J.: Artifact-driven process monitoring: Dynamically binding real-world objects to running processes. In: CAiSE-Forum-DC 2017. CEUR Workshop Proceedings, pp. 105–112. CEUR-WS.org (2017)
- Meroni, G., Plebani, P.: Artifact-Driven Monitoring for Human-Centric Business Processes with Smart Devices: Assessment and Improvement. In: BPM Forum 2017. LNBIP, pp 160-176. Springer International Publishing (2017)
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- **Meroni, G., Di Ciccio, C., Mendling, J.: An Artifact-Driven Approach to Monitor Business Processes Through Real-World Objects**. In: Service-Oriented Computing - ICSOC 2017. LNCS, pp. 297–313. Springer International Publishing (2017)
- **Meroni, G., Baresi, L., Montali, M., Plebani, P.: Multi-party business process compliance monitoring through IoT-enabled artifacts.** In: Information Systems. Volume 73, pp. 61 – 78. Elsevier (2017)

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Conclusion & future work

Conclusion

- Artifact-driven process monitoring can effectively monitor inter-organizational processes
  - The IoT makes physical objects smart
  - Operators no longer have to send notifications
  - Violations can be autonomously detected
  - Monitoring is continuous, without human intervention
  - The SMARTifact platform proved the applicability of this approach
- The information required for artifact-driven monitoring can be derived from BPMN models
  - An E-GSM model, to introduce flexibility
  - Criteria to bind and unbind smart objects to running processes

Future Work

- Integrating artifact-driven process monitoring with blockchain to achieve trusted monitoring [9]
- Introducing mechanisms to make monitoring robust when network communications are unreliable [10]
    - Exploring the capabilities of 5G mobile networks
    - Implementing corrective actions to compensate loss and delay
    - Investigating on distributed consistency among smart objects

[9] Meroni, G., Plebani, P.: Combining Artifact-Driven Monitoring with Blockchain: Analysis and Solutions. In: CAiSE 2018 Workshops
[10] Meroni, G., Plebani, P., Baresi, L.: Introducing Eventual Consistency in Artifact-driven Process Monitoring. Paper submitted to EDOC 2018

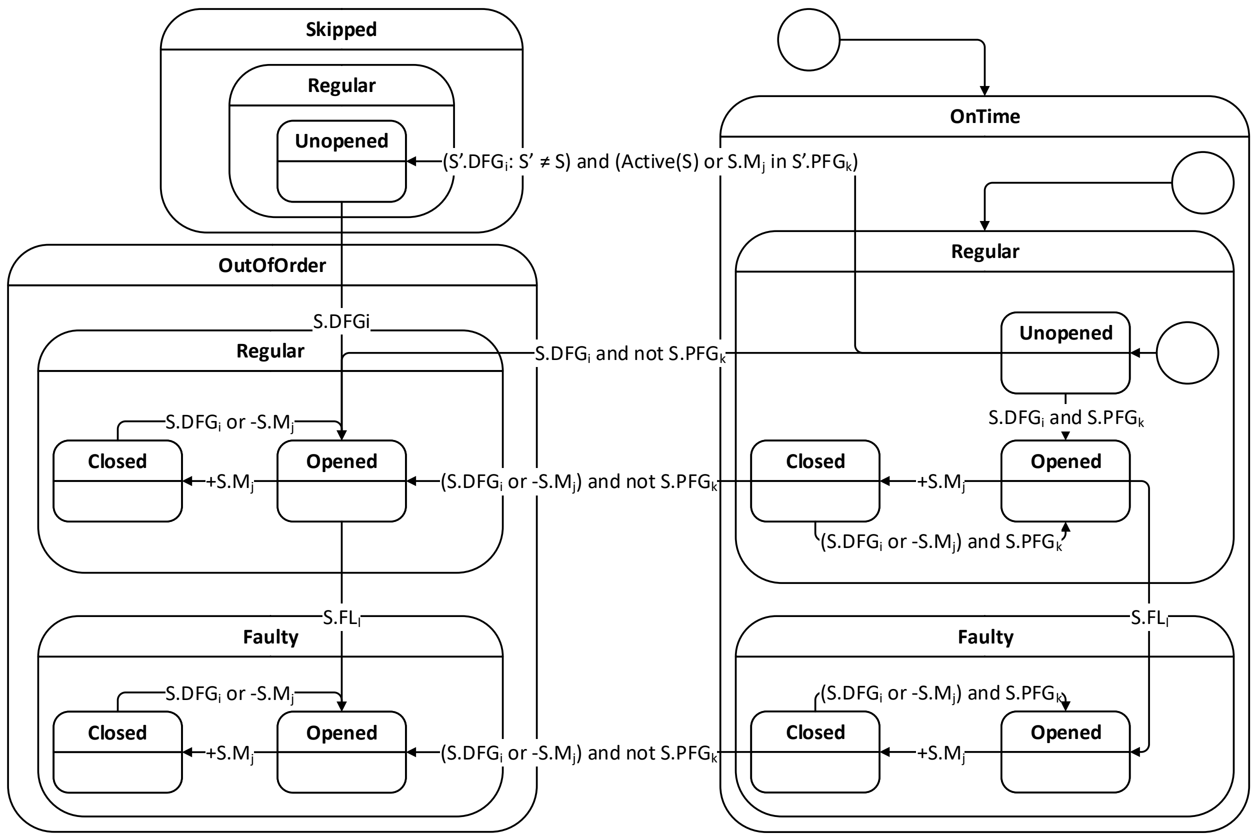
Thanks for your attention

This PhD has been funded by the Italian Project ITS2020
under the Technological National Clusters program

Backup slides

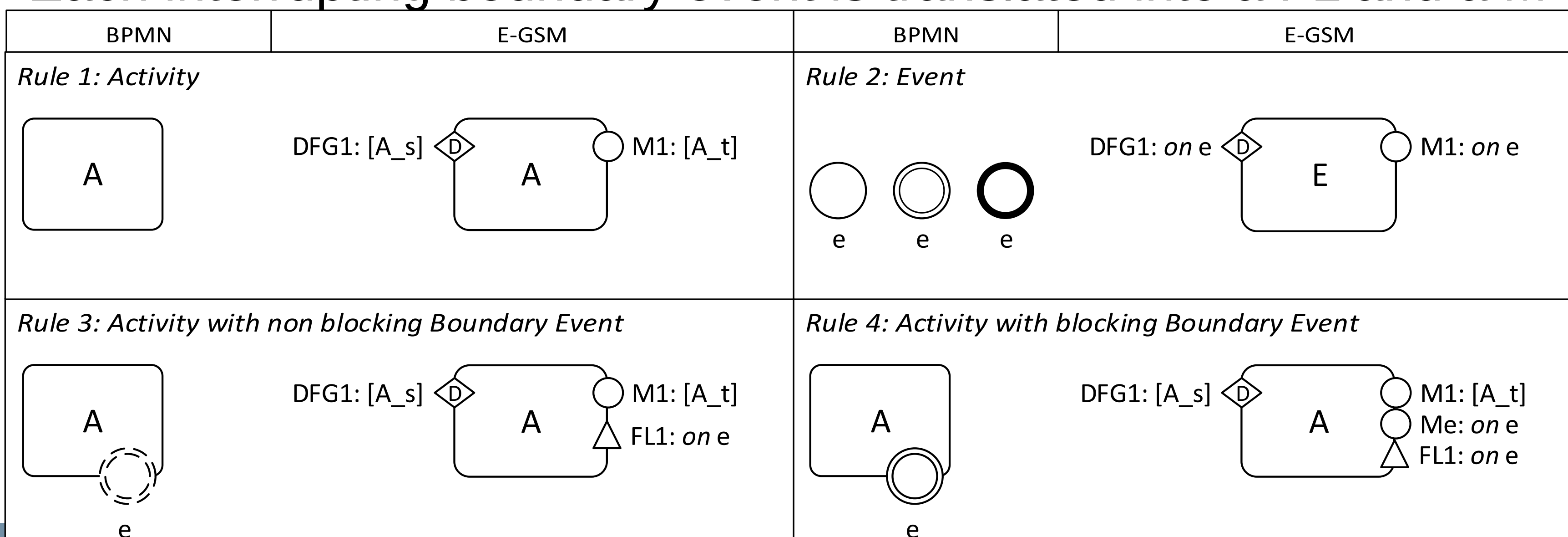
E-GSM Stage lifecycle

- E-GSM allows to monitor processes with respect to three orthogonal dimensions:
  - Execution status:
    - Unopened
    - Opened
    - Closed
  - Execution outcome:
    - Regular
    - Faulty
  - Execution compliance:
    - OnTime
    - OutOfOrder
    - Skipped



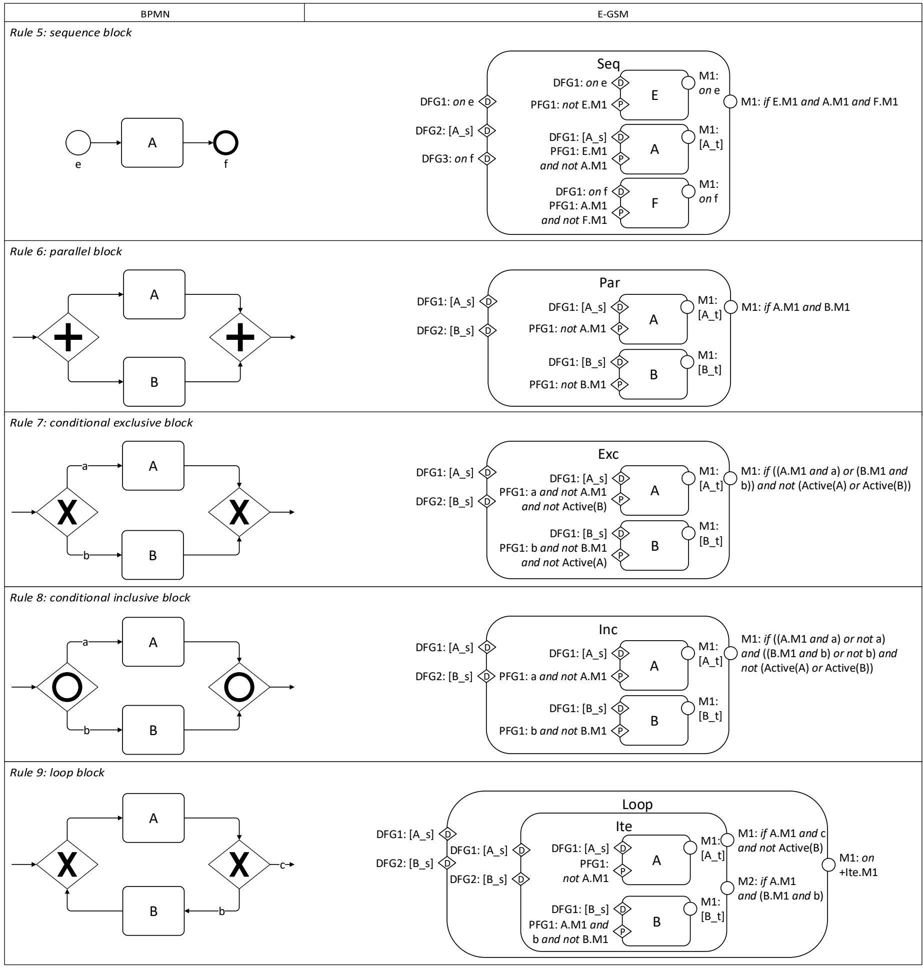
Basic translation rules

- Each activity is translated into a Stage with one or more DFG and one or more M
- Each event is translated into a Stage with a DFG and a M capturing the occurrence of the event
- Each non-interrupting boundary event is translated into a FL
- Each interrupting boundary event is translated into a FL and a M



Translating the normal flow

- Identification of process blocks
  - Single inbound and single outbound control flows
  - Can be nested
  - Five process blocks: Sequence, Parallel, Conditional exclusive, Conditional exclusive, Loop
- Each block is translated into an E-GSM stage
  - DFG, PFG an M depend on the nature of the block
  - Inner blocks become inner stages



