Performability Evaluation of ERTMS/ETCS Level 3

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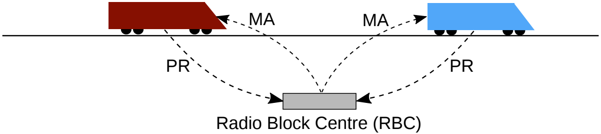
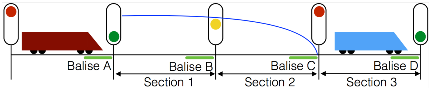
European Rail Traffic Management System (ERTMS)

- An innovative standard for train signalling and traffic management
  - Goal: improve performance, reliability, safety, maintenance costs, and cross-border interoperability of European railway networks
  - Several manufacturers: Alstom, Ansaldo STS, Thales, Siemens, Bombardier, etc.
  - ERTMS European Deployment Plan (January 2017): deadlines for key corridors by 2023, with a review in 2021-2023 to define the remaining deadlines by 2030
  - A worldwide success: investment programs in China, Taiwan, South Korea, India, Algeria, Libya, Saudi Arabia, Mexico, New Zealand, Australia, etc.
- Based on the European Train Control System (ETCS)
  - Automatic train protection system for continuous train supervision
  - A trackside equipment receives a periodic Position Report (PR) for each supervised train and sends back a Movement Authority (MA)
  - A train triggers an emergency brake if the allowed speed is exceeded

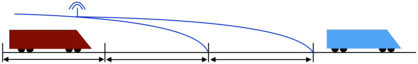


ERTMS/ETCS: three levels of operation

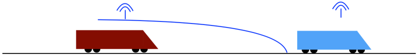
- Level 1
  - Non-continuous unidirectional (track → train) communication through balises
  - Fixed-block signalling (i.e., tracks are divided in fixed blocks)



- Level 2
  - Continuous bidirectional (track ↔ train) communication through the GSM-R, which can be unavailable due to burst noise, connection losses, cell handovers
  - No trackside signalling systems ⇒ reduced maintenance costs
  - Braking curve recomputed continuously ⇒ increased maximum speed

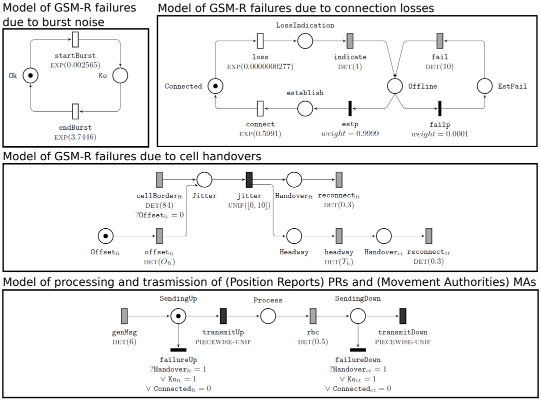


- Level 3
  - Moving-block signalling (i.e., trains check position and integrity autonomously)
  - No train detection systems ⇒ installation/maintenance savings, capacity gains
  - Mobile communication is crucial: trade-off between capacity and false alarms



Goal: characterize the first-passage time distribution to an emergency brake caused by GSM-R failures

- Models of GSM-R failures due to burst noise, connection losses, handovers composed with a model of periodic transmission of PRs and MAs
  - Non-Markovian models specified through Stochastic Time Petri Nets (STPN)
  - Periodic handovers experienced by a pair of chasing trains are dependent events
  - Stochastic parameters are derived from Zimmermann et al (2003, 2005), with amendments introduced in the evolution of the ERTMS/ETCS specification



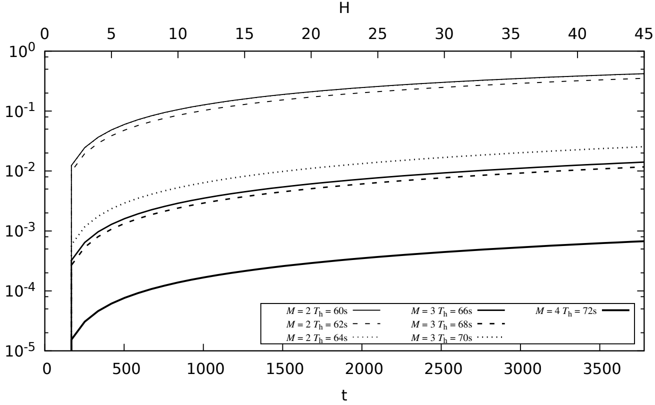
Solution combining analytic evaluation and transient analysis

- Stochastic evaluation of the flat model would be practically not feasible
  - Transient analysis via the ORIS Tool (`http://www.oris-tool.org`) [1] would suffer the many concurrent timers associated with a general (GEN) distribution (i.e., non-Markovian distribution)
  - Approaches based on the approximation of GEN transitions [2] appear not well suited due to the many concurrent GEN transitions with firmly bounded support
  - Simulation would suffer rare events and different order of magnitude of durations
- The causes of GSM-R failures are due to independent phenomena
- GSM-R unavailability is evaluated separately for each failure type either analytically or through transient analysis via the ORIS Tool
  - Multiple losses due to burst noise can be regarded as independent events
  - Connection losses negligibly affect the GSM-R availability wrt burst noise
  - At most 2 out of 4 consecutive PRs and/or MAs can be lost due to handovers
- Evaluation within 2 hyper-periods yields an upper-bound on the first passage time distribution to an emergency brake over an arbitrary duration interval

[1] Horváth et al (2012).
[2] Horvath et al (2000), Longo et al (2009), Lindemann et al (1999)

Upper-bound on the first-passage time distribution to an emergency brake caused by GSM-R failures (1/2)

- Upper-bound on the first-passage probability that an emergency brake occurs within H hyper-periods, computed for different headway delays T_h
  - The duration of a hyper-period is $84\,\mathrm{s} \Rightarrow$ 45 hyper-periods $\sim 1\,\mathrm{h}$
  - The train speed is $300\,\mathrm{km/h}$



Upper-bound on the first-passage time distribution to an emergency brake caused by GSM-R failures (2/2)

- Upper-bound on the first-passage probability that an emergency brake occurs within 45 hyper-periods ($\sim 1\,\mathrm{h}$) as a function of the headway distance s_h (expressed in km), computed for different values of speed v