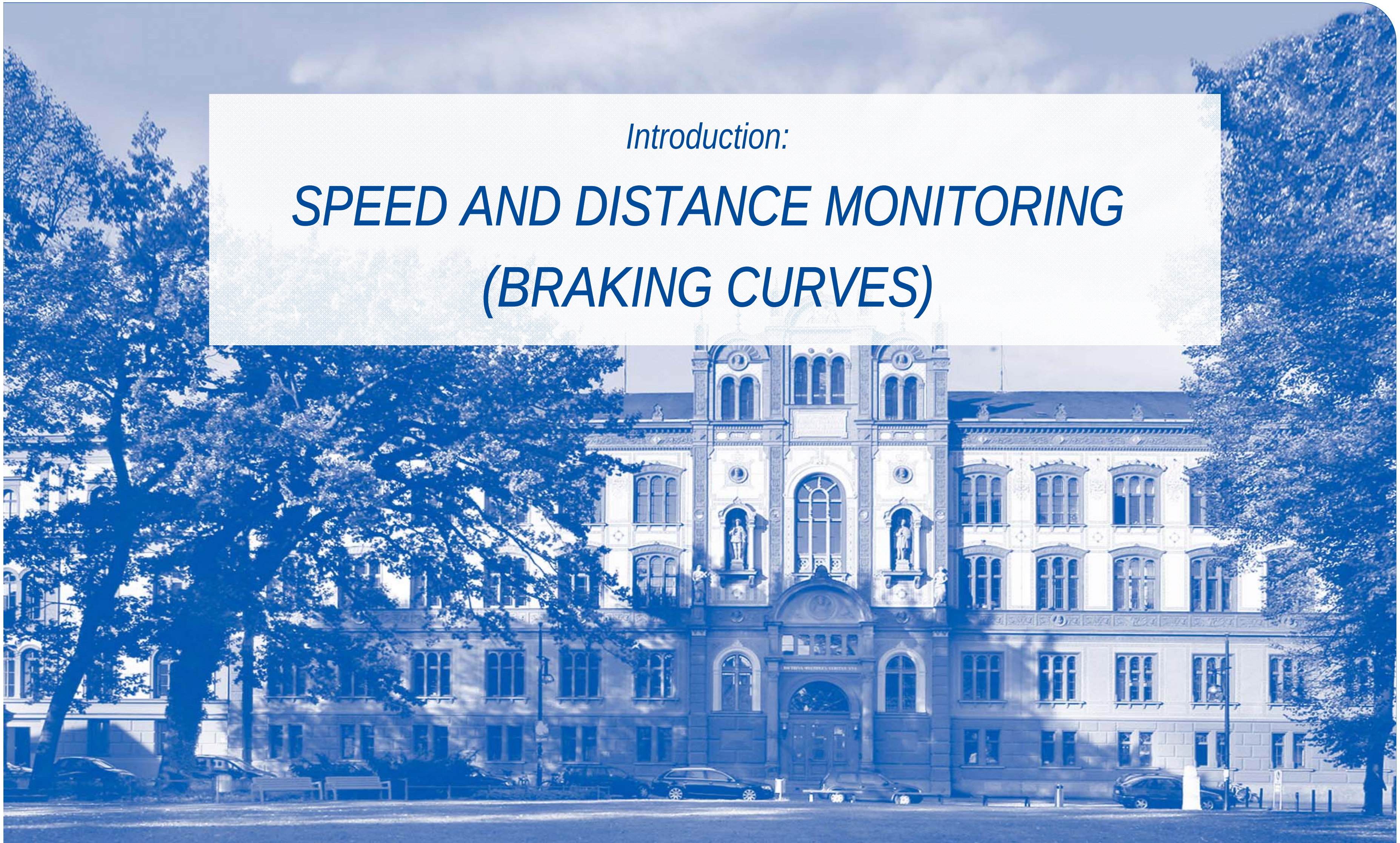
Traditio et Innovatio

Introduction:

SPEED AND DISTANCE MONITORING (BRAKING CURVES)



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Content

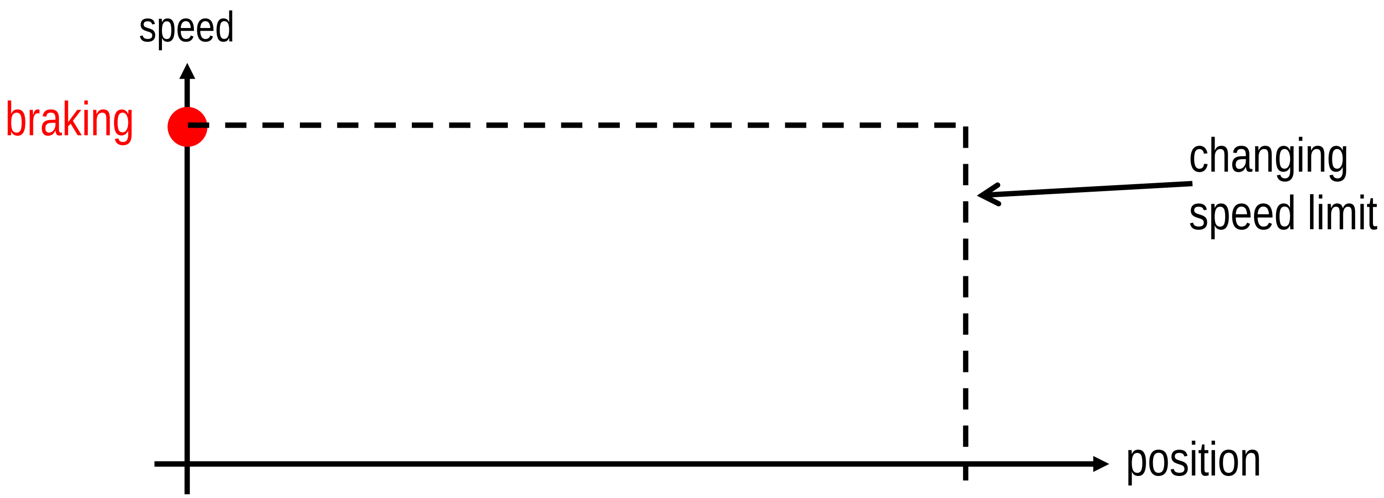
1. General Overview
   → Need of a Train Control System
   → Braking Curve
   → Speed and Distance Monitoring
2. Speed and Distance Monitoring in detail
   → Train related Inputs
   → Track related Inputs
   → Important Modules
3. User Story: University of Rostock

Why we Need a Train Control System?

- Railway vehicle: high mass, low deceleration
- Braking distance from 250 km/h:
  → ICE: ~ 2.000m (1,2m/s^2)
  → Car: ~ 240m (10m/s^2)
- Braking distance is not observably → technical assistance required
- Provided by ETCS → SPEED AND DISTANCE MONITORING