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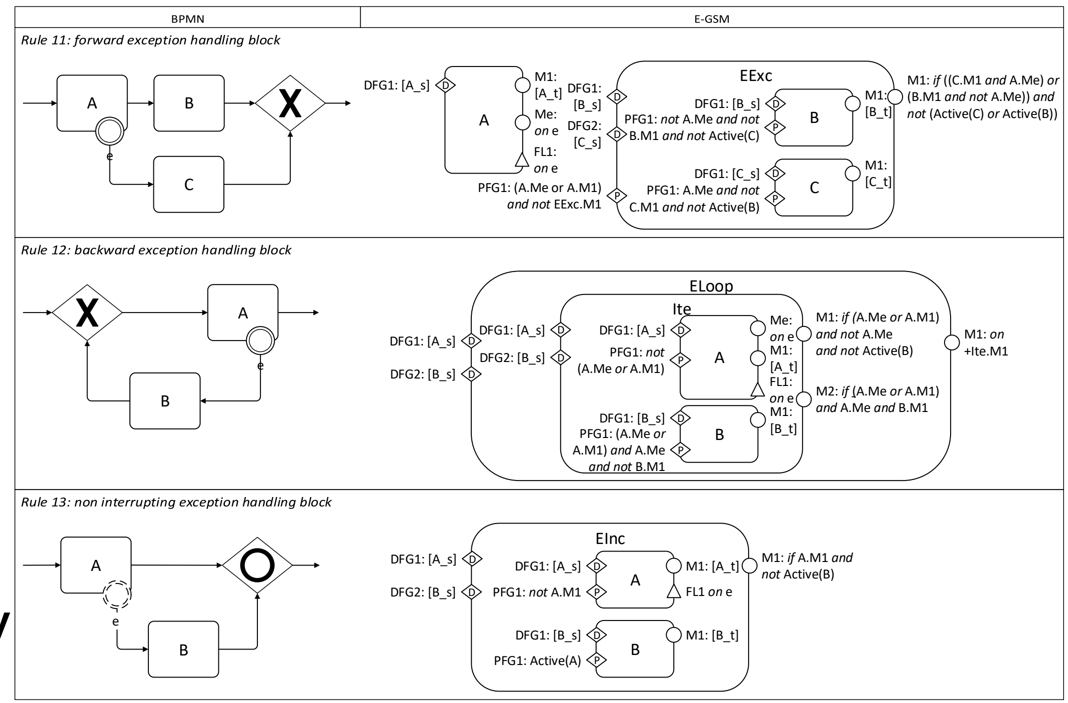
Translating the exceptional flow

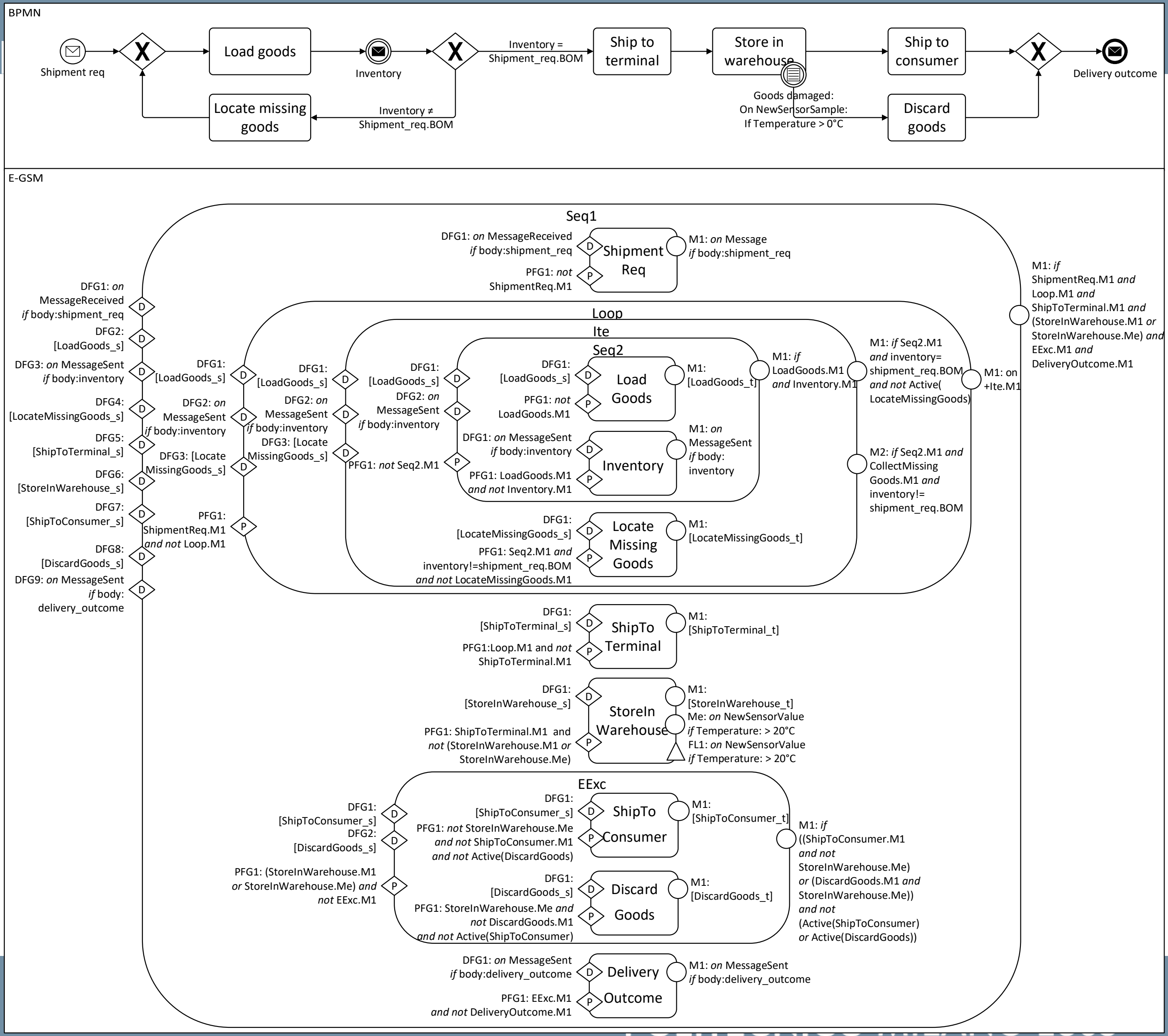
- Exceptional flow is alternative to normal flow
  - Originates from interrupting boundary events
  - Can go either in the same or in the opposite direction wrt normal flow
  - Must be merged with normal flow with an exclusive merge gateway.
- Exceptional flow runs in parallel with the normal flow
  - Originates from non-interrupting boundary events
  - Must be merged with normal flow with an inclusive merge gateway

Translating the exceptional flow

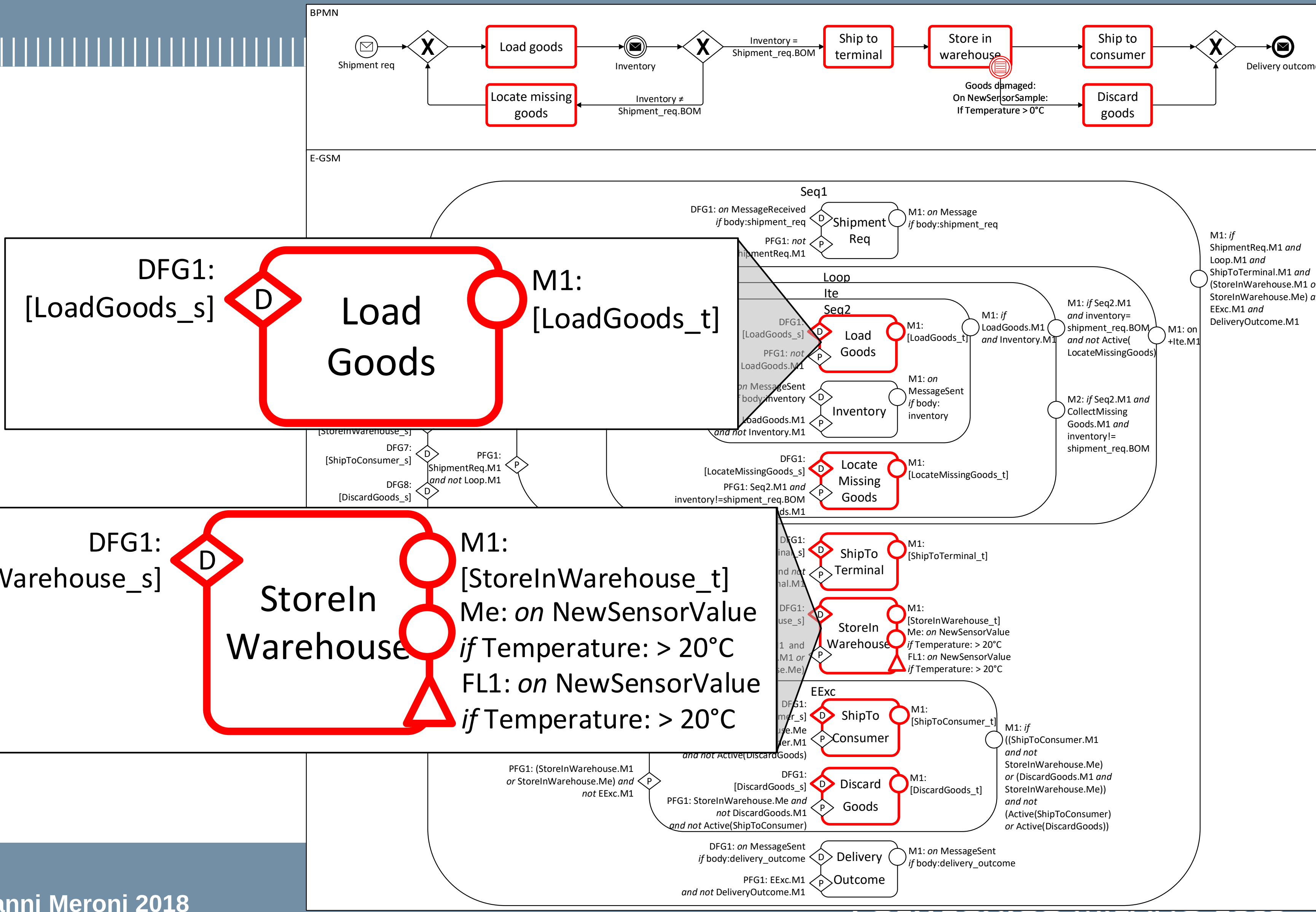
- Three exceptional blocks definable
  - Forward exception handling
  - Backward exception handling
  - Non-interrupting exception handling
- They behave similarly to Conditional exclusive, Loop and Conditional inclusive blocks, respectively



