Human-Centered Automation for Guided Transports

denis.berdjag@uphf.fr

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Denis Berdjag

- Associate Professor (Researcher & Teacher)
  - Automatic Control
  - Human-Machine System
  - Transports
  - CNU member (61st section)
  - GT-ASHM co-founder & animator
    - GDRMACS

- Research topics
  - Observer design
  - Fault
    - Detection Isolation & Estimation
    - Diagnosis
    - -Tolerant Control
  - Data Fusion
- Applications
  - Human-Machine Systems
  - Transports
    - Railway
    - Automotive
    - Aircraft

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Research activity in the field of railways

- Projects
  - Europe : GDR E **HAMASYT**
  - France : FUI ECOVIGIDRIV; UTOP **IDEFI**; **ANR**
  - HDF : CPER **CISIT, ELSAT2020**
- Collaborations
  - IRT **Railenium -** Valenciennes
  - **ALSTOM** – Petite Forêt
  - **BOMBARDIER** – Crespin
  - **IFSTTAR** – Villeneuve d'Ascq
  - ans also:
    - **VTI** (SWE) ; **TU Berlin** (GER) ; **Leeds** (UK) ; **TU Delft** (HOL)
- Platforms
  - **COR&GEST**
  - **ILLUSIO**
  - **PSCHITT**

Overview

- **Introduction**
  - HMS & Rail transport
  - Improving security ; detecting weird situations and behaviors
- **Problematic : handling unexpected situations**
  - How operators deal with UE ?
  - Choosing the appropriate representation formalism
  - Checking if operator reaction is appropriate
- **Contribution**
  - **Control theoretic approach**
    - (Model based approach using Finite State Machines formalism)
  - **Model Disambiguation** using trial and error decision algorithm
  - **Diagnoser** (UE detection, wrong behavior detection)
- **Case study** (simulation)
  - Experimental setup, modeling and results
  - Discussion
- **PSCHITT platform**

Context: Rail Driving

- Rail transport development is a major topic in R&D
  - Green & cost-efficient transportation system
- A pertinent example of Human-Machine interaction
  - The operator drives and supervises automatic procedures.
  - The system assists the operator in tedious tasks
  - The command center remotely supervises the whole network

System specifics
- High to very high speed
- Very high train inertia
- Repetitive actions required
- Lenghty mission times
- Intrusive security protocols

Context: Security

- Accident prevention through risk reduction is the prime focus
  - Statistics show that human errors leading to cascade effects are primarily responsible of documented major accidents
  - Automated systems for technical failure detection/prevention shows good performance
- Human presence is absolutely necessary to deal with complex situations
  - full-automatic systems are not resilient
  - Humans can successfully resolve awkward situation due to adaptability and imagination
- Increasing demands (ponctuality, speed,…) negatively impacts train drivers working conditions

Automatic HMS monitoring systems are required to assist train drivers and CC operators

Problem formulation

- behavior representation
- unexpected vs expected situations handling

Human behavior representation

- The operator is given
  - instructions
  - objectives
  - guidelines
- Instructions are interpreted as **tasks and sub tasks**
- Sub-tasks are decomposed into **sequences of actions**, linked or not.

However

- Each operator is unique in his interpretation based on
  - Capability / Skill
  - Habits
  - Experience

The problem

- We need to represent
  - Actions
  - Sequence of linked actions
  - Tasks and Sub-tasks
- We need to consider
  - Individual interpretation
- We need to identify
  - characteristic patterns

Situations handling
expected vs unexpected

- Situations (problem occurrence) are either
  – Expected : the issue is relatively common and guidelines exist
  – Unexpected : the issue is rare or unprecedented and guidelines do not exist
- Two main approaches exist
  – Developing rules & guidelines for all cases and requiring strict execution
  – Proposing solutions for selected generic cases and requiring adaptation from operators to manage situations.

First approach	**Second approach** (Best choice)
• Operators can be relatively unskilled • It is difficult to predict every possible situation • Learning & formation are not cost-efficient	• Operators are necessarily skilled • The approach is better suited to handle rare problems • Learning & formation are cost-efficient

Objectives

Checking human behavior adequacy

- Easy to check operator behavior adequacy in known or predictable situations.
- Very difficult to avoid false alarms if the given instructions are not strict

Detect unexpected events occurrence

- Monitoring operator behavior and detecting characteristic changes will indicate UE occurrence

Design a system

Checks adequacy w/o false alarms and estimates UE occurrence time

Contribution

- control theoretic approach
- disambiguation
- UE detector

HMS modeling

- Two types approaches
  - **Data based**: needs experimentation to extract characteristics
  - **Model-based:** need knowledge of the process dynamics
- Model-based formal approaches are adapted for powerful mathematical analysis tools
  - (Shin & al 2006).
- Model based approaches are
  - State-oriented
    - Finite State Machines, Nets (Petri), Programming Languages and Abstract Model Methods
  - Transition-oriented
    - Process Algebras, Traces and Grammars

Finite State Machine formalism is compatible with transition oriented analysis and offers the best of two worlds in this case

Finite State Machine

Definition: FSMs are automata that, reading an input sequence, produce an output sequence.

The FSM is defined by

- States (generic, initial and final)
- Inputs
- Outputs
- Transition rules

Based on the transition behavior the FSM is

- Deterministic : a specific sequence of inputs produce unique sequence of outputs
- Non-Deterministic : the sequence of outputs is not unique

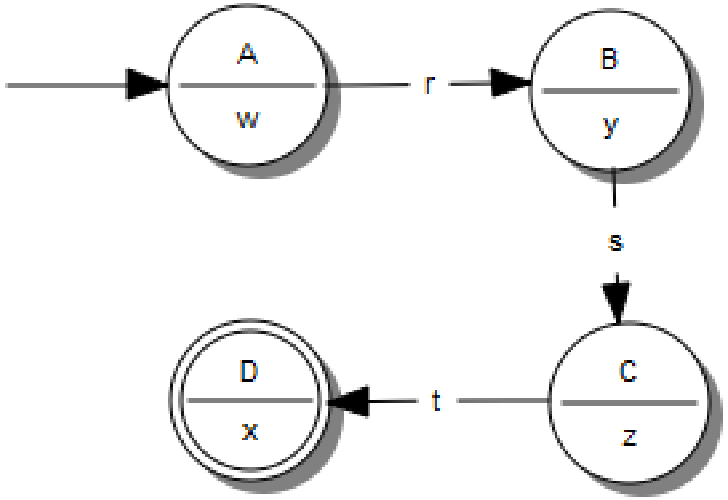
- Used extensively in control theory (see Ramadge & al 1987)
- Very flexible formalism