Braking Curve

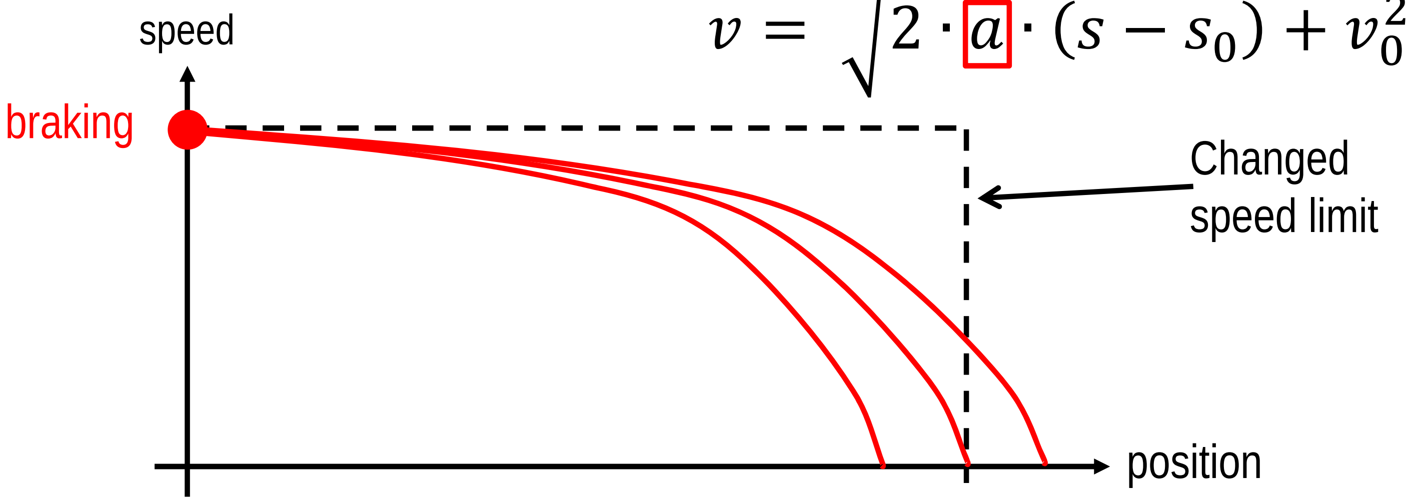
- = speed decrease versus distance



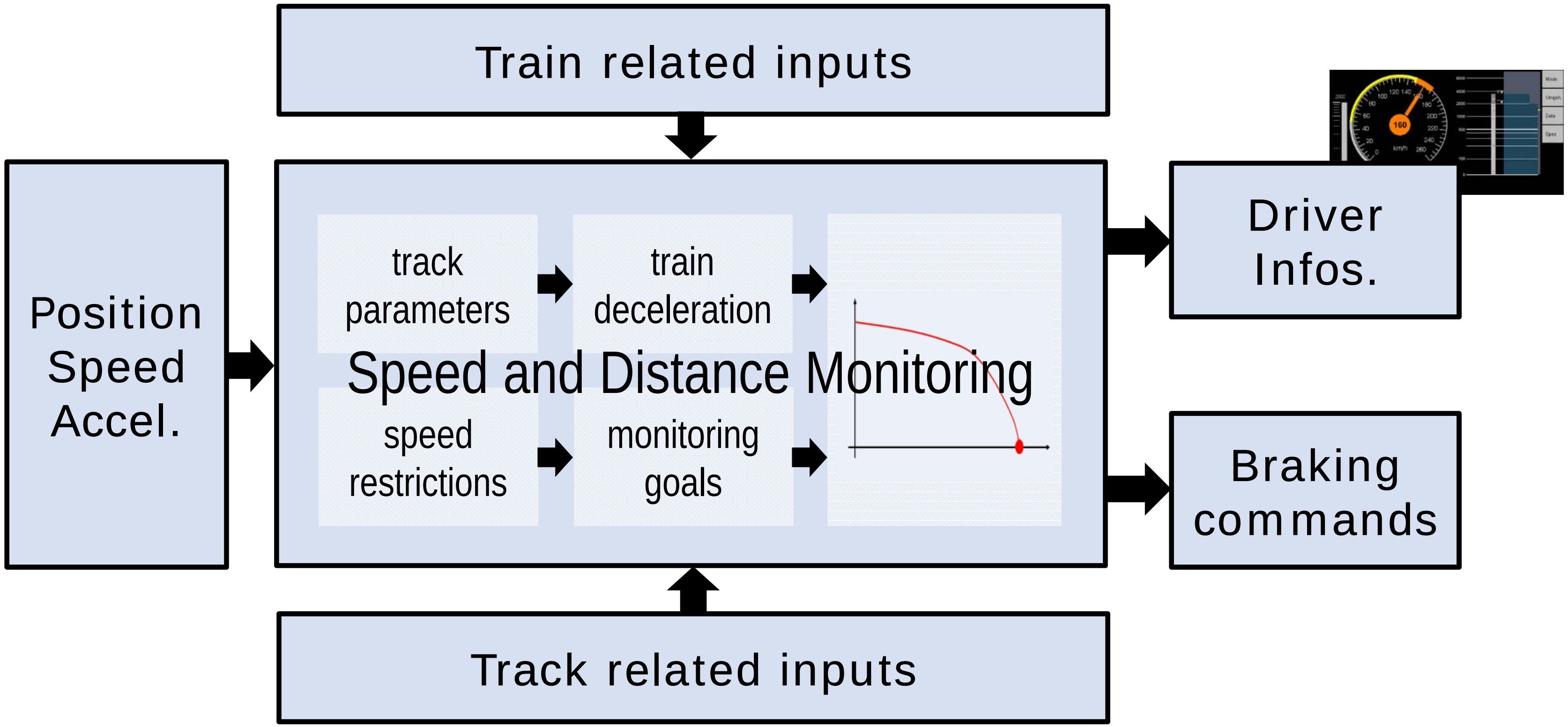
Braking Curve

- = speed decrease versus distance

$$v = \sqrt{2 \cdot \boxed{a} \cdot (s - s_0) + v_0^2}$$



Speed And Distance Monitoring



Relevant Inputs

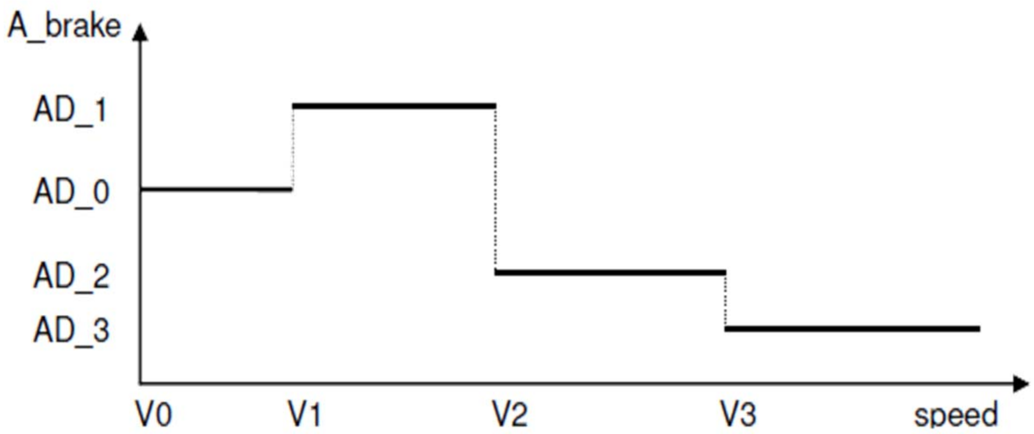
Train related Inputs

- Braking Model
- Special Brakes
- Onboard correction factors
- Traction model
- Train specific parameters

Speed And Distance Monitoring

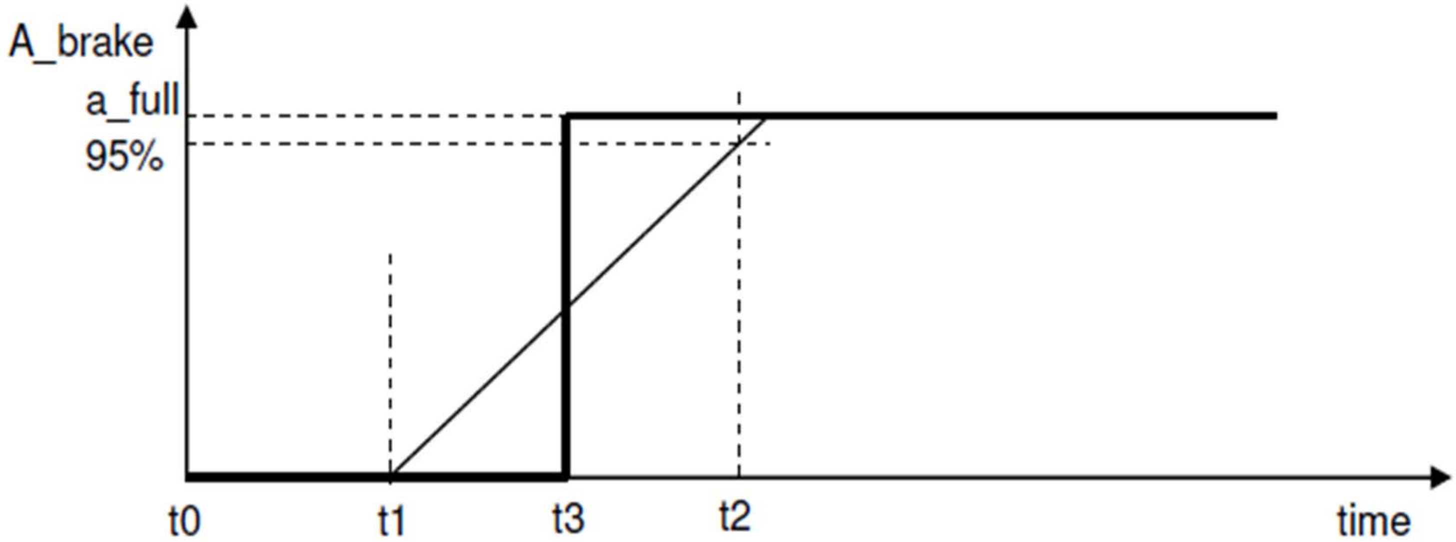
Braking Model

- to **compute** the **braking distance**
  → determining braking performance
- quantitative description of braking performance:
  1. Brake-weight percentage (legacy)
     →Problem: no speed dependency
  2. instantaneous deceleration as a function of speed (step function)