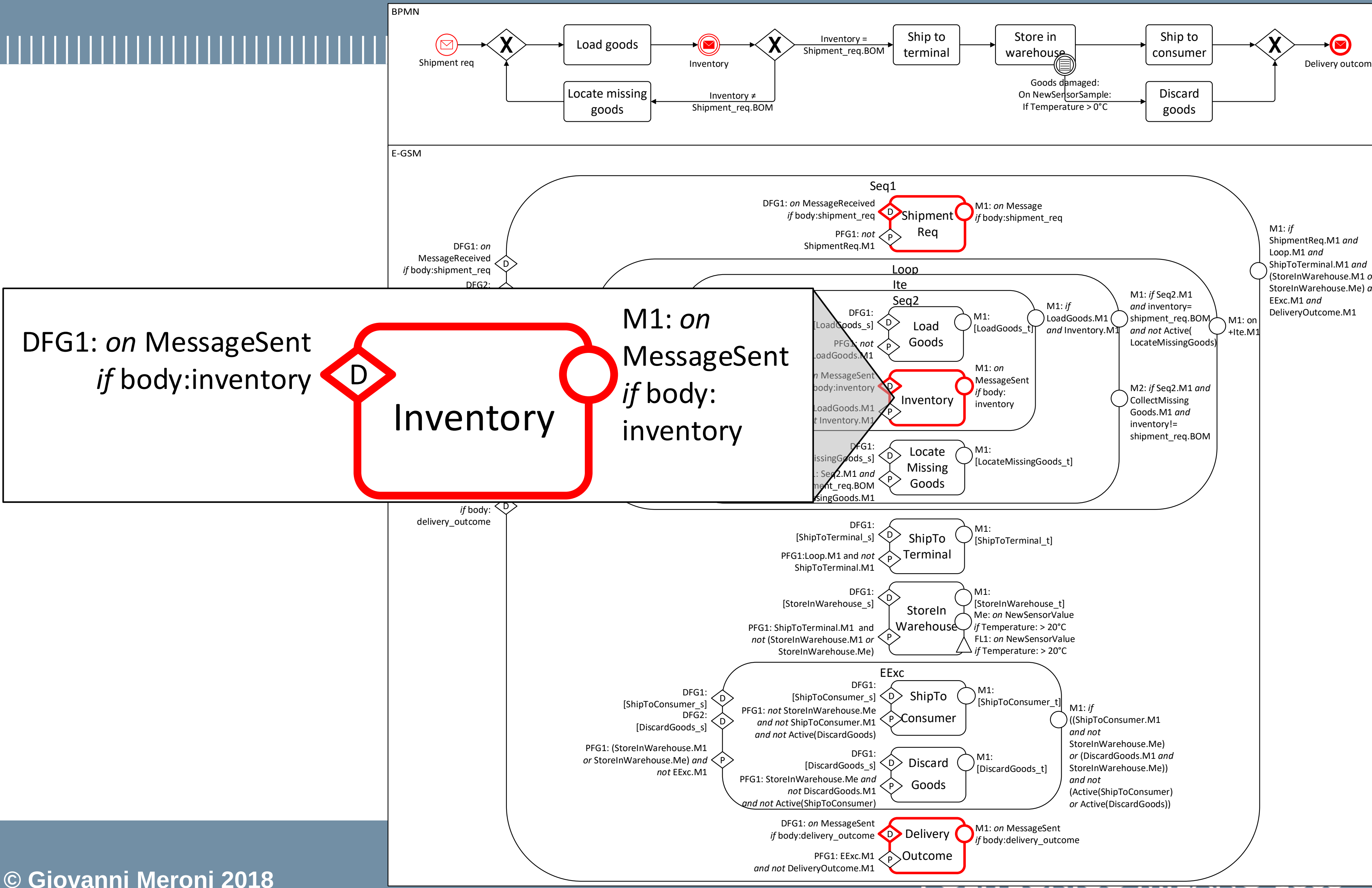
Translation by Example



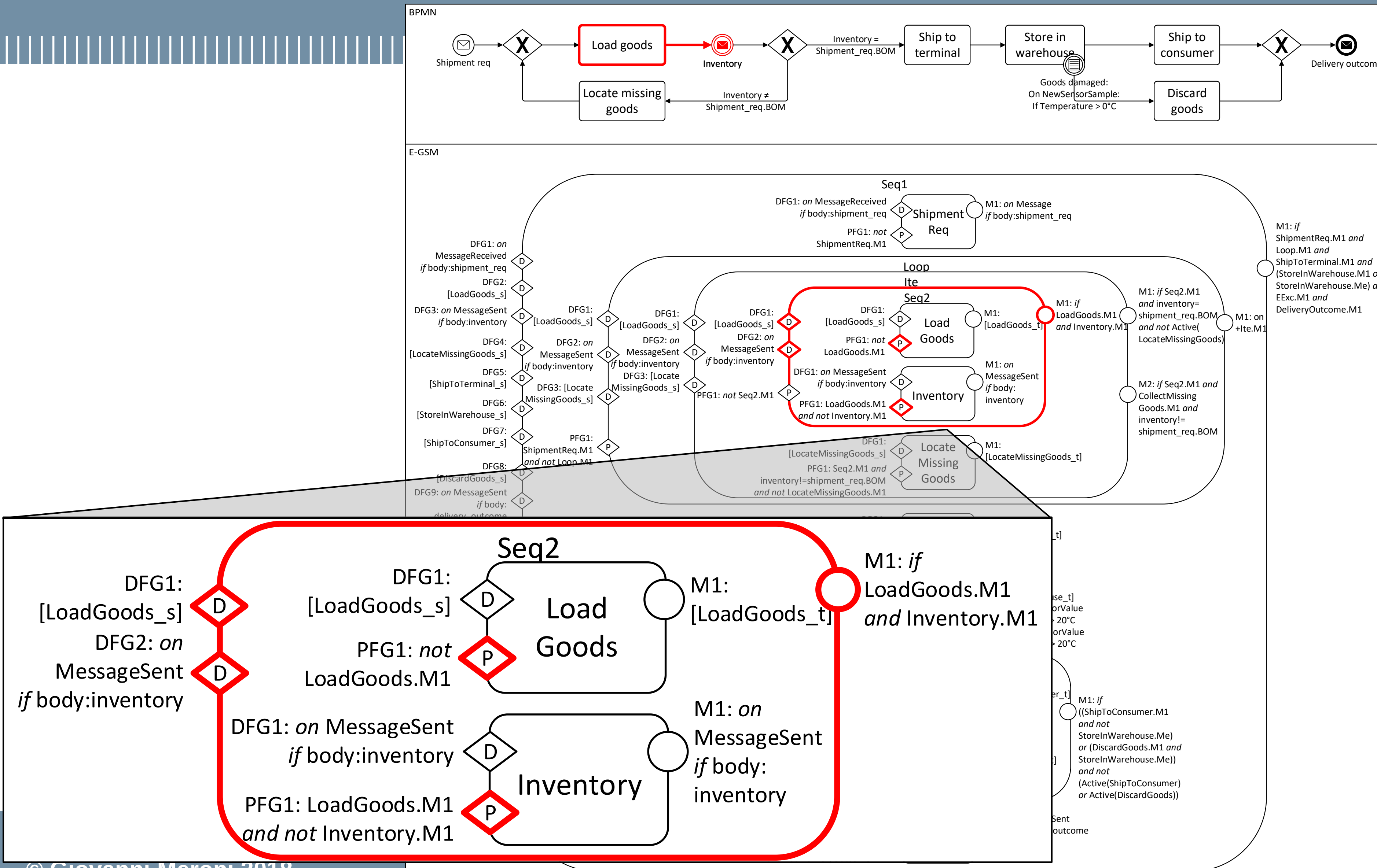
Translation by Example Activities



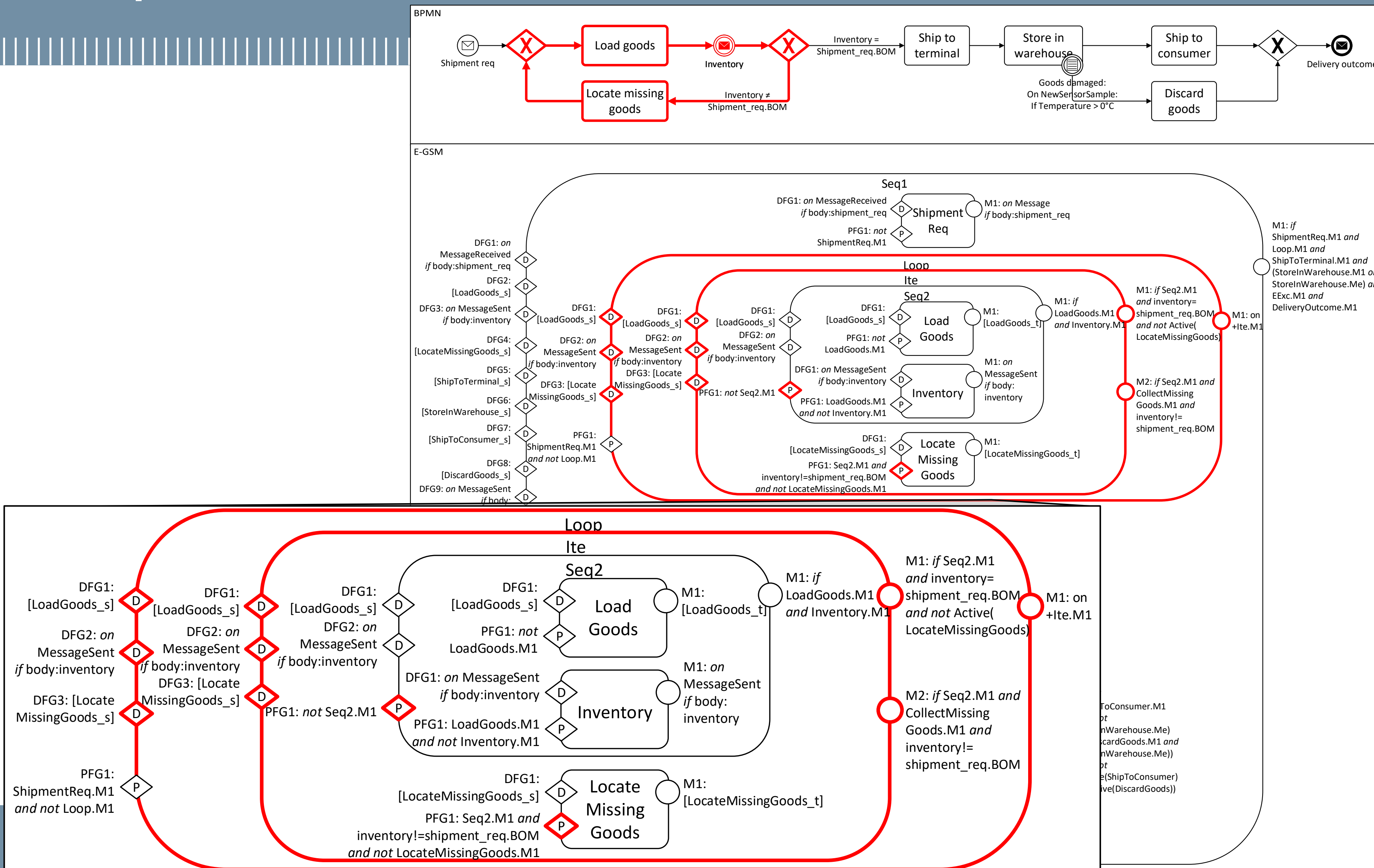
Translation by Example
Non-boundary Events