Example (illustrative)

Consider a sequence of actions : { M1 → M2 → M3 } needed to accomplish some task

It can be modeled by a four state FSM

- {r,s,t} are the inputs {r=M1;s=M2;t=M3}
- {A,B,C,D} are states, A is initial and D is final
- {w,y,z,x} are observable outputs



- The sequence r→s→t is **accepted**
  - (task accomplished)
- Other sequences are rejected

Remark : instruction interpretation

- Instructions usually are interpreted as
  - Parallel actions
  - Serial actions
- Serial actions imply determinism, the **sequence is unique**
- Parallel action imply non-determinism usually expressed using a probabilistic approach

In the general case, the FSM model is non deterministic → PFSM

Problem :
non-deterministic FSM (PFSM) are difficult to analyze because of the inherent AMBIGUITY of transition rules

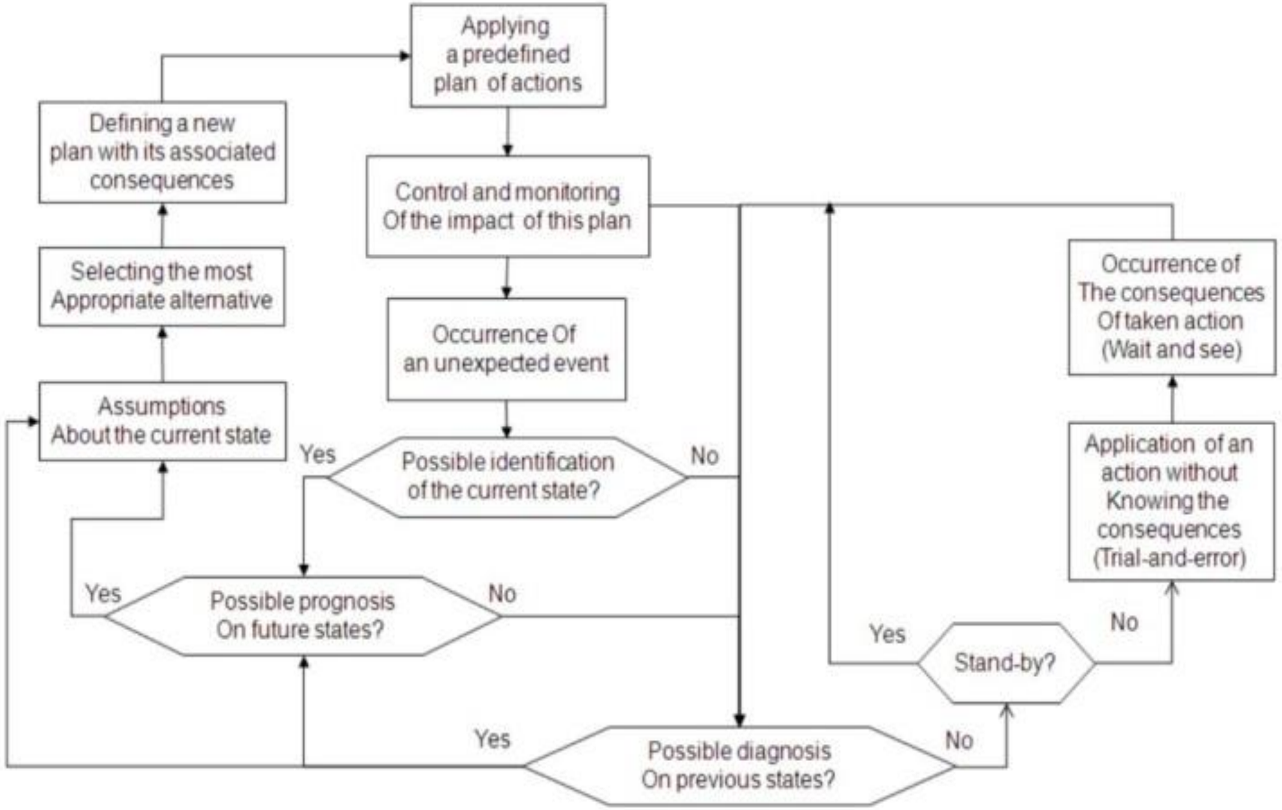
Disambiguation :

- Algorithms exist for the transformation of FSM into PFSM and *vice et versa*
- Pro :
  - Fully automatic algorithms
- Cons :
  - The number of states increases very significantly (exponentially)