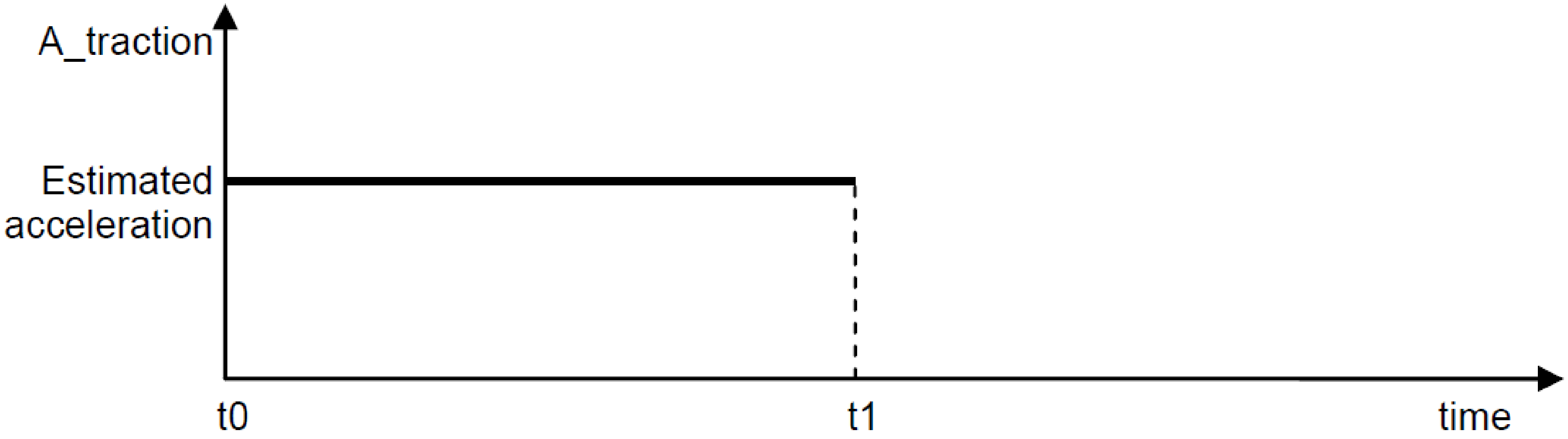
Brake build up time

- A_brake = deceleration value
- Time delay until full brake force
  → A_brake is not available immediately after braking command



Traction Model

- A_traction: acceleration of the motor
- Model: motor of the traction vehicle can not be arbitrarily fast decoupled from axes
- e.g. → braking command → time delay (T_traction_cut_off) due to traction is zero



Special Brakes

- Special brakes can be active/inactive → affects deceleration value

- beside the **pneumatic brake** exists special brakes:
  - Electro-pneumatic brake
  - Eddy current brake
  - Magnetic shoe brake
  - Regenerative brake

- OBU:

→ usage of special allowed?

→ conditions?

Correction Factors

- Need of correction factors, because:

  → Braking model only describes nominal value of deceleration

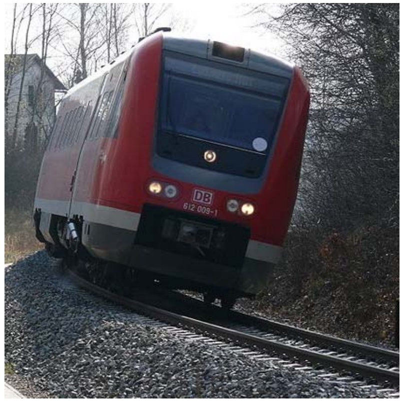
  → rolling stock braking behavior depends also on track conditions:

  dry, wet, icy, gradients and brake inhibitions

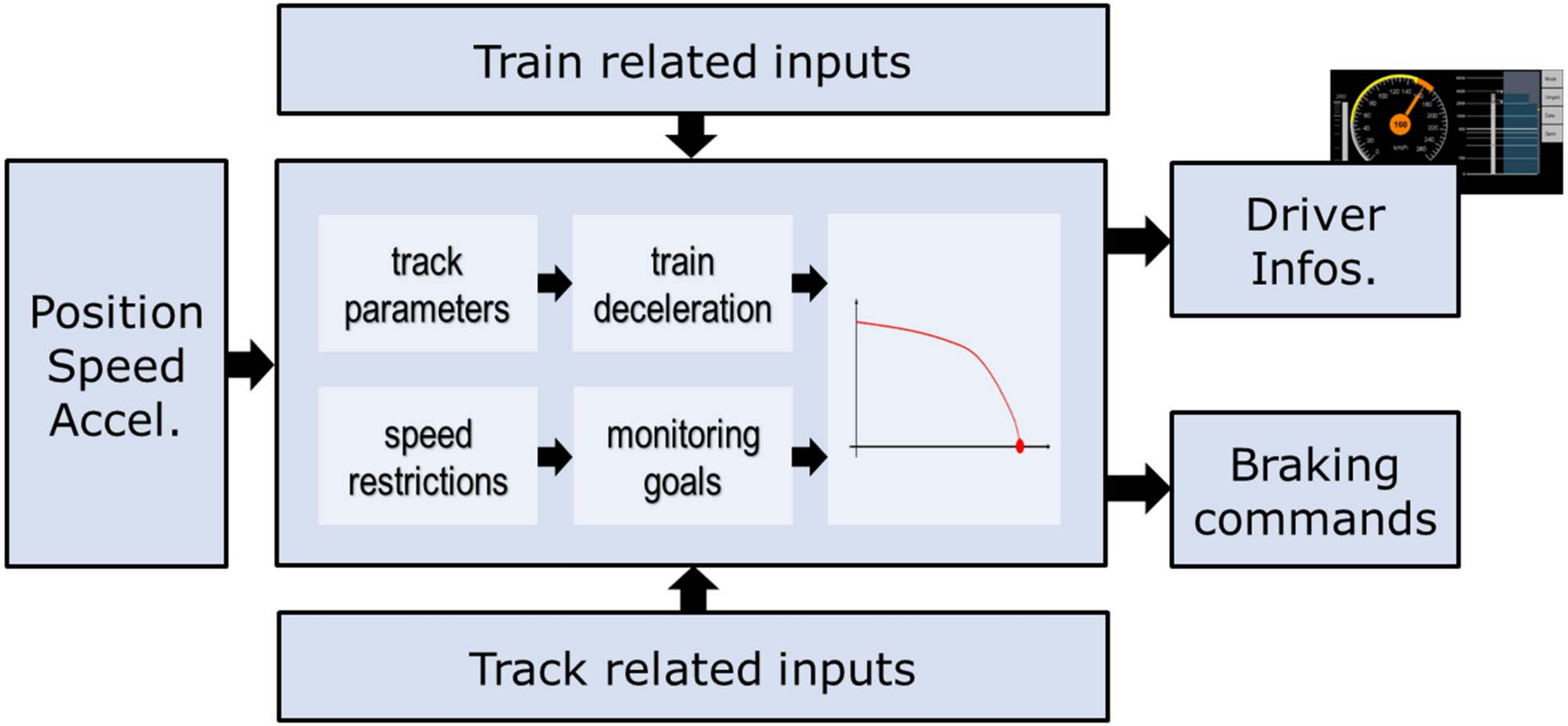
- Nominal value is reduced by correction factor and statistical deviation
  → empirical determination by train manufactures (test scenarios)
  → indicated by confidence level

Train specific parameters

- Maximum train speed
- Train length
- Maximum axle load
- Nominal Rotating mass (for compensating the gradient)
- Fixed values (defined constants for Distance and Speed Monitoring)
- Train category (e.g. train specific speed limits in curves – tilting train)



Speed And Distance Monitoring



Track related Inputs

Speed And Distance Monitoring

- Movement Authority
- Trackside related speed restrictions
- Speed and distance limits
- Gradient profile
- Track conditions
- National values

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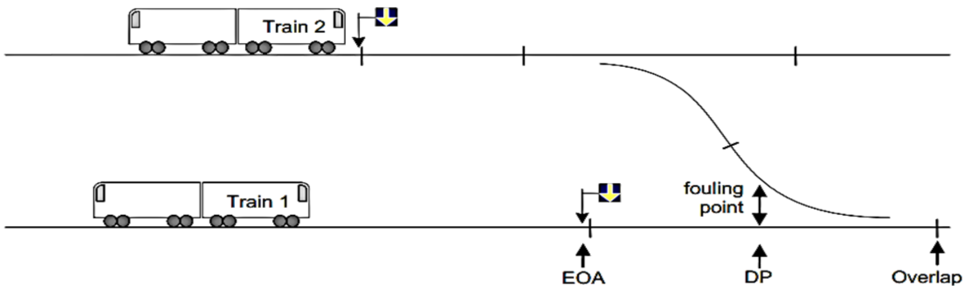
Movement Authority (MA)

- MA = Permission of a train to proceed on a given piece of track
  → go to a specific location within the constraints of the infrastructure



- **End of Authority (EOA):**
  → the location to which the train is authorized to move
- **Target Speed:** permitted Speed at the EOA
- **Limit of Authority (LOA):**
  → EOA with target Speed = 0
- **Danger point (DP):** reachable by the front end of train (no risk)
- **Overlap (OL):** beyond DP
- **Supervised Location**
  → location that the train is absolutely prevented from passing
  → is one of either the: EOA, DP and OL
  → determined from OBU