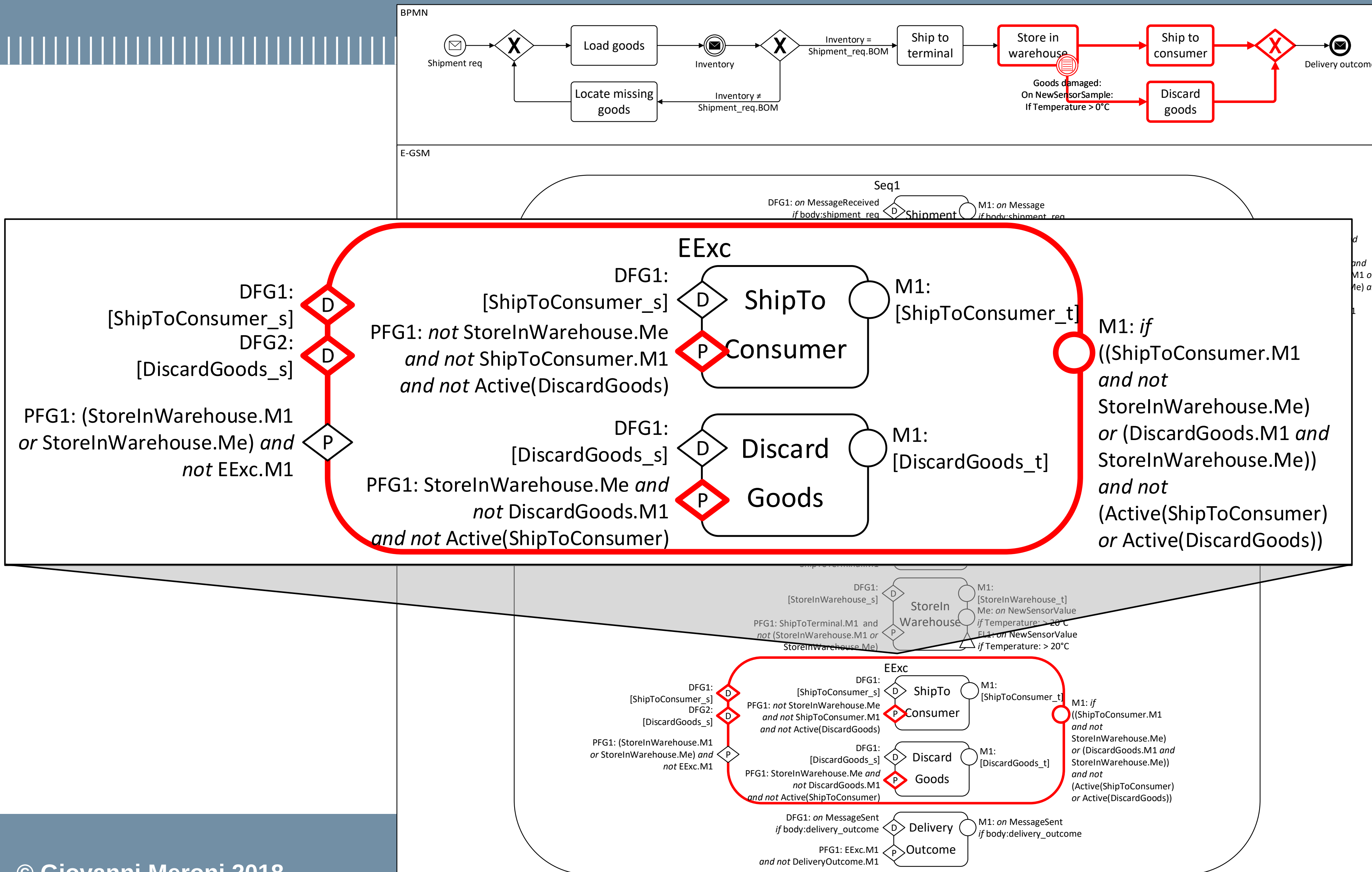
Translation by Example
Inner Sequence Block



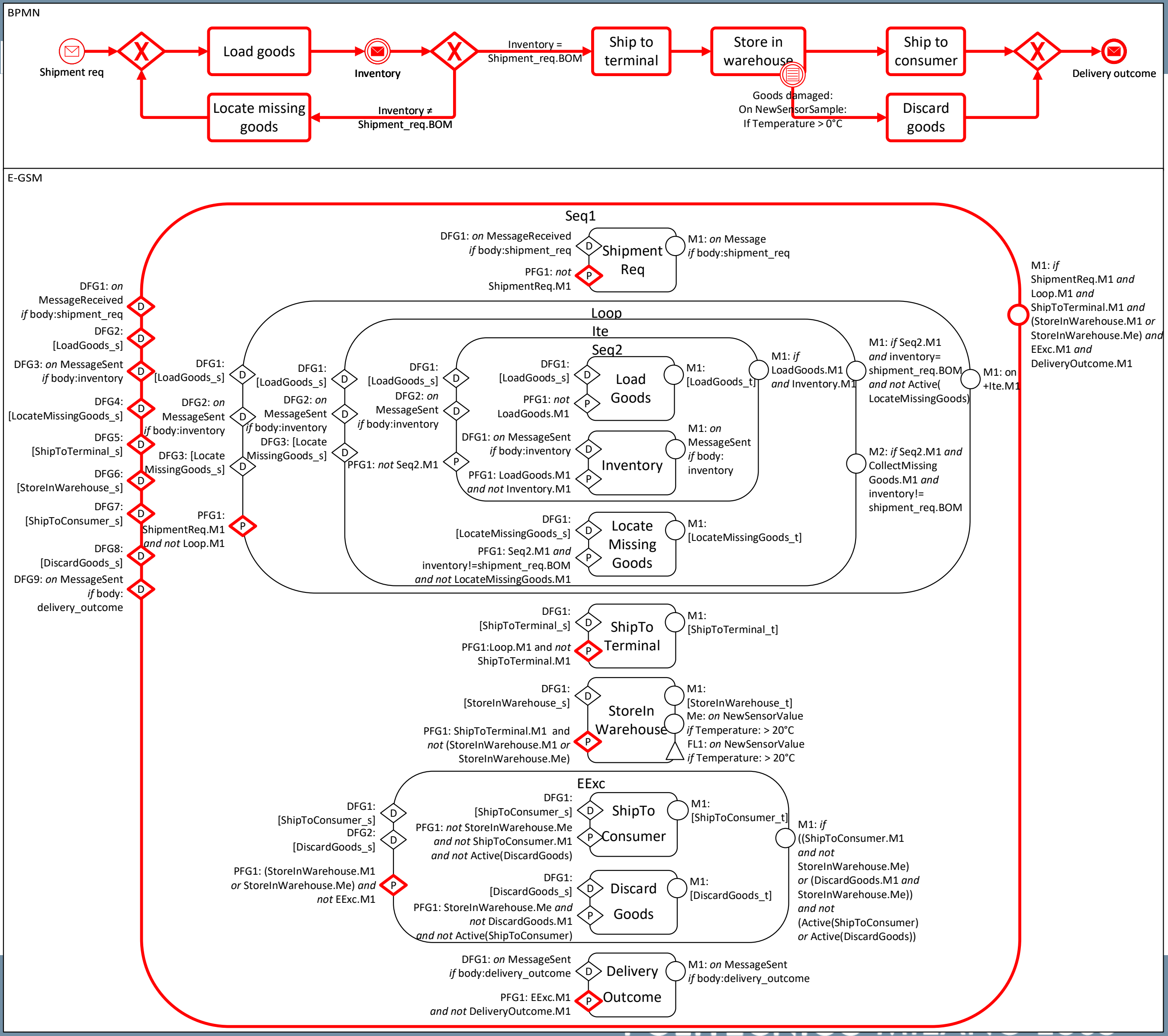
Translation by Example
Loop Block



Translation by Example
Forward Exception Handling Block



Translation by Example
Outer Sequence Block

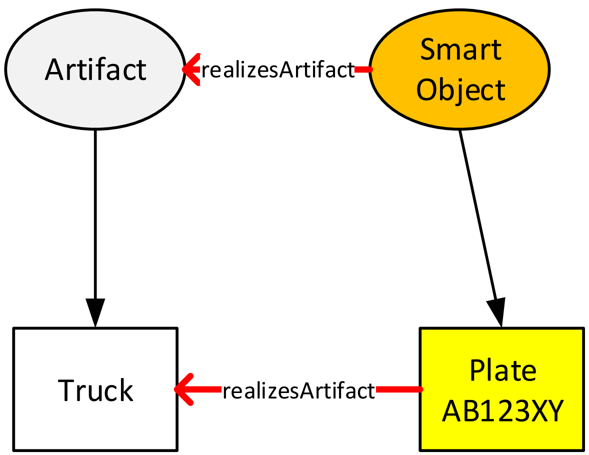


Monitorability of a process

- Not all smart objects are suited to monitor a process
- The **monitorability** of a process indicates how many activities in a process can be monitored by smart objects
- The capabilities of the Smart Objects affect monitorability
  - The execution of activities is determined by the state of the smart objects
  - The state of a smart object is inferred from its physical properties
  - The physical properties of a smart object are measured by sensors
- We propose an ontology-based approach to:
  - Formalize the capabilities of smart objects
  - Estimate the monitorability
  - Provide suggestions to improve the monitorability

Smart object ontology

- Ontology derived from FIESTA-IoT that captures the capabilities of the smart object



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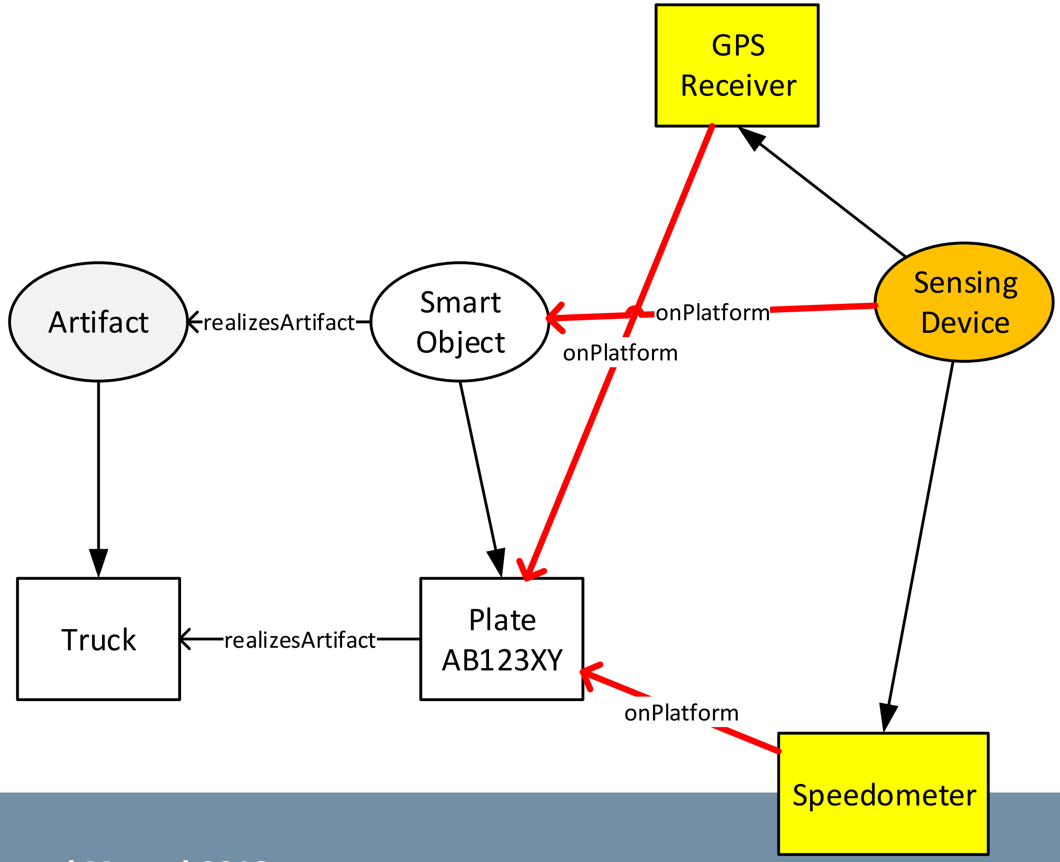