Proposed solution:
use specific guidelines to perform disambiguation

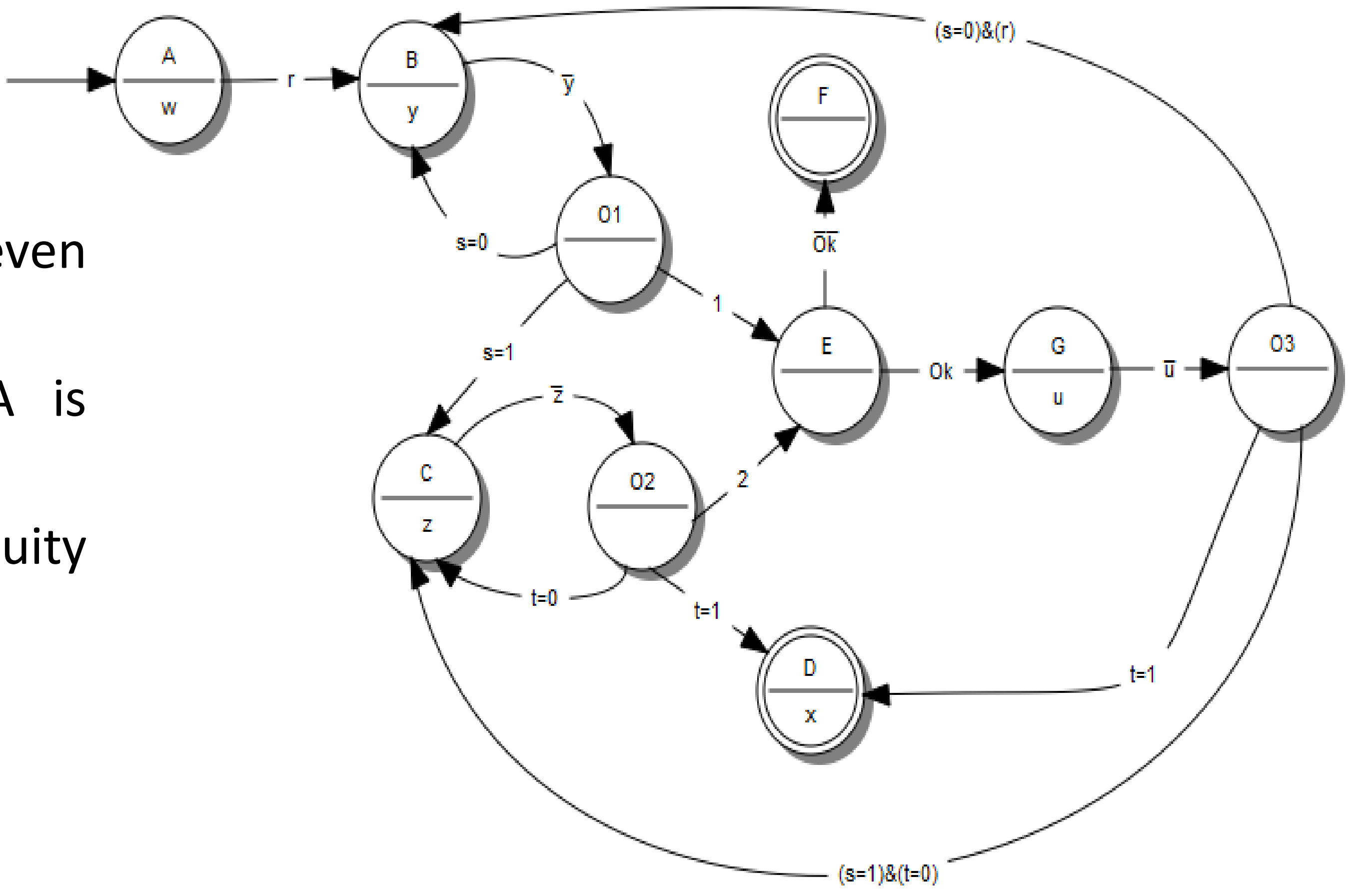
Guideline-based disambiguation

- Using the human specific approach to handle the unexpected (algorithm)
- A handful of states is added to represent operator induced variability when dealing with unexpected events
- Pros :
  - The state number explosion is contained
  - FSA are way easier to analyze than PFSA
- Cons
  - semi-automatic process involving some expertise.



Disambiguation example

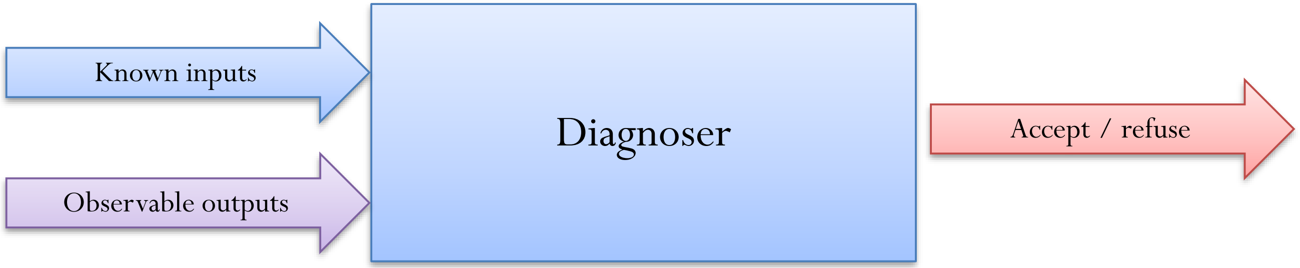
- An example of Disambiguation of a seven state PFSM
- Original states are {A,B,C,D,E,F,G}, A is initial, D and F are final.
- Three states are added to lift ambiguity {O1,O2,O3}



Diagnoser : Detecting wrong behavior

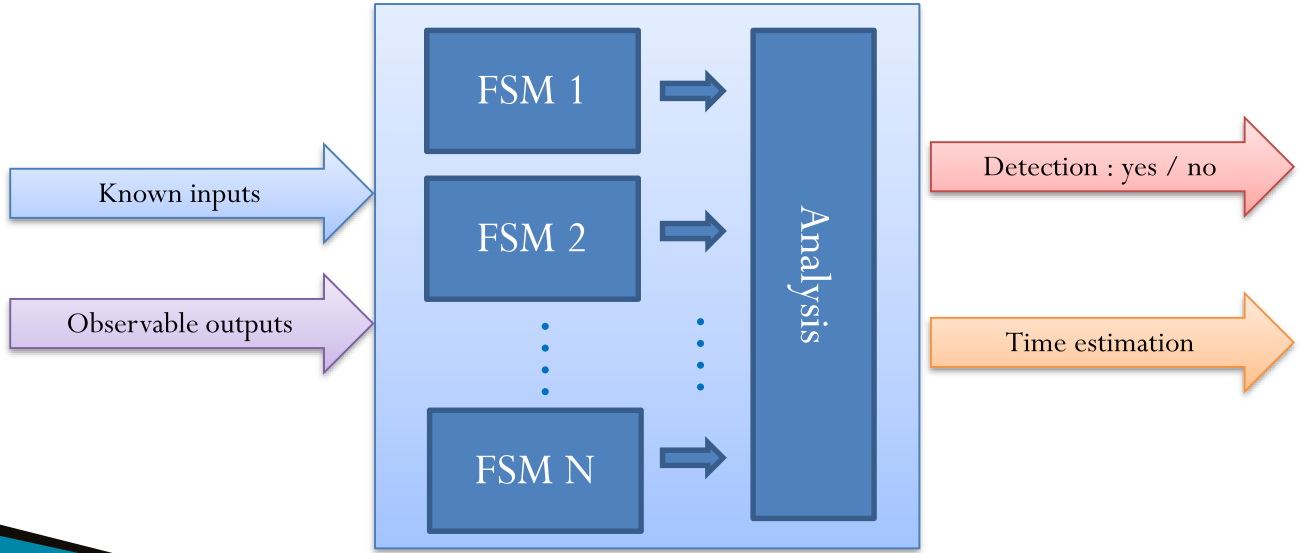
- This approach will allow a formal FSM model synthesis that will serve as a base for “adequate/inadequate” behavior categorization
  - (real-time or offline depending on the purpose).