Trackside and other speed restrictions

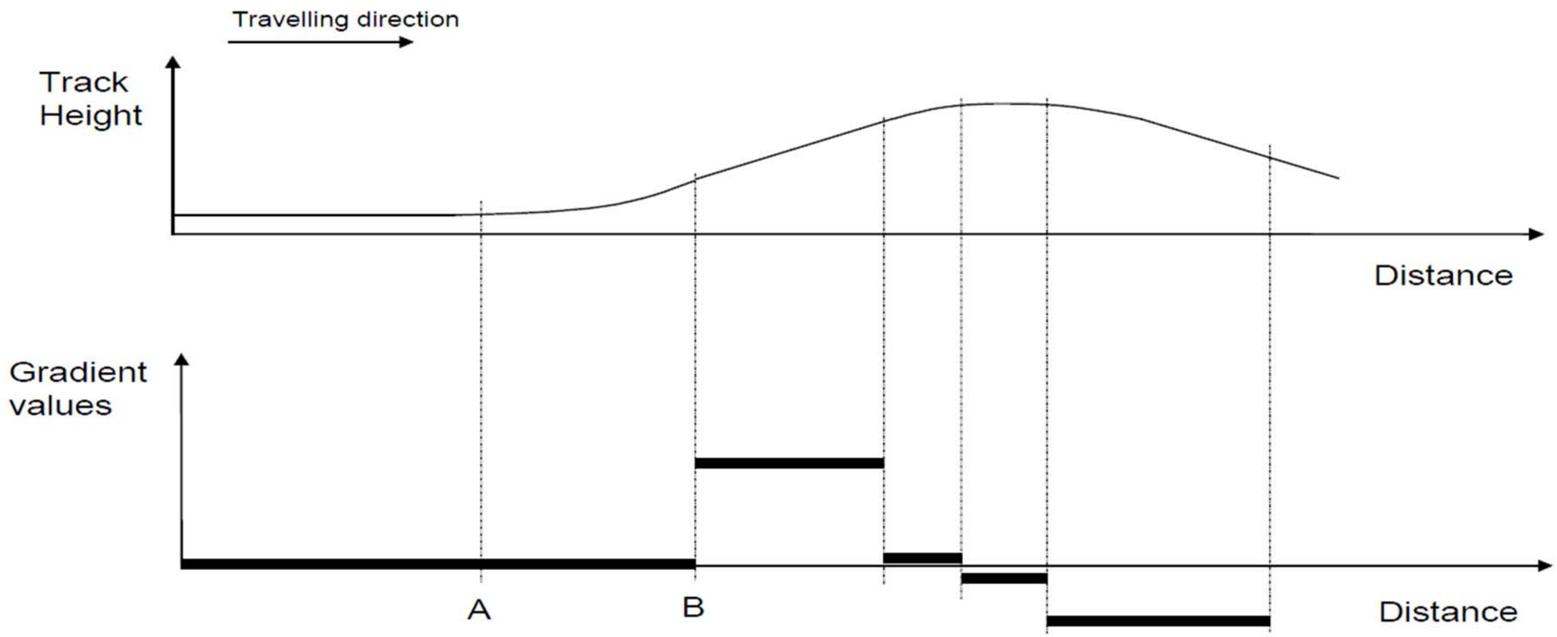
- Static speed profile: (SSP)
  → fixed speed restrictions for a given piece of track
- Axle load speed profile: (ASP)
  → train is categorized through its specific axle load
  → applied speed restriction to a specific category
- Temporary Speed Restrictions: (TSR)
  → e.g. mandatory while track is under construction
  → possibility of overlaying different TSR: identified by a number

Trackside and other speed restrictions

- Signaling related Speed Restrictions:
  → while ETCS-Level 1: given speed restriction through balise
  → for compatibility to legacy systems
  → train driver don’t need to watch out stationary signals (*FS*)
- Mode related Speed Restrictions:
  → speed restrictions depending on operation mode of the ETCS train
  → e.g. while shunting: max speed is restricted by “*National Value*”
- Level Crossing Speed Restrictions:
  → unsecured level crossing: stopping or what is the allowed speed for passing
- Speed Restriction to ensure permitted braking distance:
  → concrete braking distance is given
  → OBU determines resulting speed to ensure this braking distance
  → braking distance depends on allowed brake

Gradient profile

- Gradient Profile:
  → height information of the track



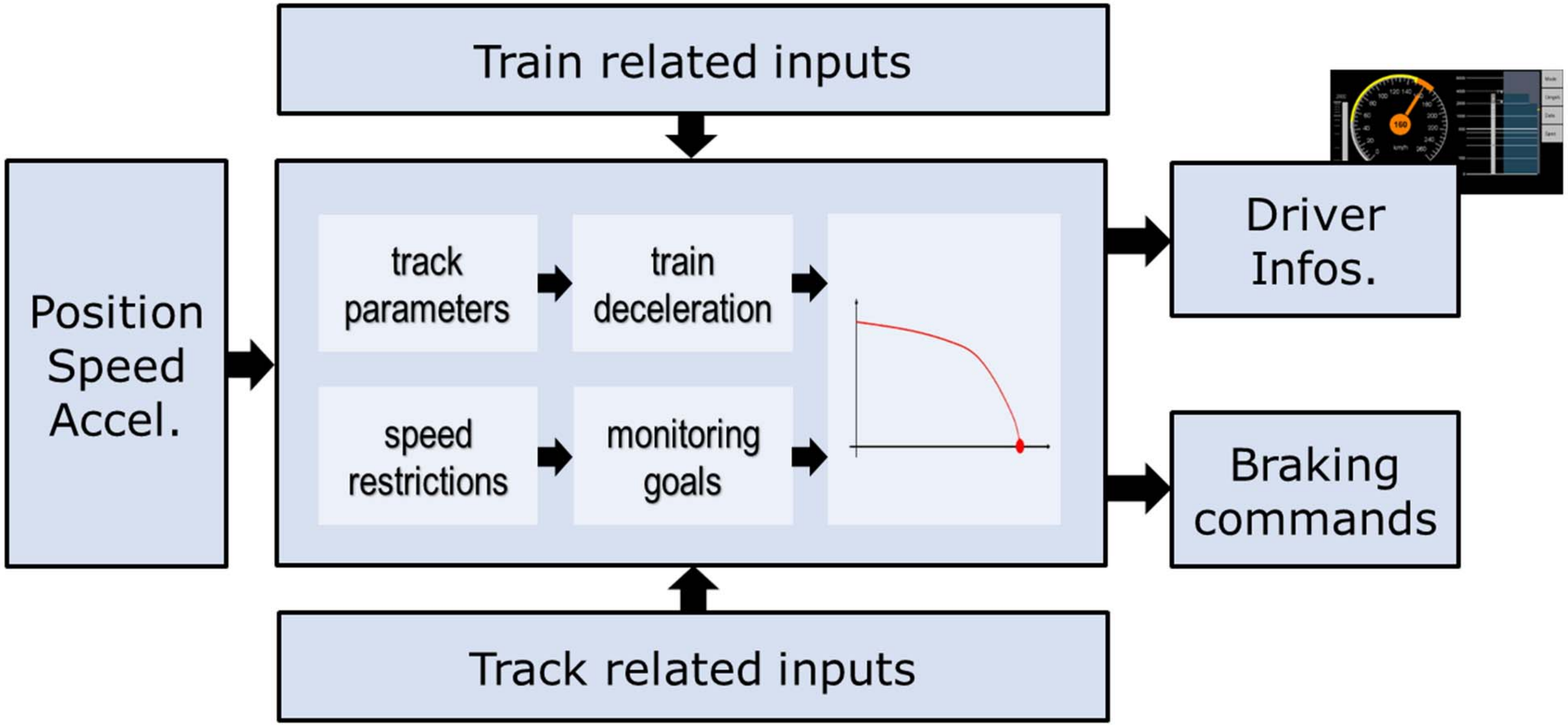
→ for uphill slope (pos-value) and downhill slope (neg-value)

Track conditions and National Values

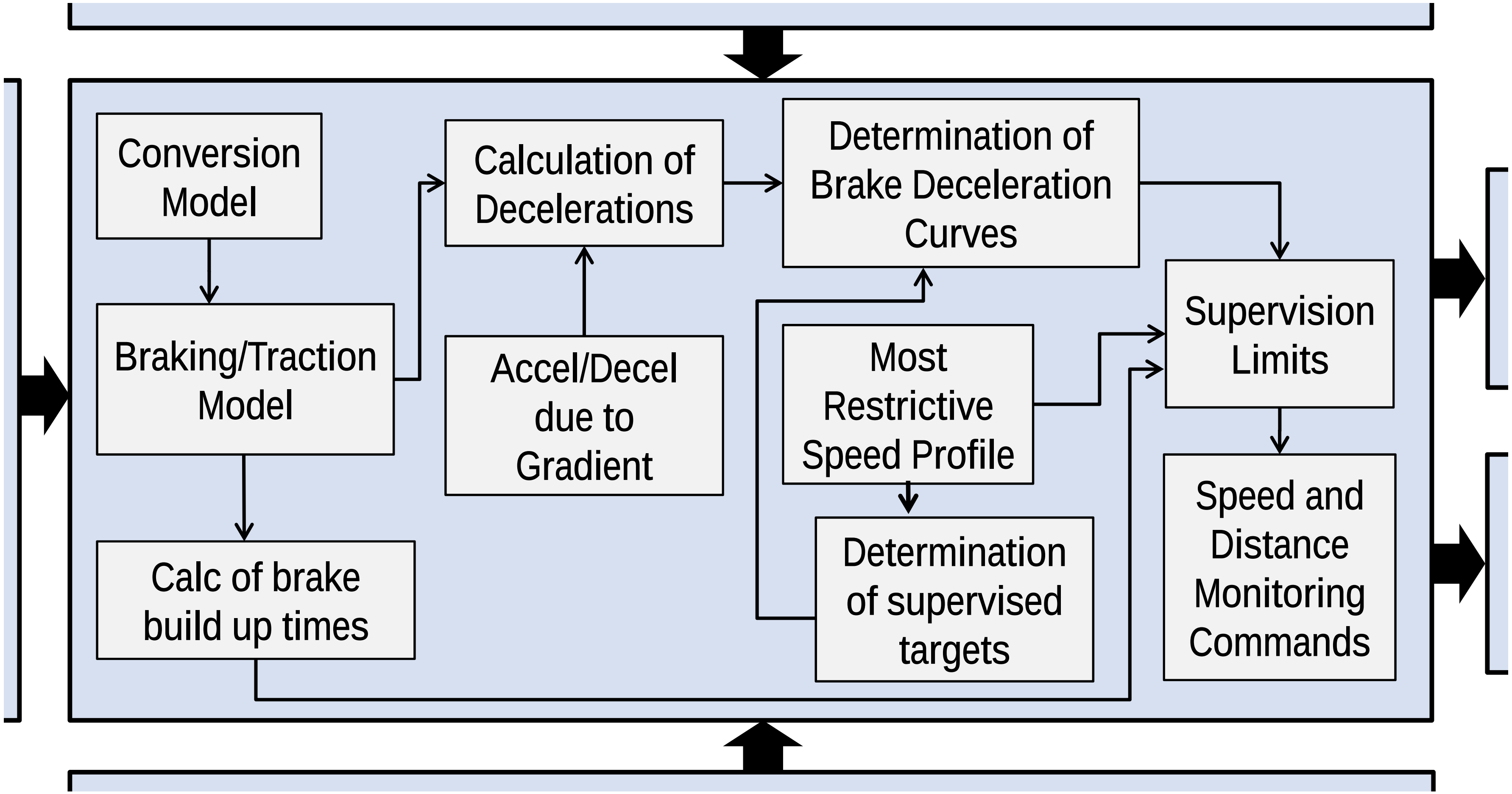
- Track condition:
  → restrictions of using special brakes
  (e.g. no regenerative brake is allowed while energy feed back to the grid is not possible)
  → notification about reduced adhesions (slippery track)