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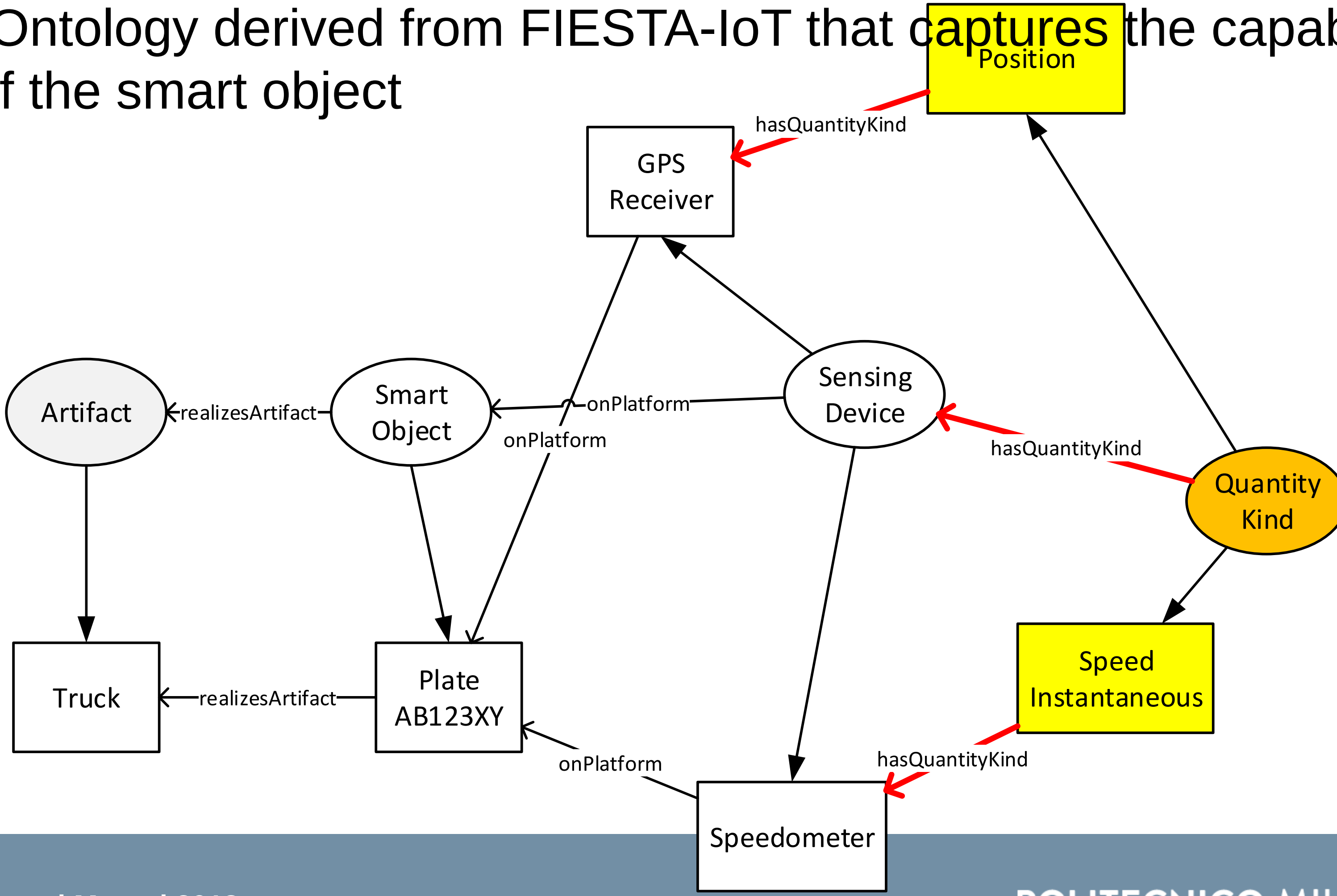

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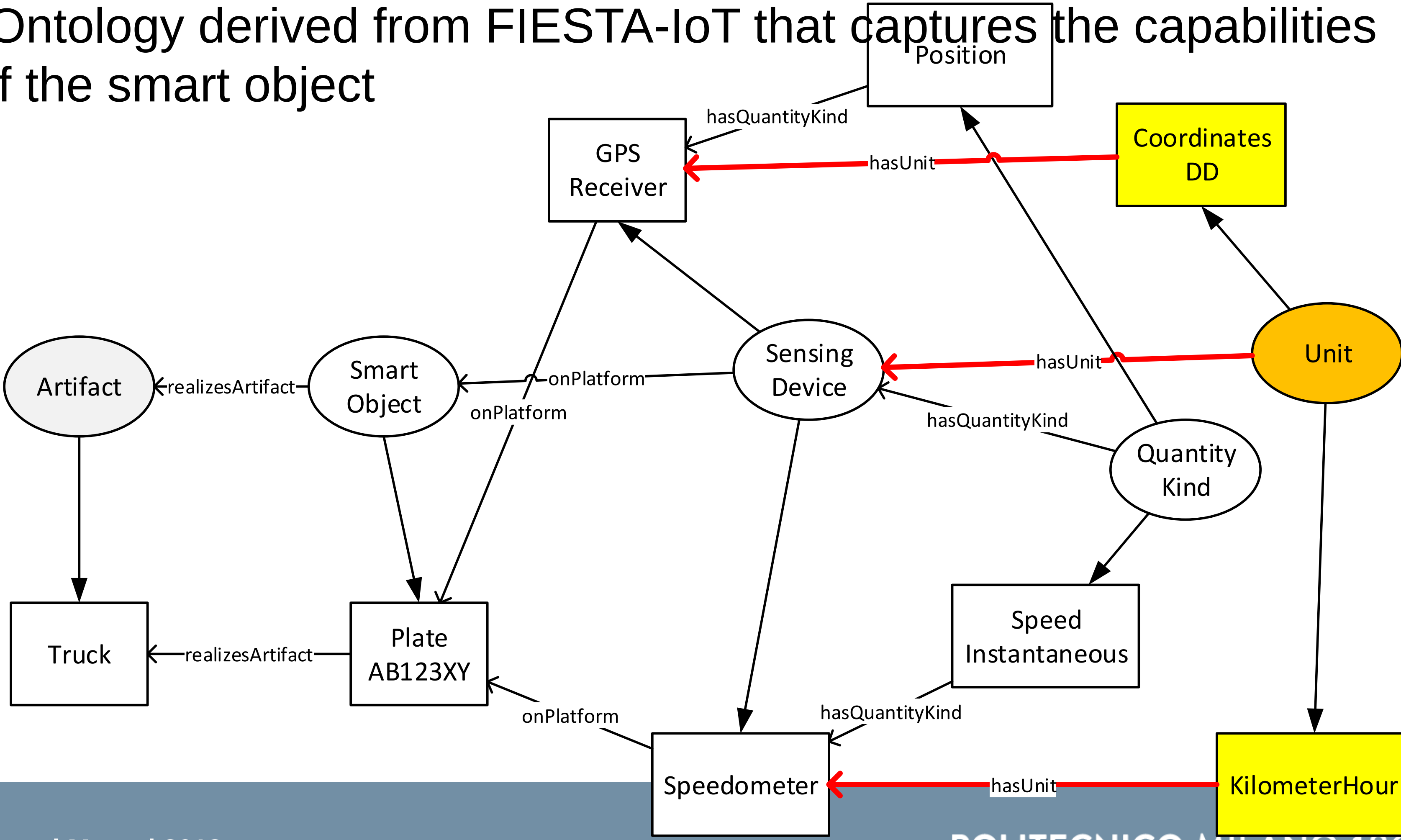
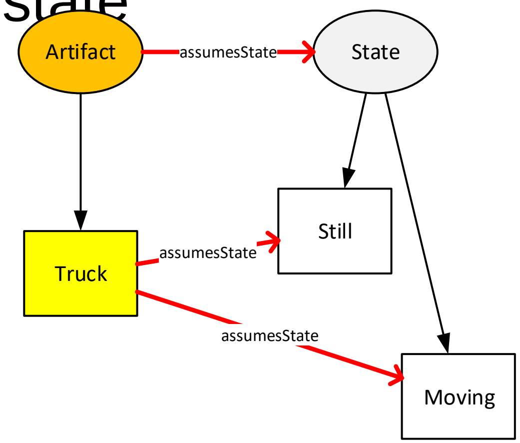


State detection rules ontology

- Ontology derived from Physics Domain ontology (Hachem et al. – MDS 2011) that formalizes how sensor data is used to infer a state



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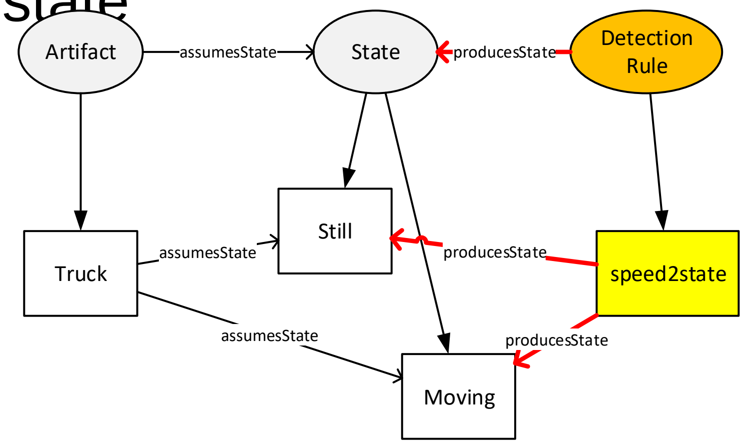

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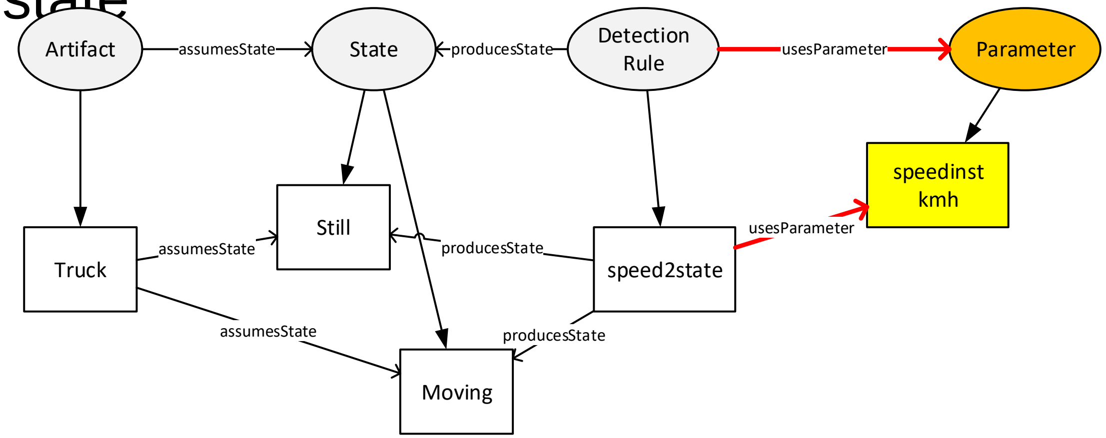

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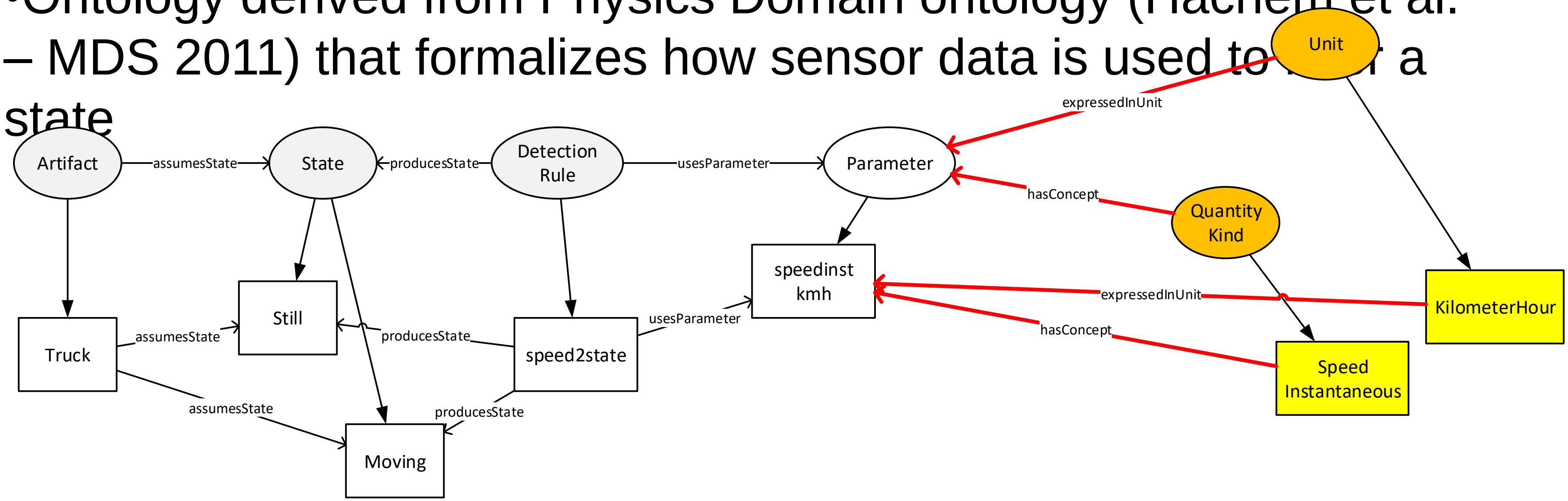