- This diagnosis approach using FSM is widely used
  - (Frank Jin 1996; Rachedi et al. 2012; Zoltan et al. 2005)

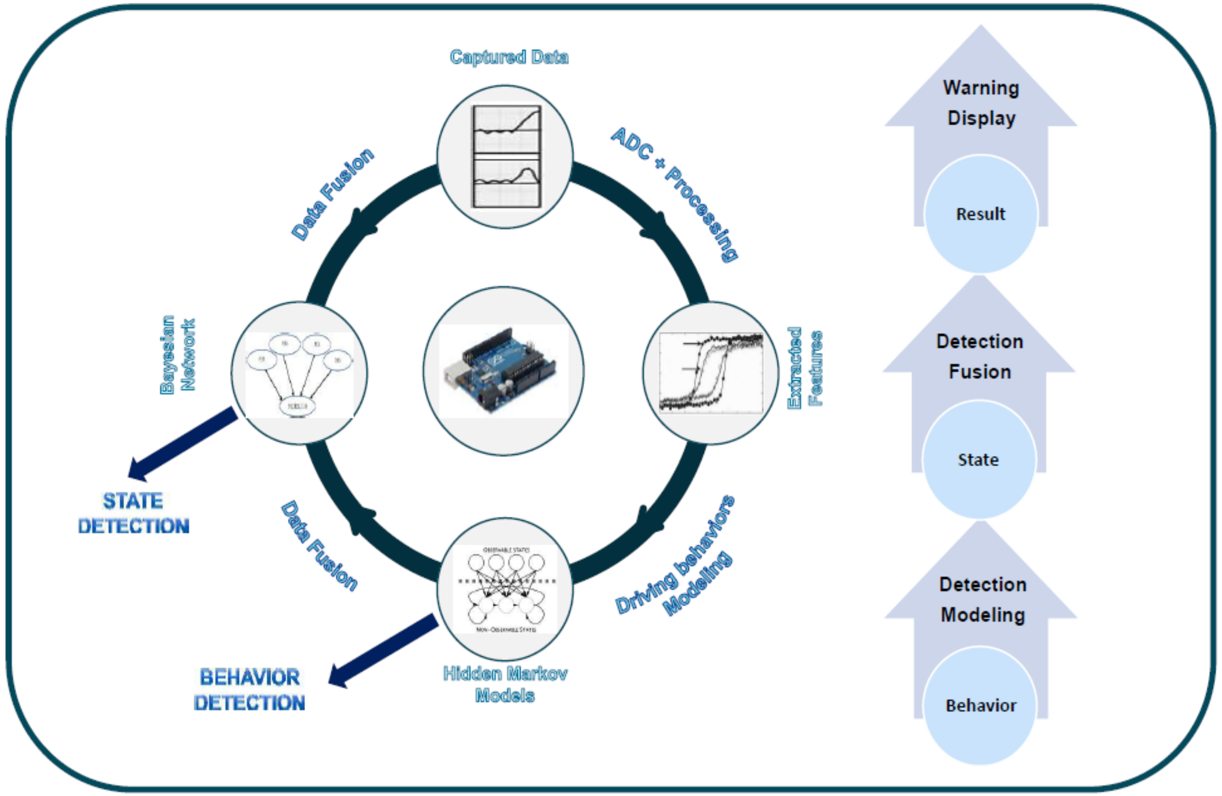


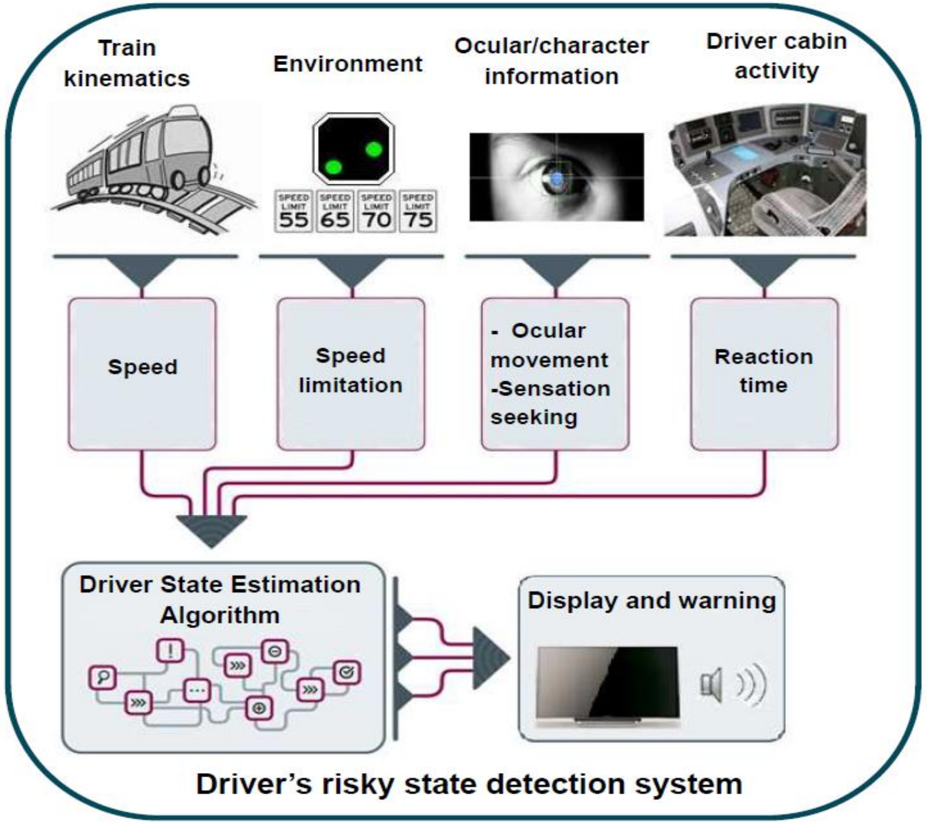
Diagnoser : Detecting UE occurrence

- This function requires the synthesis of a FSM bank expected behaviors
- Checking acceptability of the observed actions with the modeled behaviors will allow detection and estimation of unexpected event occurrence.