- National Values:
  → different calculations values
  → prohibition of ETCS functions possible
  → country-specific – but not consistent in usage
  → variation on different tracks

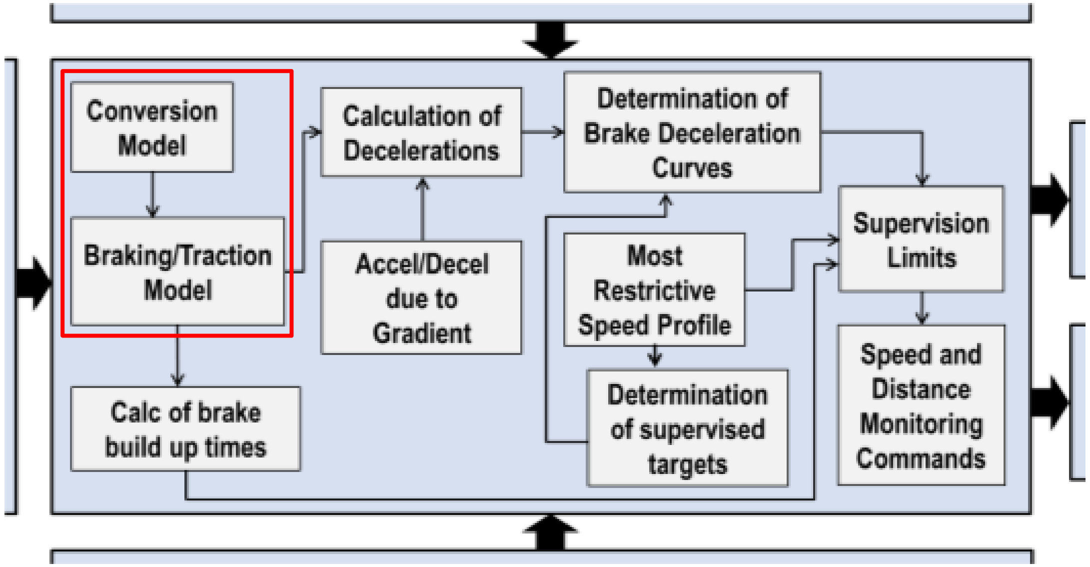
Speed And Distance Monitoring



Modules within the Speed and Distance Monitoring

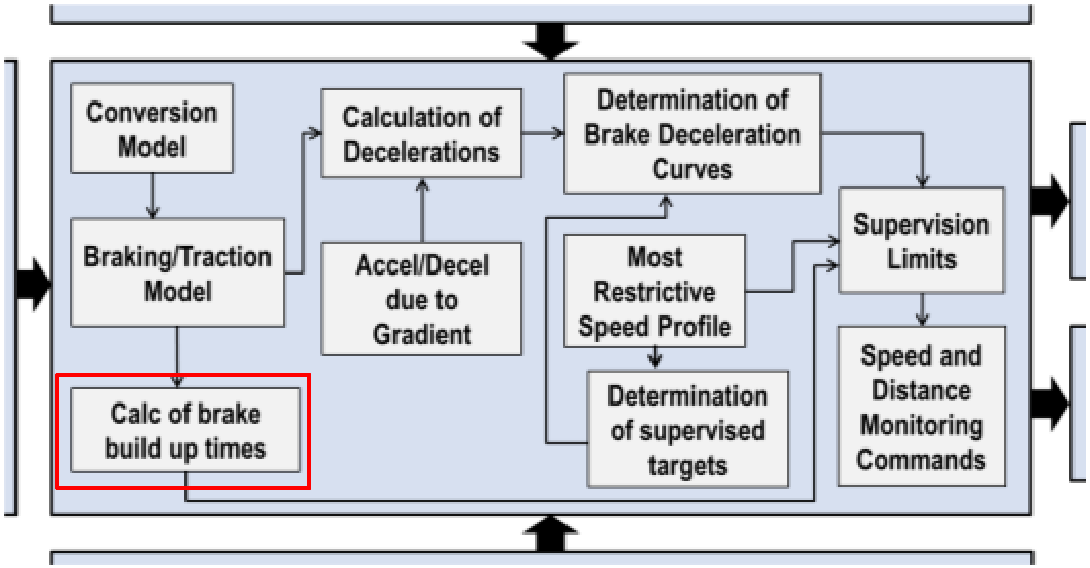


Conversion Model Braking/Traction Model



- trains with variable compositions → train brake characteristics vary
- train driver:
  → data entry, but no knowledge about brake percentage/position
- Conversion of entered data into the corresponding brake model

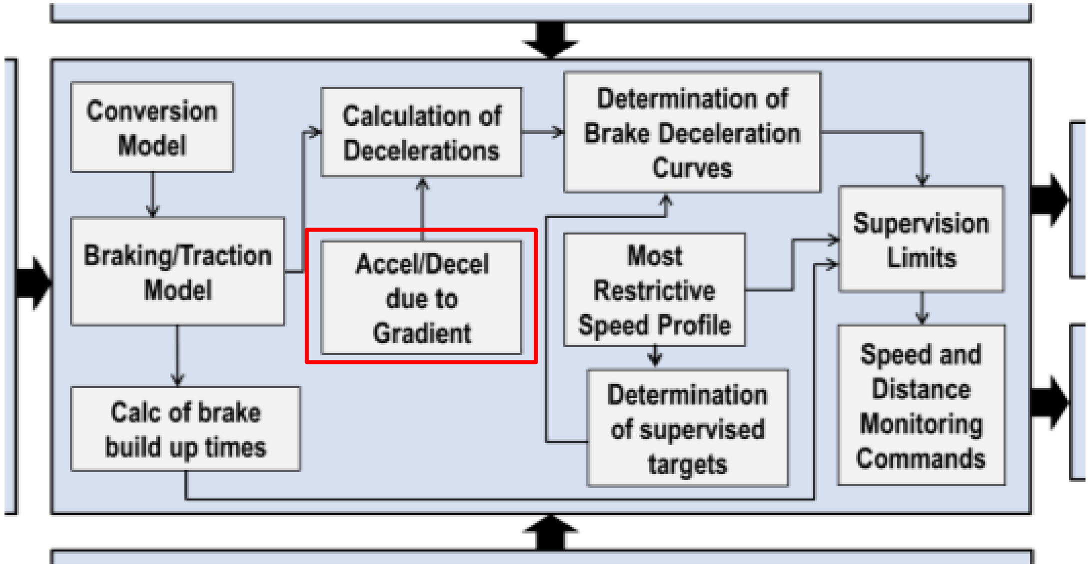
Calculation of brake build up times



- deceleration value:
  → not available immediately after braking command

  → T_be = *brake build up time* for emergency brake [safety relevant]
  → T_be = Correction factors * T_brake_emergency
  → T_brake_emergency: combination of available special brakes

Accel./Decel. due to Gradient



- Calculates the **acceleration/deceleration caused by the elevation of the track**
- 2 steps, calculating:
  → train length compensation: (lowest gradient over train length)
  → rotating mass/inertia: (down → lower accel.; up → lower decel)
- Output: **A_gradient(d)** = mapping: position → accel./decel.