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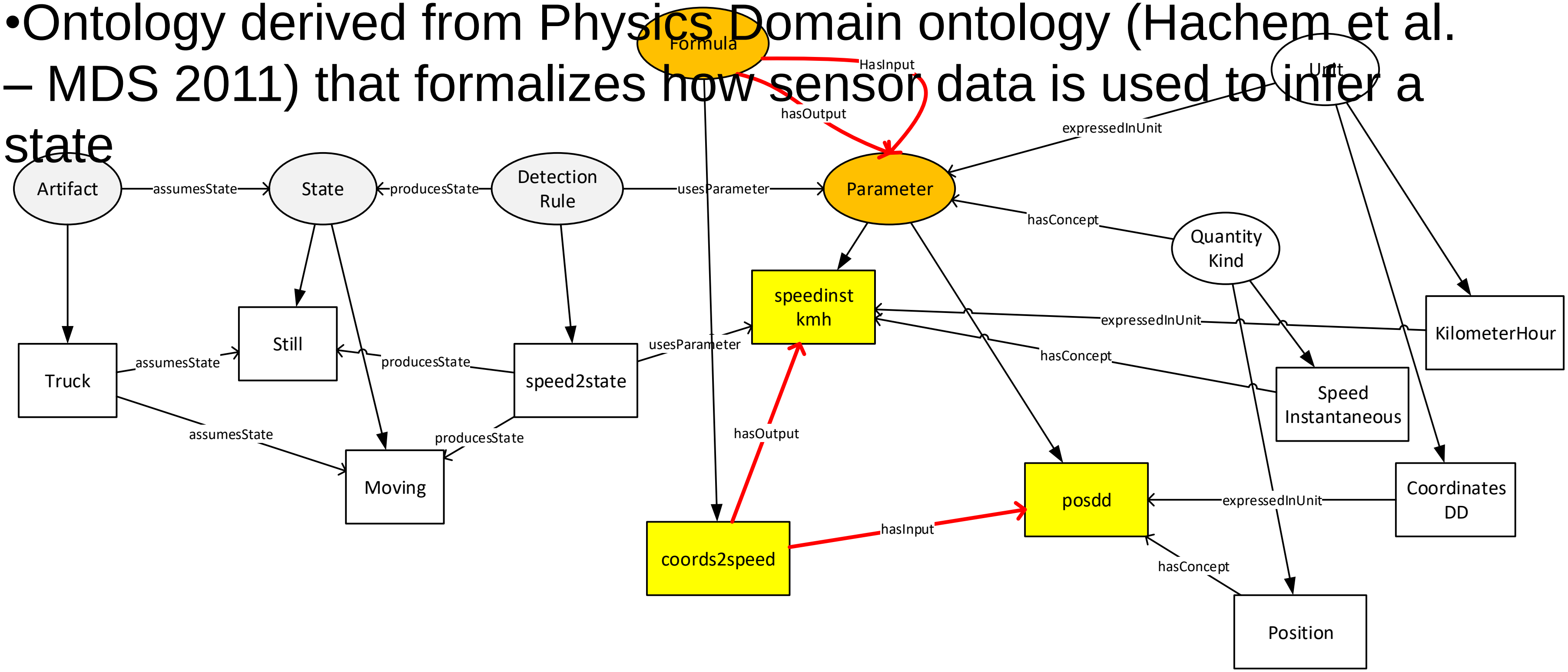
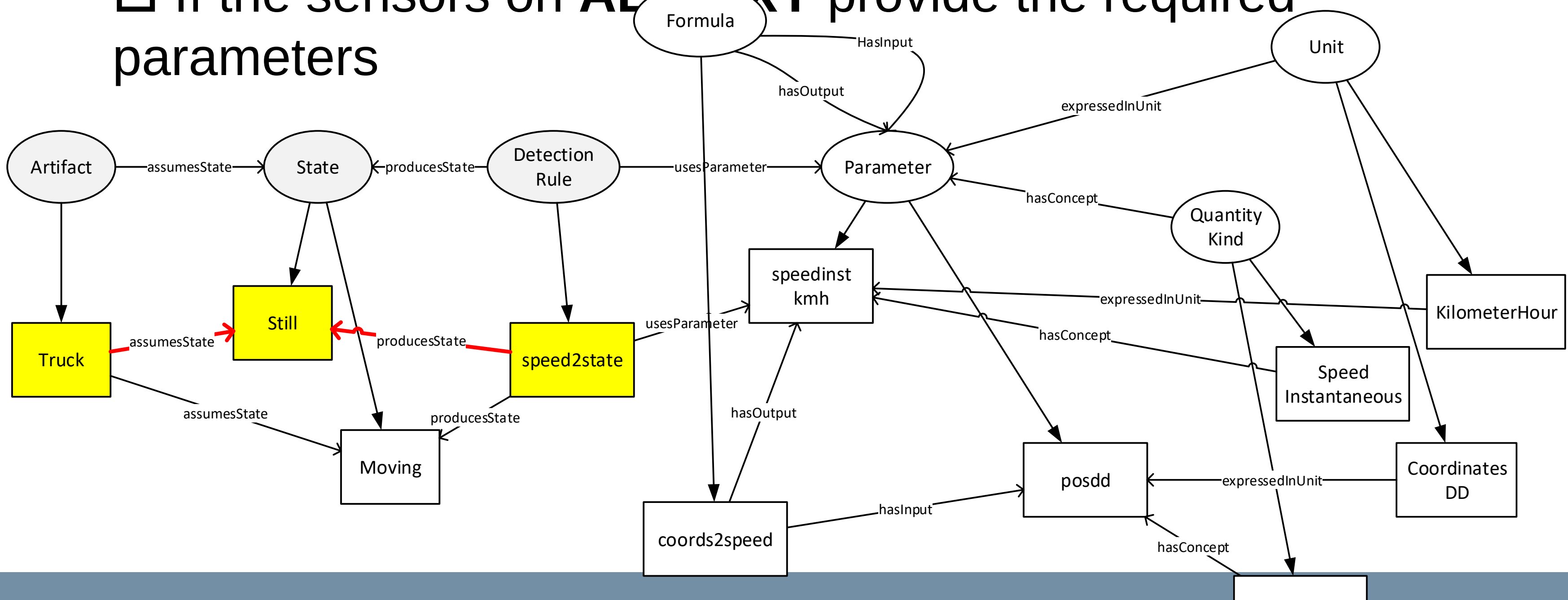


Process monitorability assessment

- For each couple **<artifact, state>** in the process model, we need to determine how many smart objects $\overline{SSO}$ can infer that state based on their capabilities
- To do so, for each smart object SSO that embodies **artifact**, the ontologies are queried to determine:
  - If a detection rule to infer **state** exists
  - Which parameters are required by that rule
  - If the sensors on the smart object provide the required parameters
- Then, the monitorability of **<artifact, state>** is computed as: $Mon^{ARS}(\langle artifact, state\rangle, I) \rightarrow [0,1] = \left|\overline{SSO}\right| \;/\; |SSO|$

Process monitorability assessment

- Determine if truck **AB123XY** can infer **<truck, still>**:
  - ☑ If a detection rule to infer **still** exists
  - ☐ Which parameters are required by that rule
  - ☐ If the sensors on **AB123XY** provide the required parameters



Process monitorability assessment

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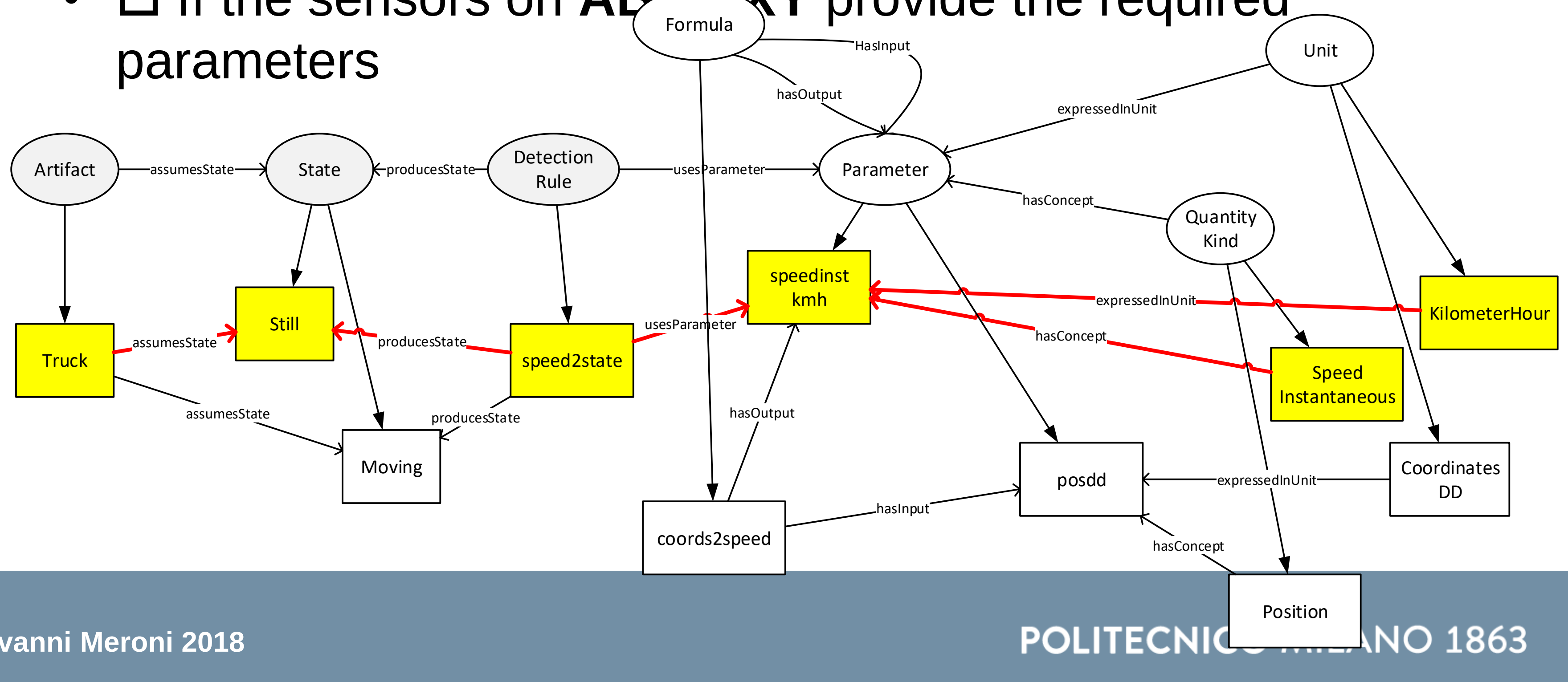