Diagnoser implementation

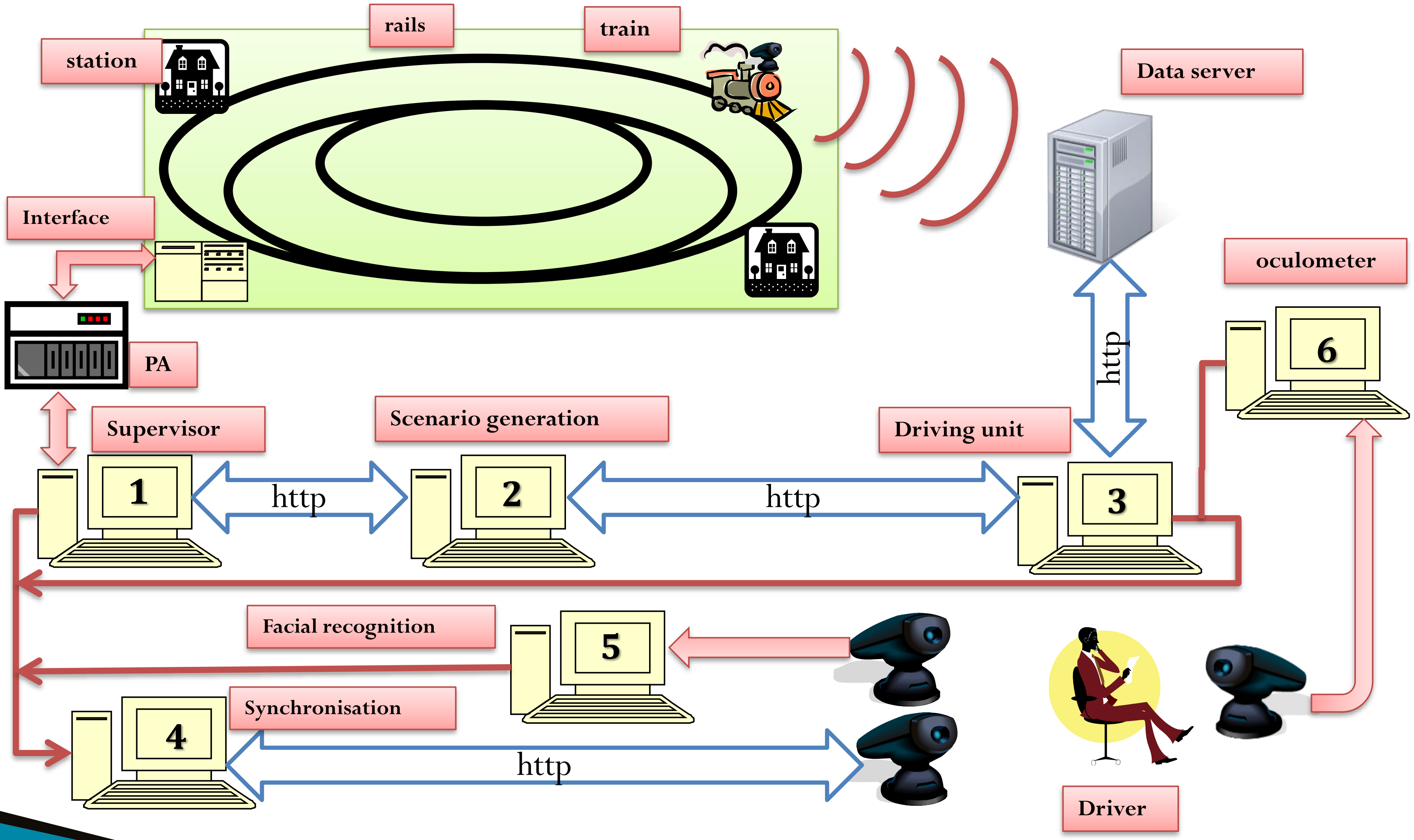




Case study

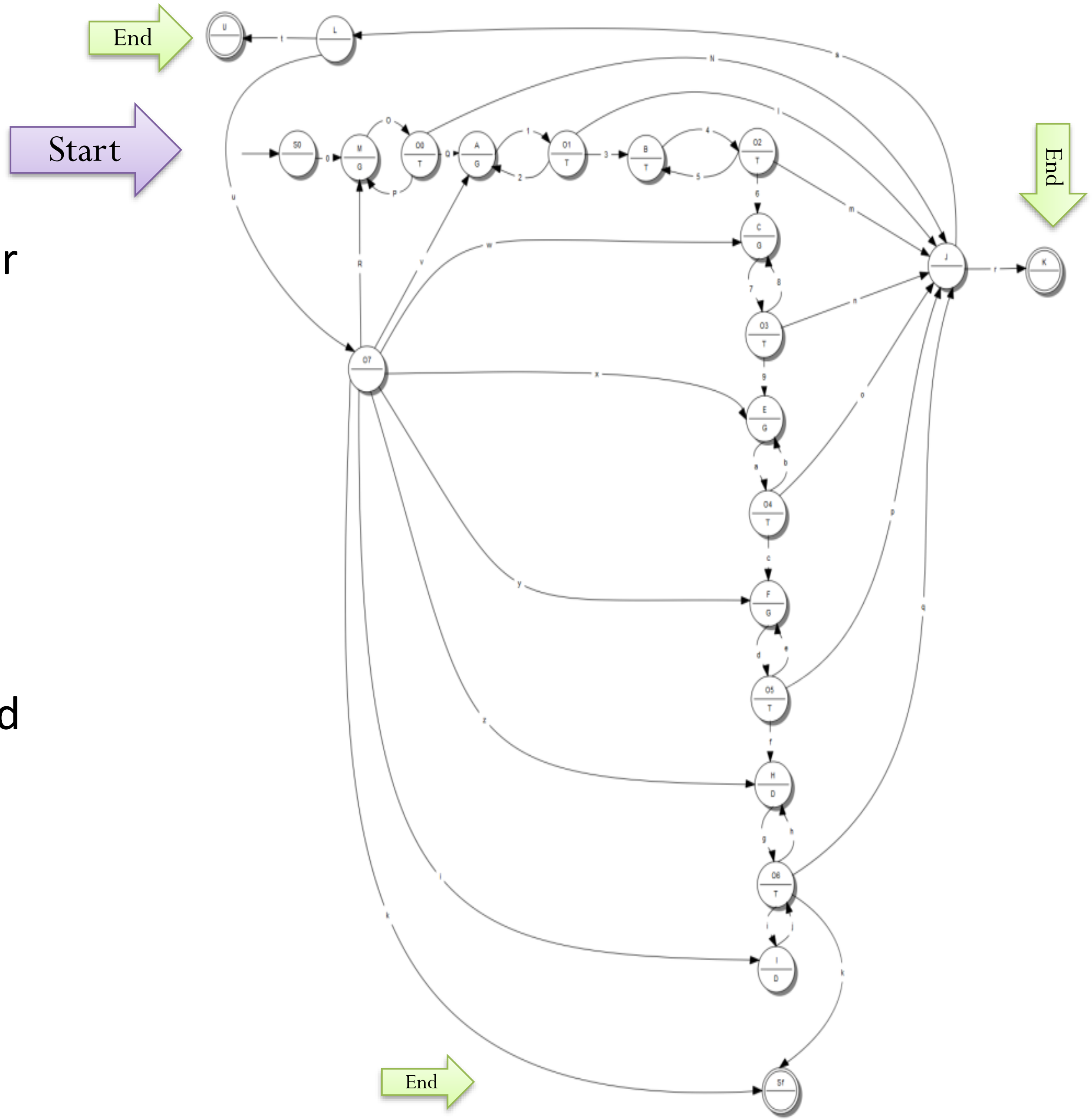
- experimental setup
- the model
- results