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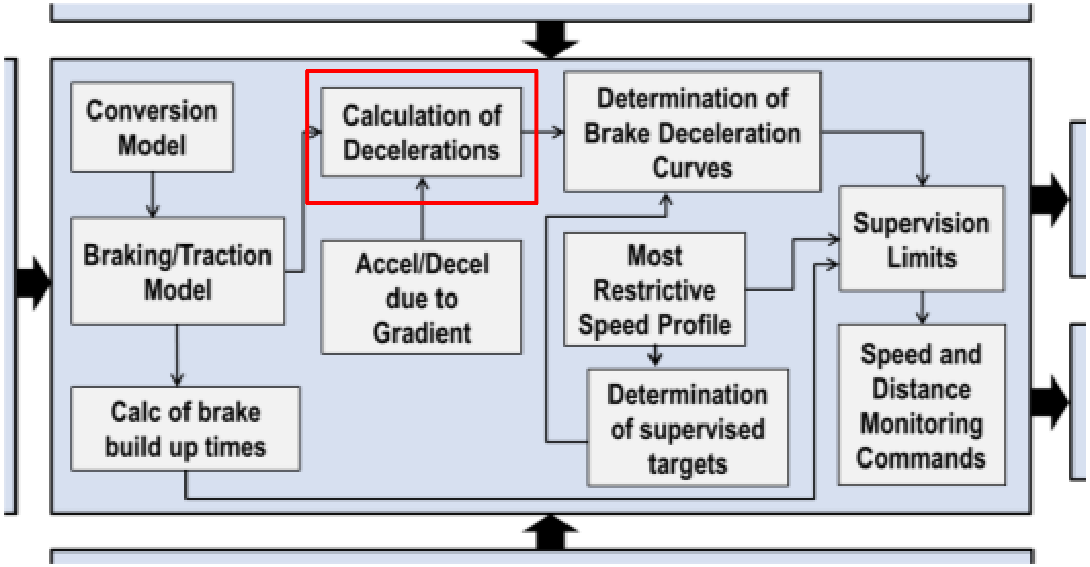
Calculation of decelerations



1. Calculation: A_brake_emergency(V,d)
   → braking model *A_brake_emergency(V)* + *train length* + *actual speed* + *track conditions* + *allowed special*
2. Calculation: A_brake_safe(V,d)
   → A_brake_emergency + correction factors
3. Calculating: A_safe(V,d)
   → A_safe(V,d) = A_brake_safe(V,d) + A_gradient(d)

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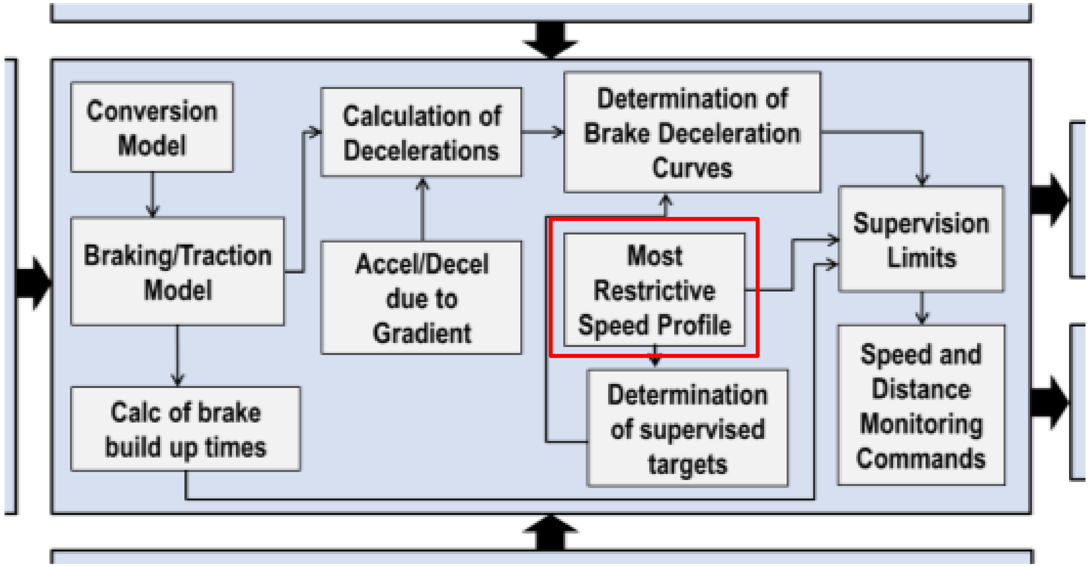
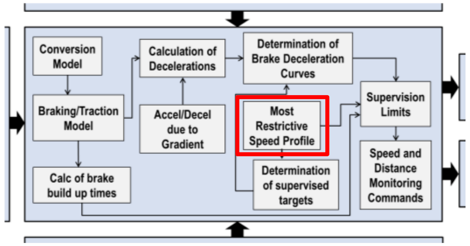
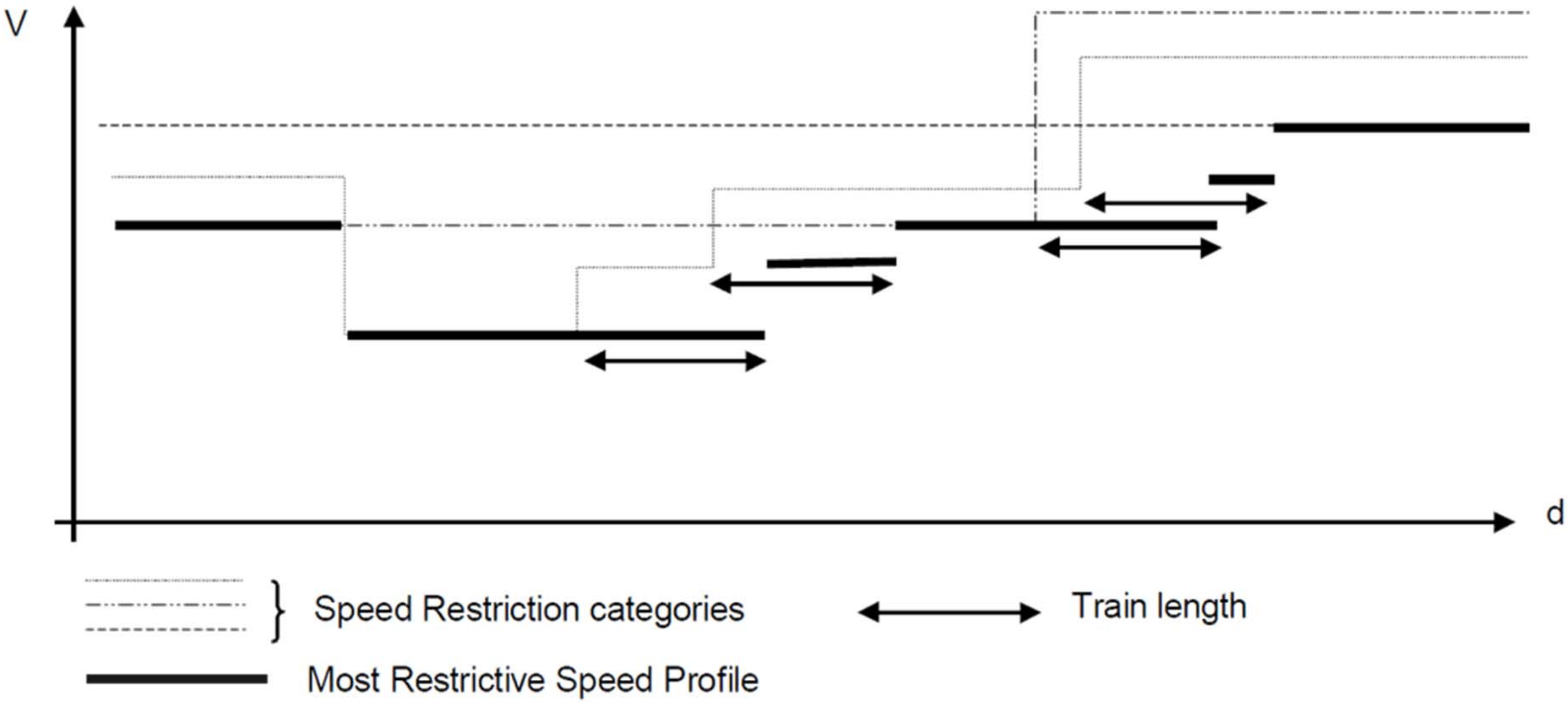
Most restrictive speed profile