Process monitorability assessment

- Determine if truck **AB123XY** can infer **<truck, still>**:
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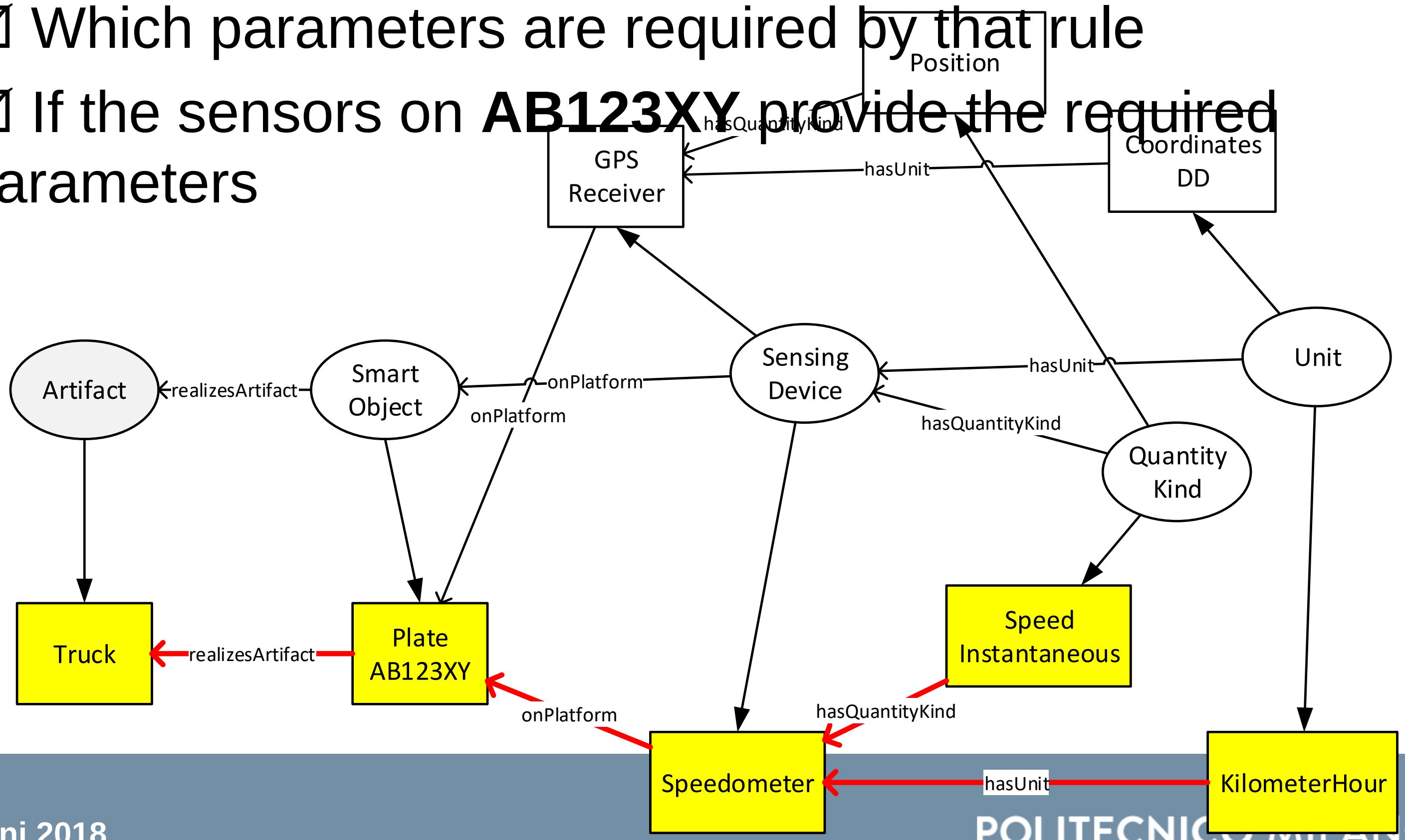


Process monitorability assessment

- Once Mon^{ARS} has been determined for every couple <artifact, state>, the monitorability of the activation and the termination of an activity is determined as:

$$Mon^{C}(A_i.C_i^{start}, I) \rightarrow [0,1] = \prod^{ARS_{i,j} \in A_i.C_i^{start}} Mon^{ARS}(ARS_{i,j}, I) \quad (1)$$

$$Mon^{C}(A_i.C_i^{stop}, I) \rightarrow [0,1] = \prod^{ARS_{i,k} \in A_i.C_i^{stop}} Mon^{ARS}(ARS_{i,k}, I) \quad (2)$$

- Then, the monitorability of an activity is:

$$Mon^{A}(A_i, I) \rightarrow [0,1] = \frac{1}{2} \cdot \left(Mon^{C}(A_i.C_i^{start}, I) + Mon^{C}(A_i.C_i^{stop}, I) \right)$$

- Finally, the monitorability of the process is:

$$Mon^{P}(P, I) \rightarrow [0,1] = \frac{\sum^{A_i \in P} Mon^{A}(A_i, I)}{|A_i \in P|}$$

Process monitorability improvement

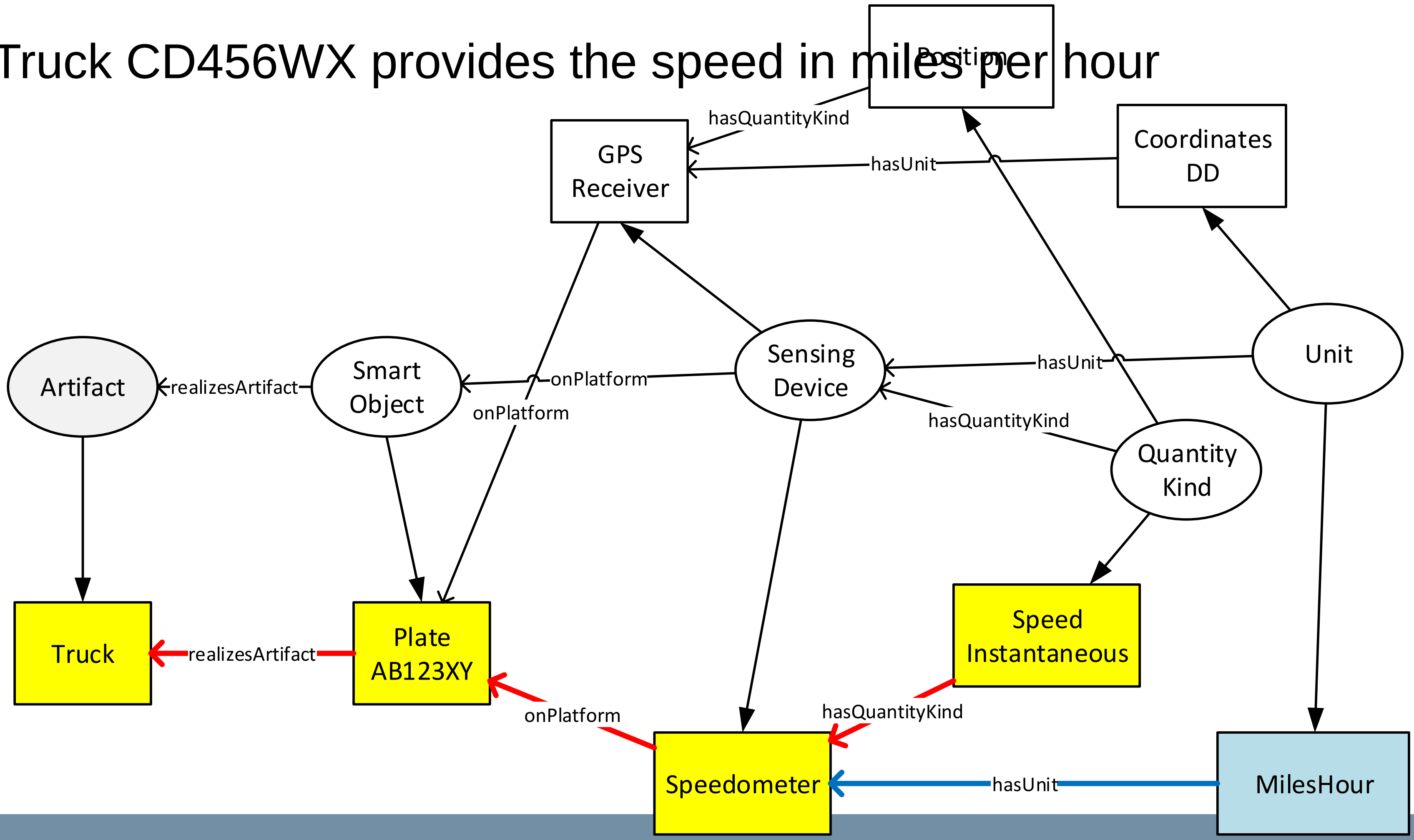
- To improve monitorability, three types of actions are possible:
  - Alter the process model to rely on different artifacts or states to determine when activities are executed
  - Improve the state detection rules
  - Modify the smart objects introducing new sensors
- When altering the process model, for each couple **<artifact, state>** that cannot be monitored, the ontologies can suggest:
  - Another state **state’** for **artifact** such that:
    $$Mon^{ARS}(\langle artifact, state' \rangle, I) > 0$$
  - Another artifact **artifact** such that
    $$Mon^{ARS}(\langle artifact', state \rangle, I) > 0$$

Process monitorability improvement

- To improve the state detection rules, the ontologies can detect smart objects that:
    - Cannot detect a state just because their sensors use a data format different from the one required by the detection rule
    - Cannot detect a state, but provide sensor data that can be used to indirectly derive that state
- By introducing a new detection rule similar to the existing one except for the input parameters, these smart objects can detect that state.
    - This positively affects the monitorability of the process
- For smart objects that cannot provide sensor data to detect that state, either directly or indirectly, the ontologies can suggest which sensors should be introduced

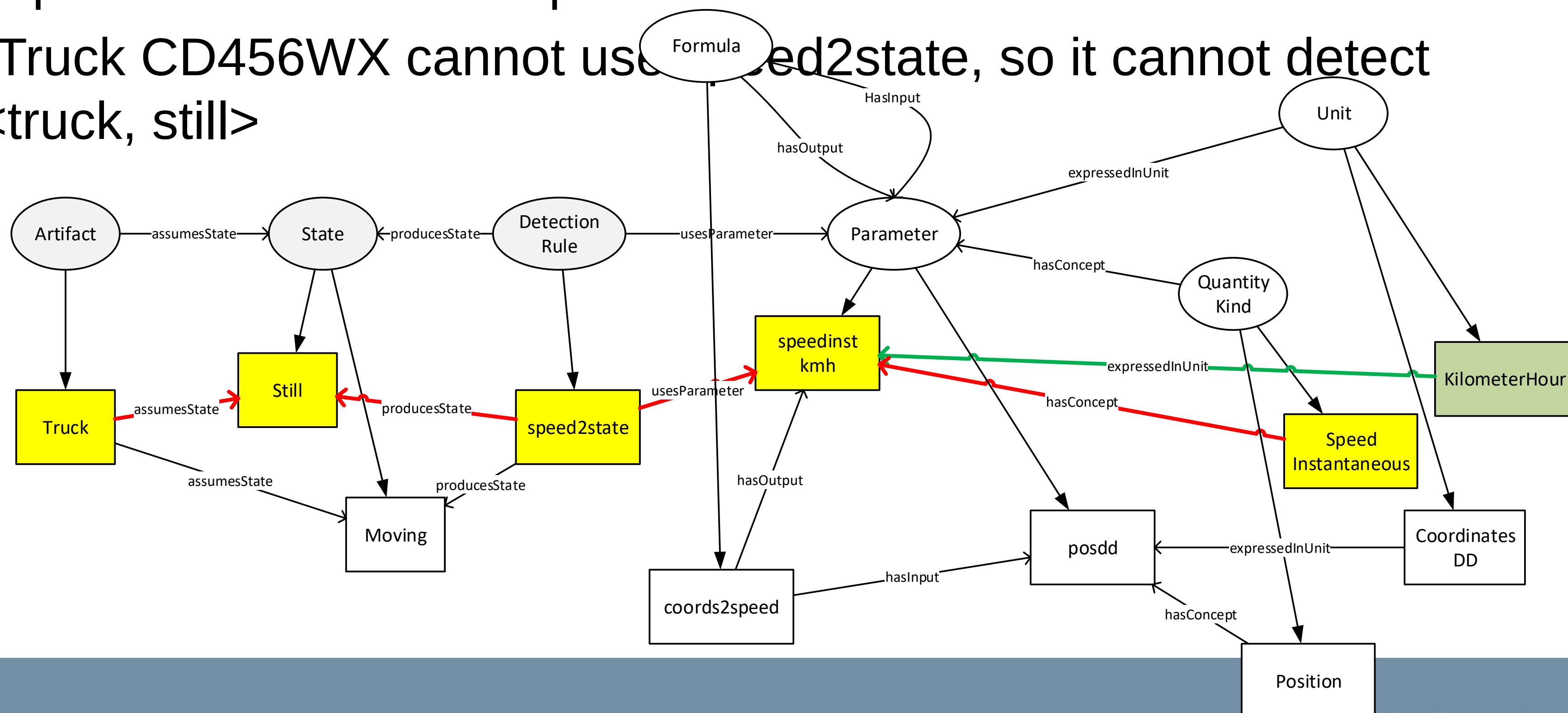
Process monitorability improvement

- Truck CD456WX provides the speed in miles per hour



Process monitorability improvement

- Truck CD456WX provides the speed in miles per hour
- To detect <truck, still>, rule speed2state requires the speed to be expressed in kilometers per hour
- Truck CD456WX cannot use speed2state, so it cannot detect <truck, still>