Experimental setup



The model

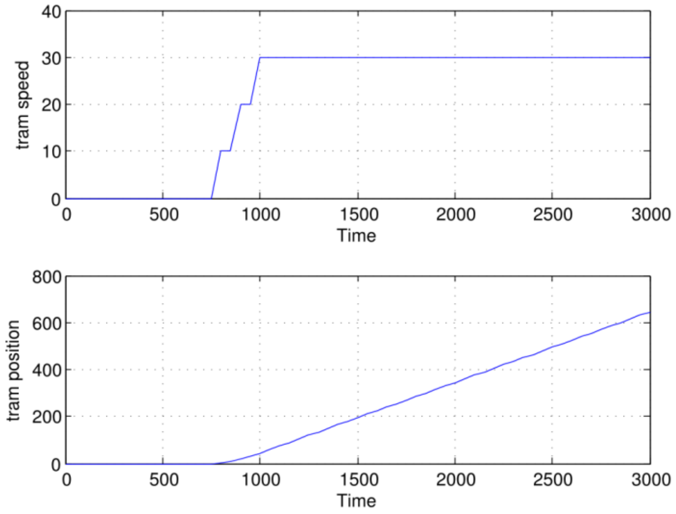
- Station departure scenario
- Plan of action is used to obtain a diagnoser
- The diagnoser is a 22 state FSM with an initial state and 3 terminal states
  - Terminal states are links to other situations
- States correspond to different driver actions and sub-actions
- States are labeled in a generic way to avoid confidentiality issues
- Transitions correspond to events