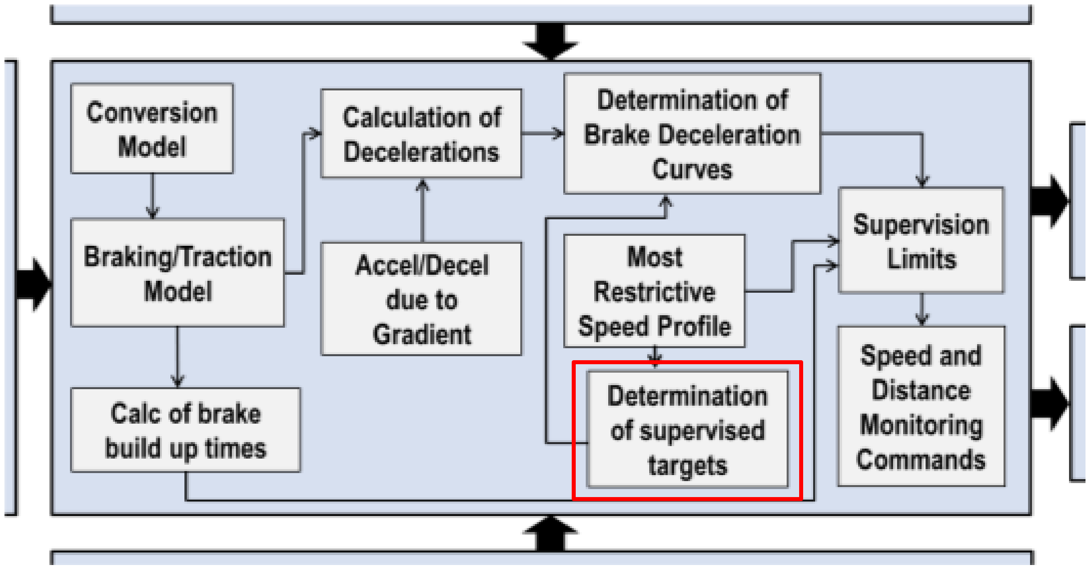
- Covering the **variety of different speed limits** from the track and train
- MRSP **outputs the lowest allowed speed** of all speed restriction categories (most restrictive speed)



Most restrictive speed profile

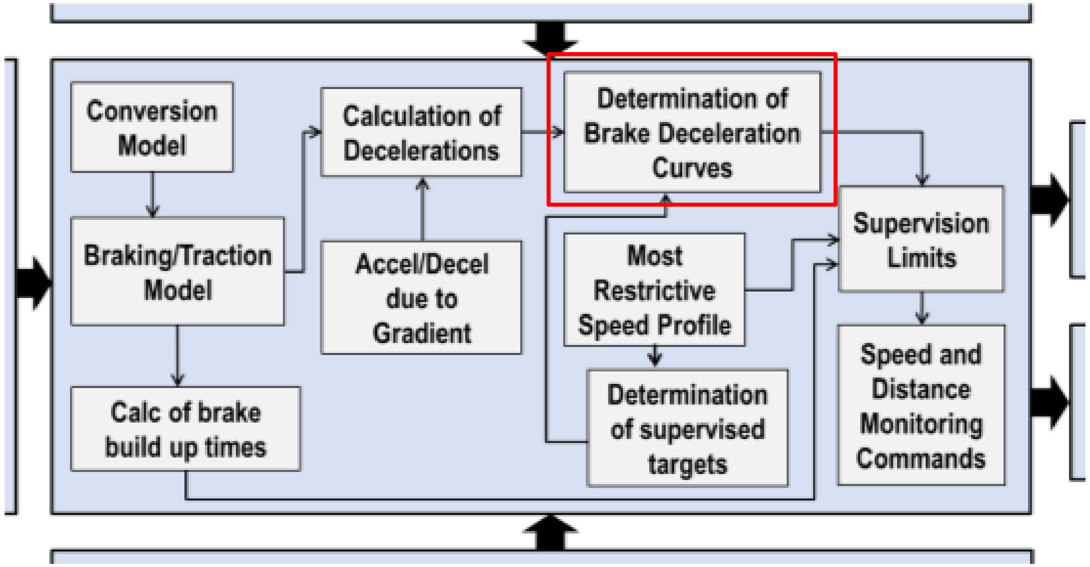


Determination of supervised targets



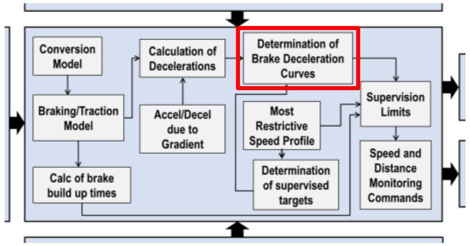
- Considering simultaneously several targets
- this module **maintains a list of these monitoring targets**
- Possible targets, e.g.:
  → location corresponding to a speed decrease of MRSP
  → Limit of Authority **(LOA)** (V > 0)
  → End of Authority **(EOA)** and Supervised Location **(SvL)** (V = 0)

Determination of brake deceleration curves



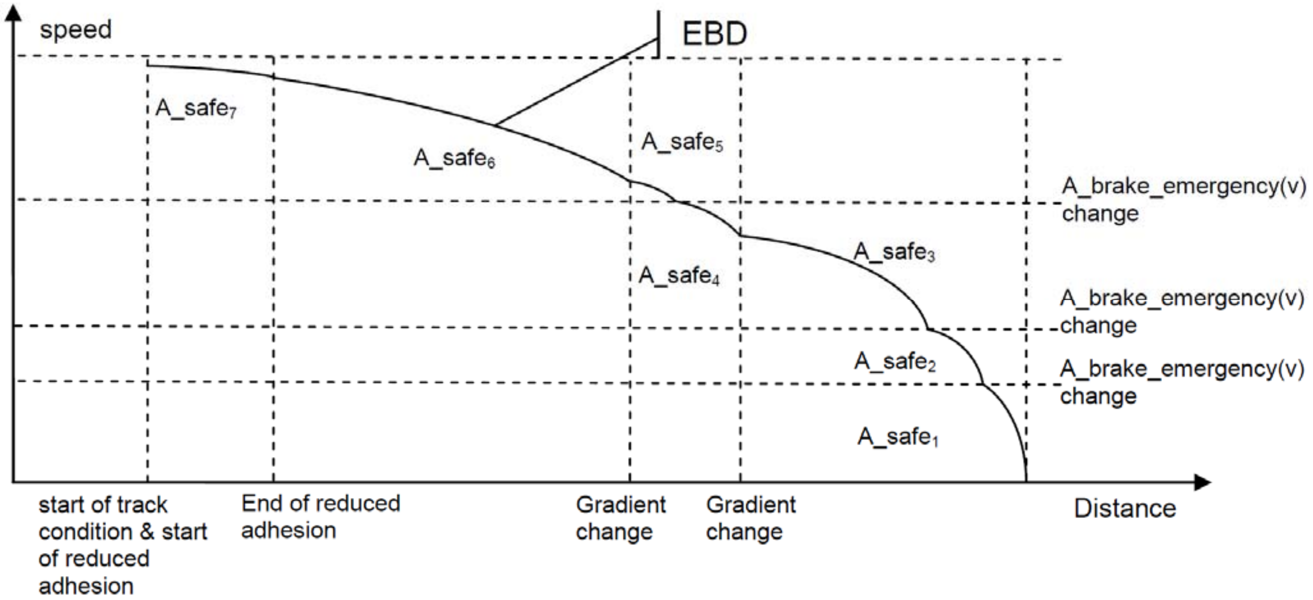
- Here: **Calculating braking curves**
  → train has to *decelerate before reaching the target* location/speed
  → OBU uses deceleration values which are speed and distance depended (varying over distance and speed)
  → piecewise calculation: interconnected parabolic arcs

Calculating: EBD, SBD and GUI curves

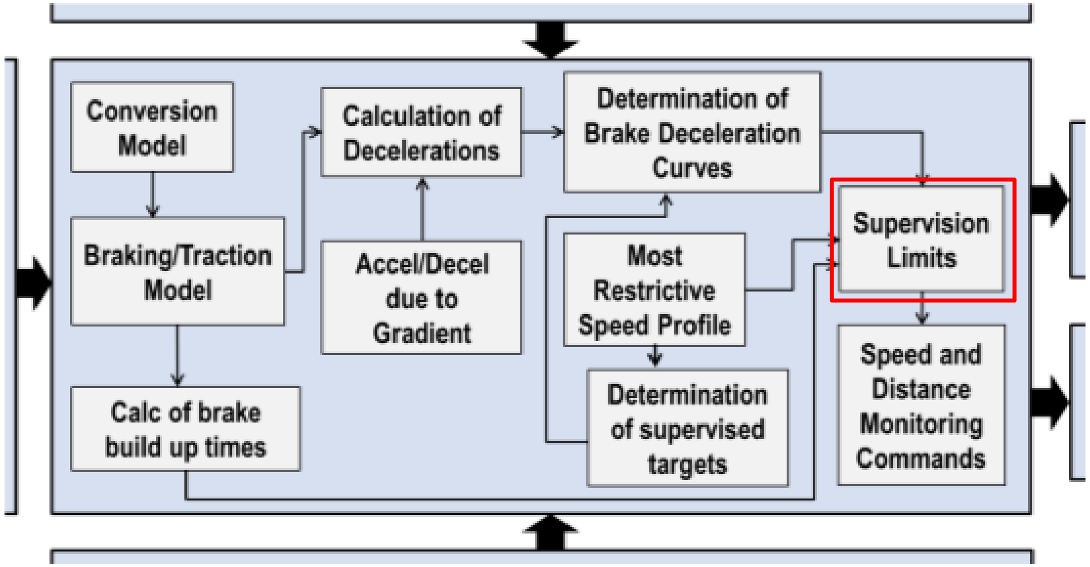


Determination of brake deceleration curves

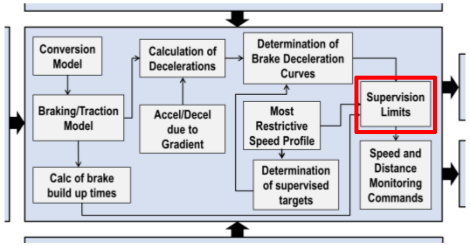
- EBD curve:
  → Target = SvL (stop location) or MRSP (speed reduction)
  → based on A_safe(V,d)
  → most important curve: reference for other curves [safety relevant]
  so called "parachute of ETCS"