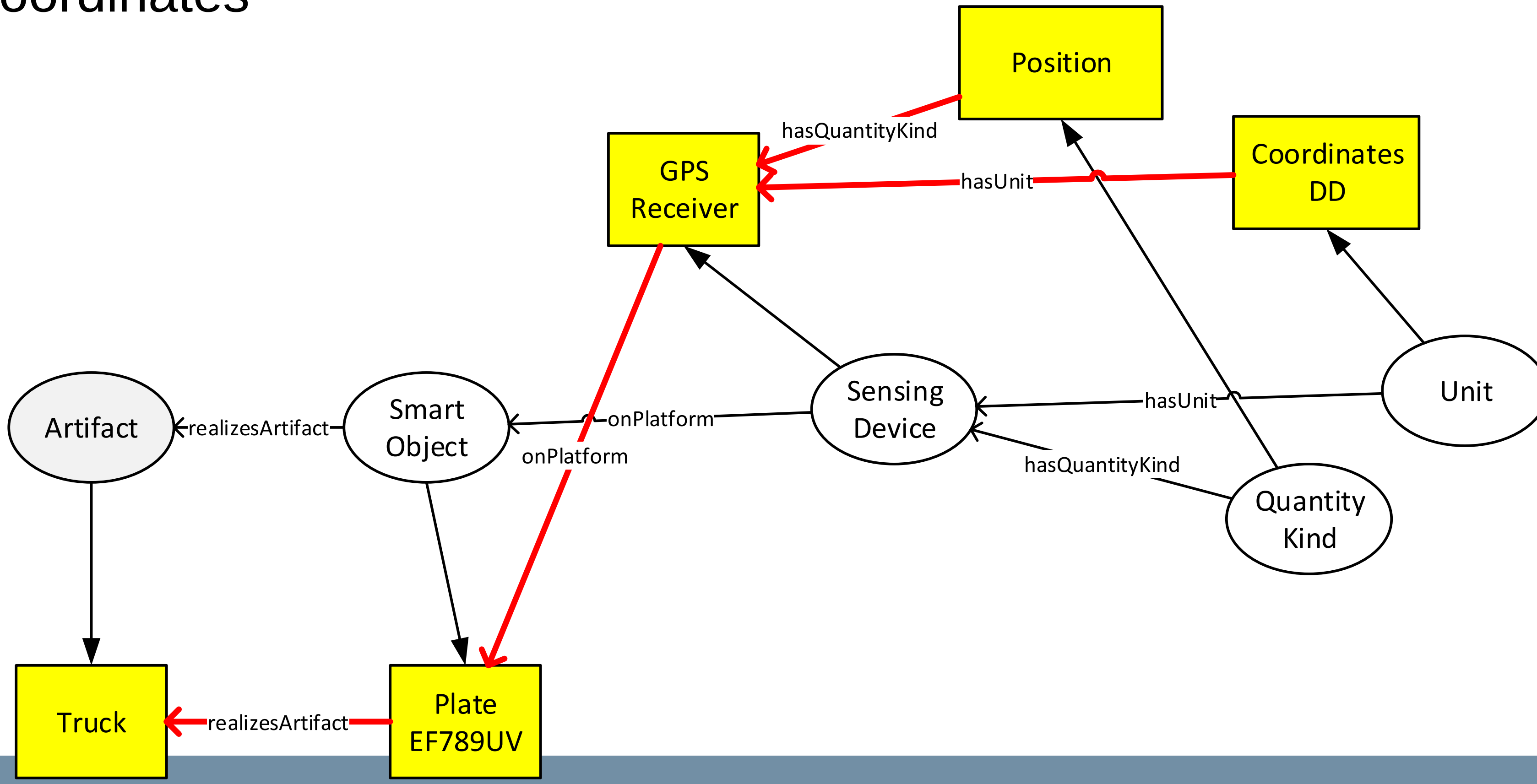


Process monitorability improvement

- Truck CD456WX provides the speed in miles per hour
- To detect <truck, still>, rule speed2state requires the speed to be expressed in kilometers per hour
- Truck CD456WX cannot use speed2state, so it cannot detect <truck, still>
- A new rule speed2state’ can be derived from speed2state by converting the speed from miles per hour to kilometers per hour
- With speed2state’, Truck CD456WX can now detect <truck, still>

Process monitorability improvement

- Truck EF789UV provides its own position in decimal degrees coordinates



Process monitorability improvement

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- To detect <truck, still>, rule speed2state requires the speed
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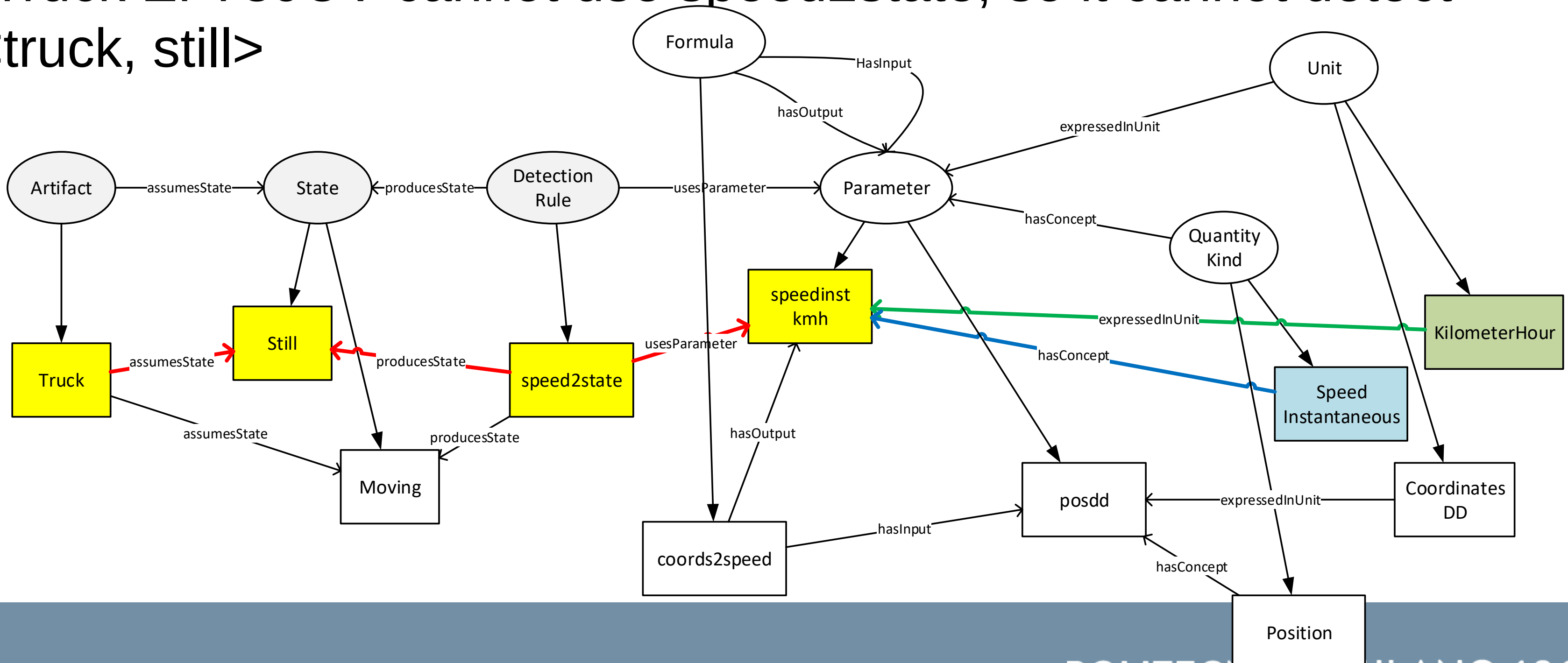
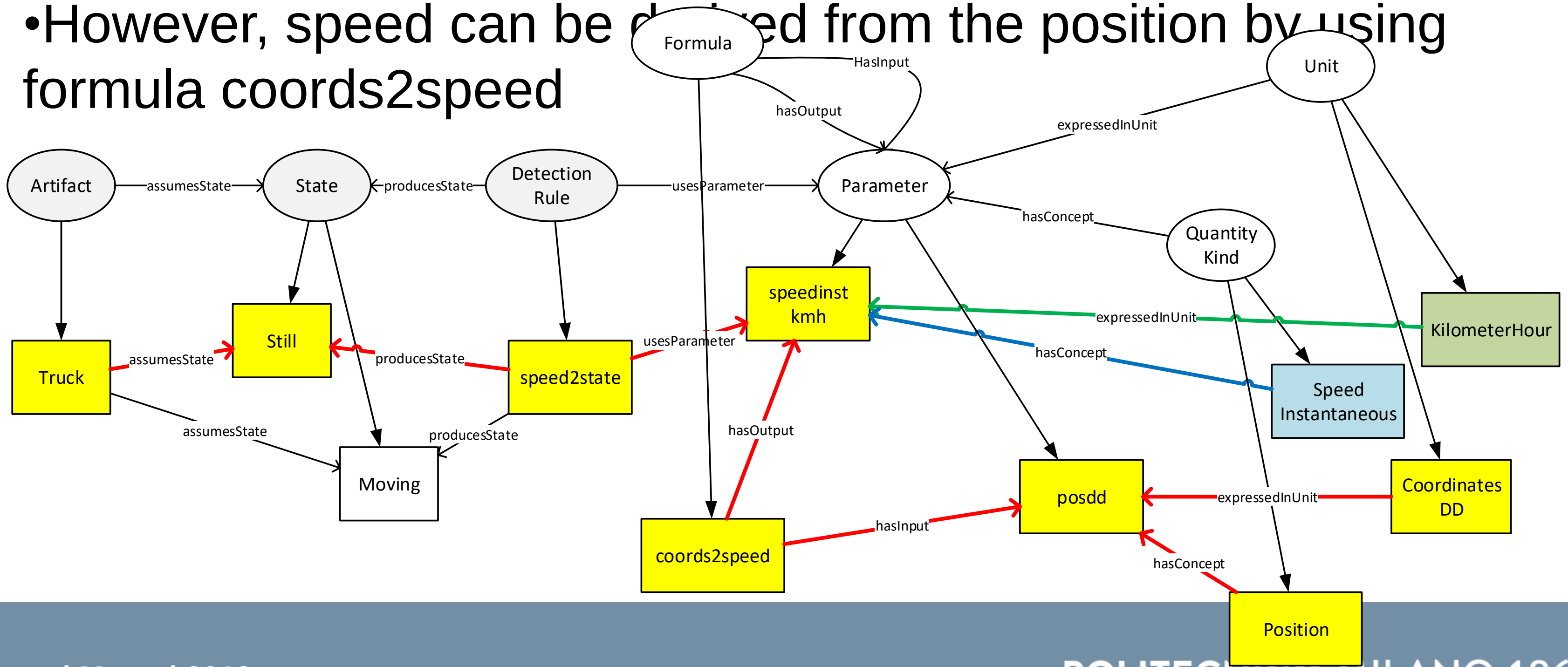


Process monitorability improvement

- Truck EF789UV provides its own position in decimal degrees coordinates
- To detect <truck, still>, rule speed2state requires the speed
- Truck EF789UV cannot use speed2state, so it cannot detect <truck, still>
- However, speed can be derived from the position by using formula coords2speed



Process monitorability improvement

- Truck EF789UV provides its own position in decimal degrees coordinates
- To detect <truck, still>, rule speed2state requires the speed
- Truck EF789UV cannot use speed2state, so it cannot detect <truck, still>
- However, speed can be derived from the position by using formula coords2speed
- A new rule coords2state can be derived by combining speed2state with coords2speed
- With coords2state, Truck CD456WX can now detect <truck, still>