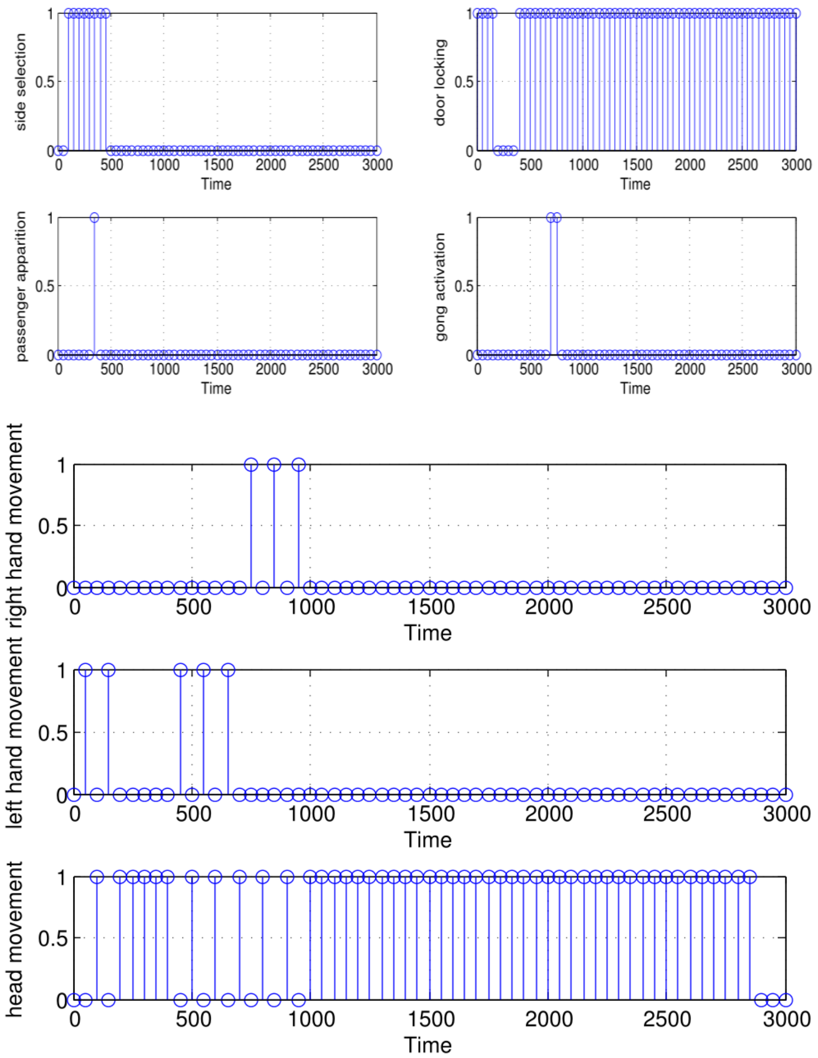
Results
Scenario 1

- Standard departure situation
- No Unexpected Events

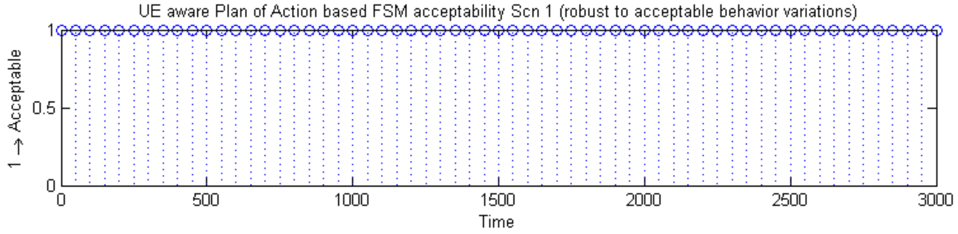
Tramway speed & position



Chronogram of driver actions



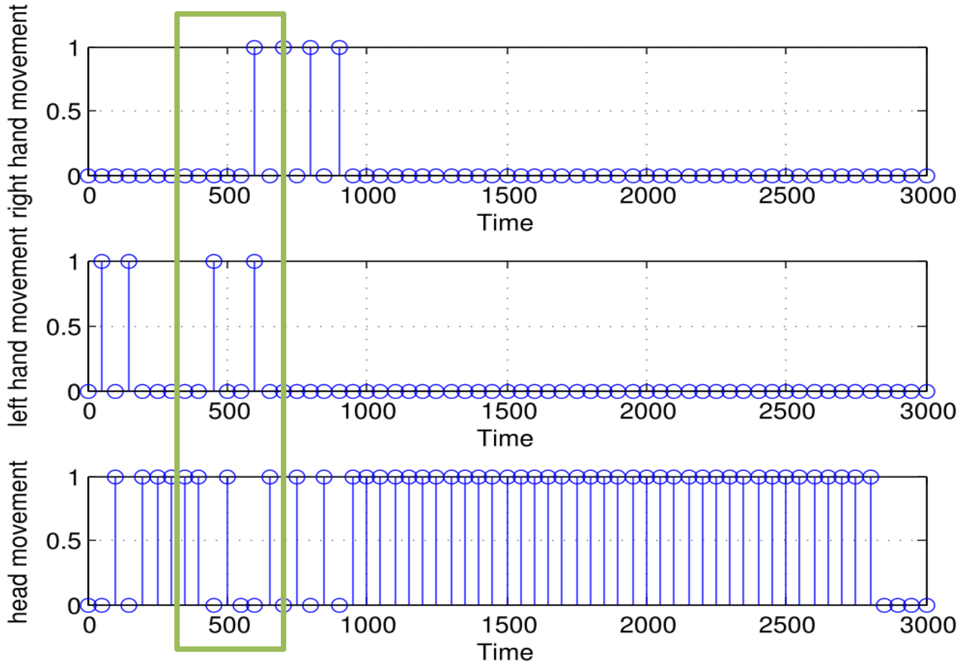
Diagnoser output



All clear

Results
Scenario 2

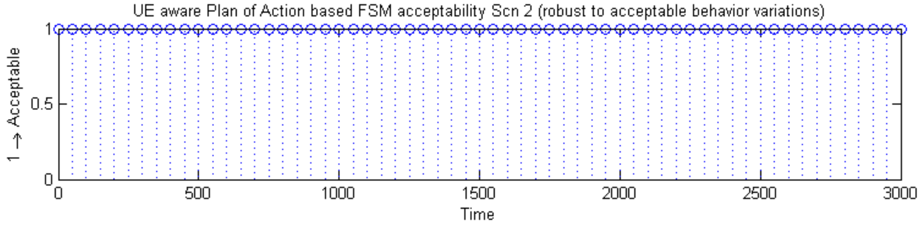
- The same situation
- Unexpected event occurred
  - [400 - 600]
  - Doors briefly blocked
- Driver actions are slightly different form the previous case
- Since the variation is acceptable, the diagnoser is green.



Blocked doors

Diagnoser output

All clear



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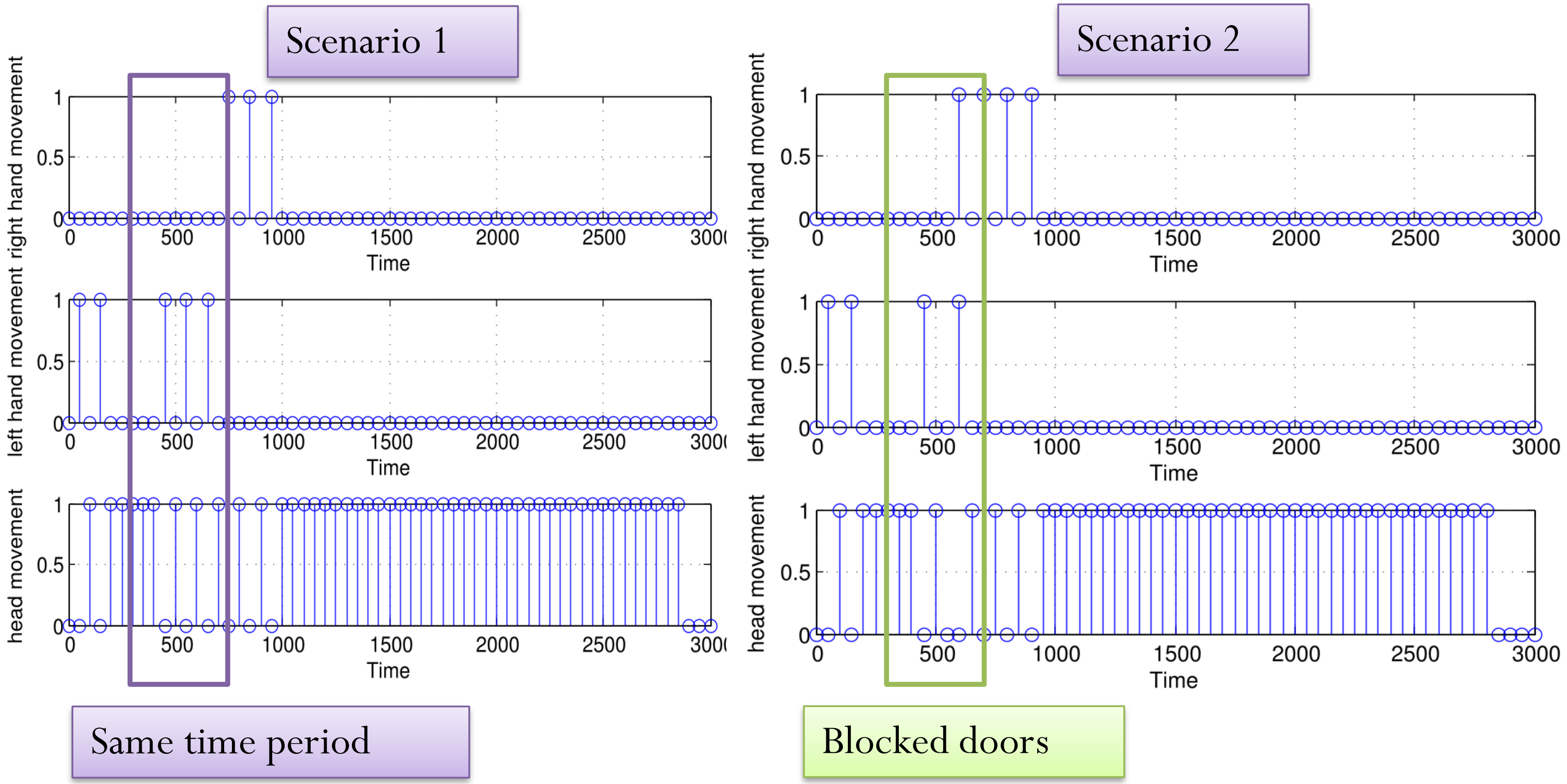
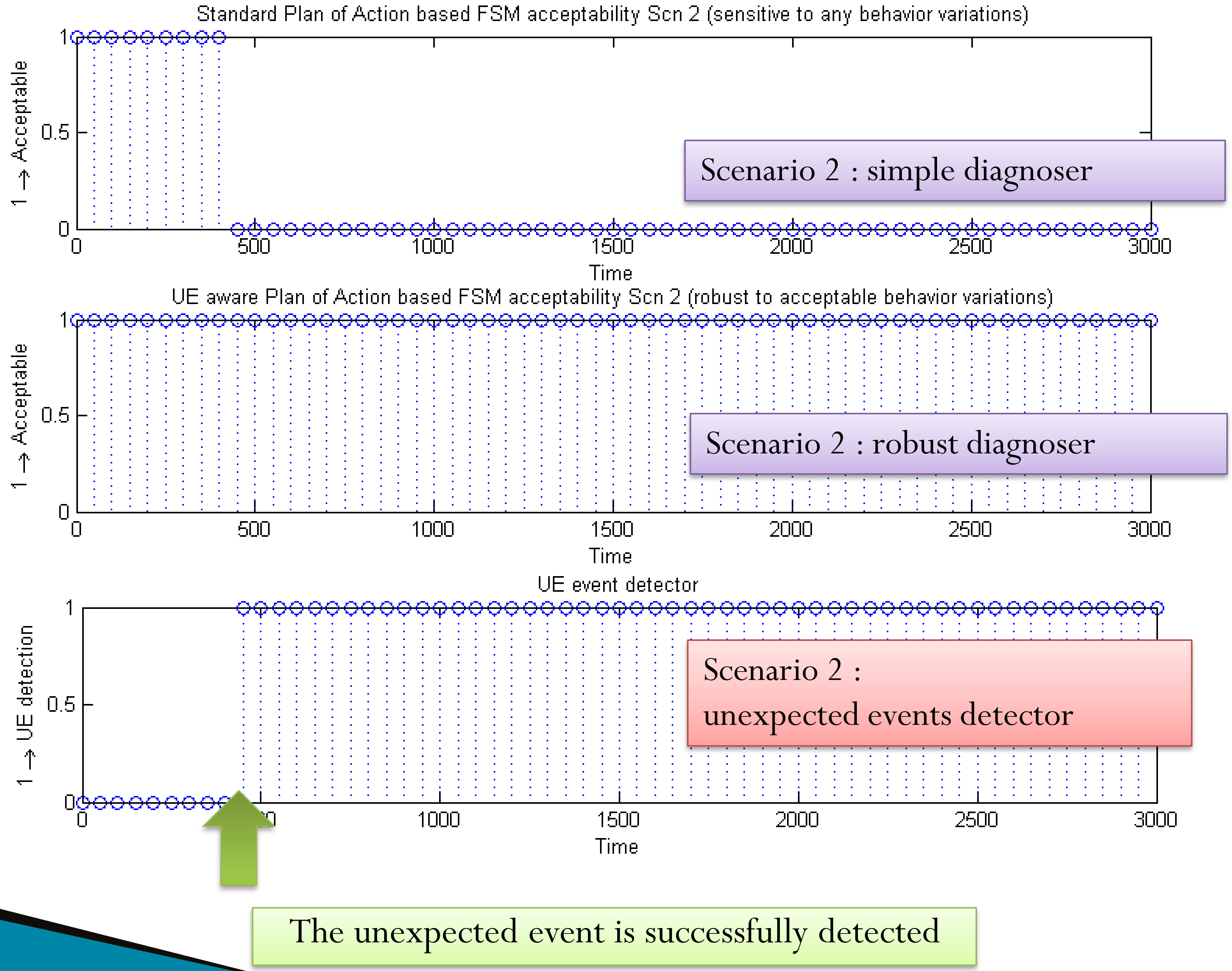
Observations



The diagnoser is robust : a natural variation in action sequence is accepted

Using the variation robust diagnoser prevents false alarms


Standard Plan of Action based FSM acceptability Scn 2 (sensitive to any behavior variations)
1 → Acceptable
Time
Scenario 2 : simple diagnoser
UE aware Plan of Action based FSM acceptability Scn 2 (robust to acceptable behavior variations)
1 → Acceptable
Time
Scenario 2 : robust diagnoser
UE event detector
1 → UE detection
Time
Scenario 2 :
unexpected events detector
The unexpected event is successfully detected

Discussion

- The proposed approach dealt successfully with the case study
  - The proposed « unauthorized behavior » detector proved to be robust
  - UE detector successfully detected door blockage.
  - The original “Disambiguation” approach allowed a significant reduction in detectors state count
- The false detection problem can be handled for the tested cases.
- The UE detector has a significant limitation : only the first occurring unexpected event can be detected.

PSCHITT
Collaborative, Hybrid, Intermodal Simulation Platform in Land Transports

- versatile, dynamic and immersive simulator
  - 1,5 M€
- PSCHITT-Rail :
  - tram/train driving,
- PSCHITT-PMR :
  - wheelchair movement
- PSCHITT-Colibri :
  - movement in aircraft seats

PSCHITT RAIL modality

- Railway field
  - evaluate the integration of new equipment in the train
  - study the behaviour of drivers
    - faced with situations at risk of accidents.
  - The PSCHITT-Rail Simulator is a tool to conduct such studies in safety conditions.

- Functionality:
  - Immersion (audio and visual)
    - driving view and rear view of the docks during stops in station),
  - Integration of real components in the simulated environment
    - (hardware-in-the-loop),
  - Scripting,
  - Acquisition of environment and driver related data
    - (actions, direction of gaze, behavior).

- Operational since April 2016
  - ECOVIGIDRIV project
    - 80 professional drivers.

Conclusion

- In safety critical applications, the human is the last resort to handle unexpected situations

- Automation design should be based on the human
  - human abilities will transcend the machine

- Human centered control theoretic approaches have the potential to
  - improve technology penetration & acceptability
  - insure resilience of the system
  - be most cost efficient solution to most problems

- Adapted technological benchmarks are necessary

Thank you for your attention

- denis.berdjag@uphf.fr

- http://www.uphf.fr/LAMIH/
- https://www.uphf.fr/LAMIH/en/PSCHITT
- Ecovigidriv project : https://youtu.be/_9BjV6P13kI