Supervision Limits

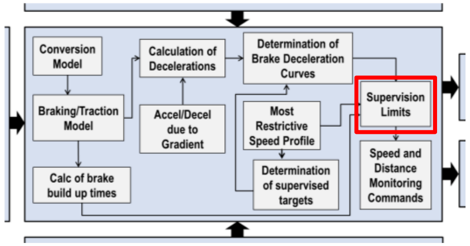


- Considering all previous results
- determining a series of supervision limits:
  - → Indication (I)
  - → Permitted speed (P)
  - → Warning (W)
  - → Service brake intervention (SBI)
  - → Emergency Brake Intervention (EBI)



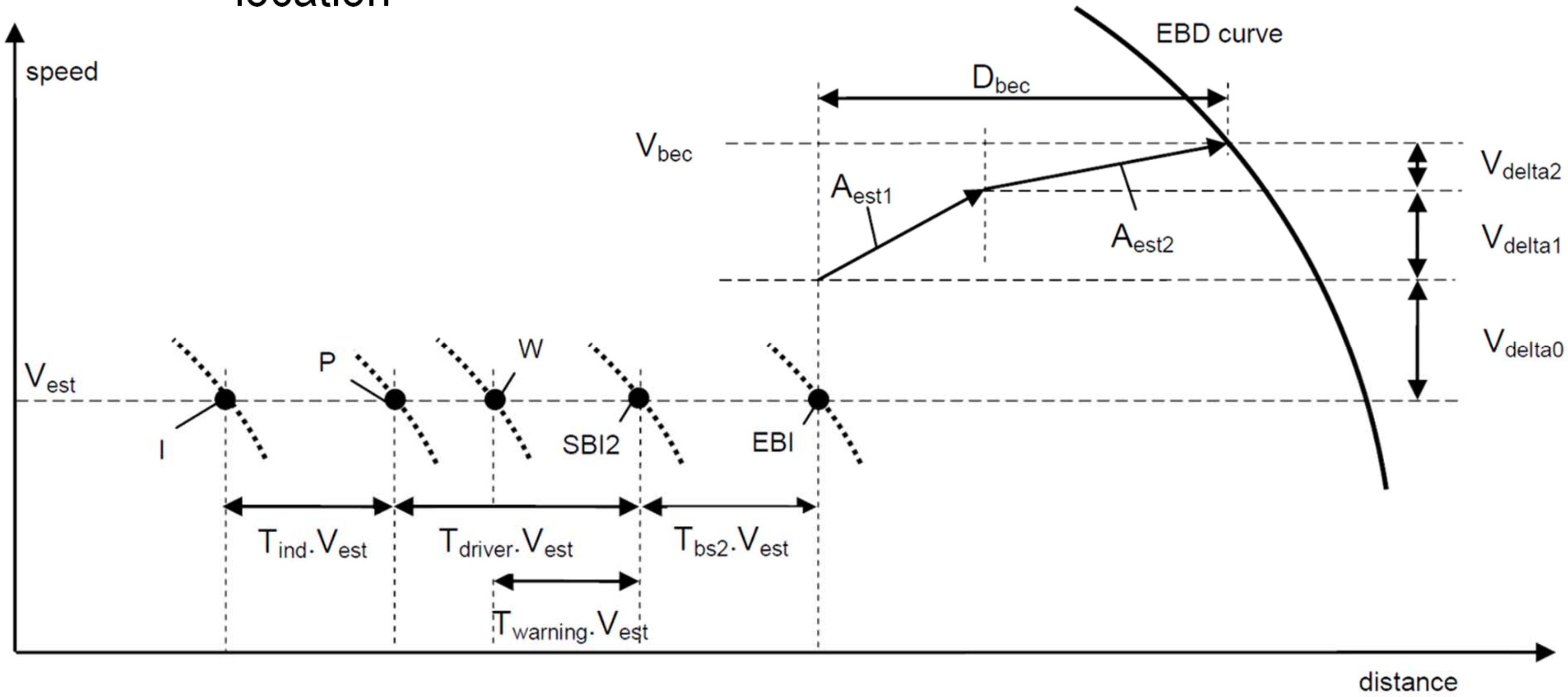
Supervision Limits

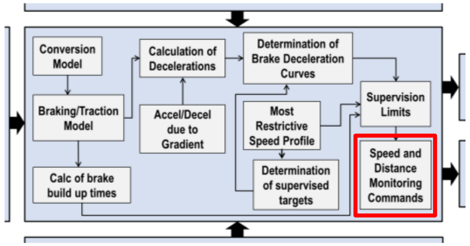
- Indication (I):
  → visual information of a changing speed ahead
- Permitted speed (P):
  → speed that the train should not exceed
  → indicated to the driver on the DMI (Driver machine interface)
- Warning (W):
  → if train exceed permitted speed: audible warning to the driver
  → train driver should initiate a suitable braking
- Service brake intervention (SBI):
  → before using the emergency brake
  → EVC uses service brake to decrease on allowed speed



Supervision Limits

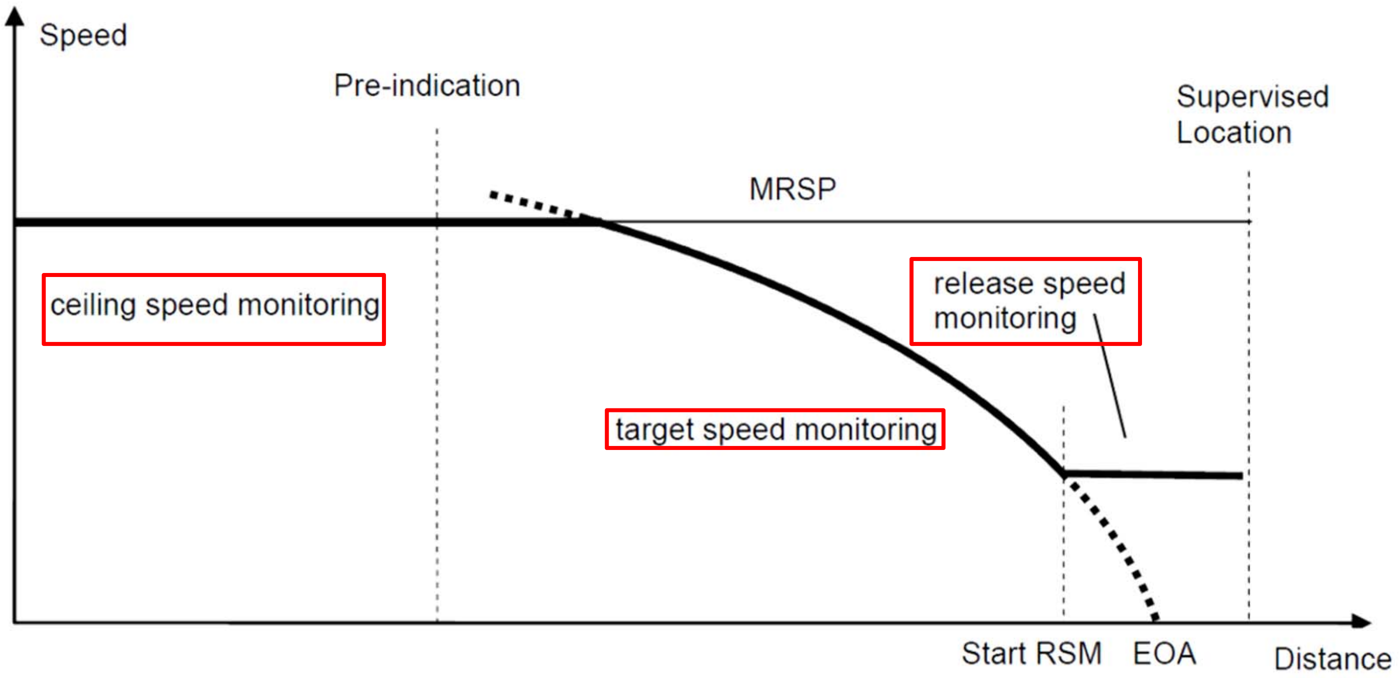
- Emergency brake deceleration (EBI):
  → EVC initiate emergency brake
  → ensuring the train remains within allowed speed limit or stop location





Speed/Distance Monitoring Commands

- Comparing: actual speed/position vs. supervision limits
- Types of speed and distance monitoring:



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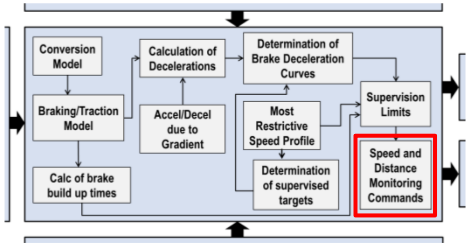


Speed/Distance Monitoring Commands

- Ceiling speed monitoring:
  → MRSP = constant: train runs a speed that is defined by MRSP
- Target speed monitoring:
  → train brakes to a target
- Release speed monitoring:
  → train is allowed to run release speed to approach EOA

- After all the OBU generates:
  → braking commands
  → cut-off commands
  → driver information

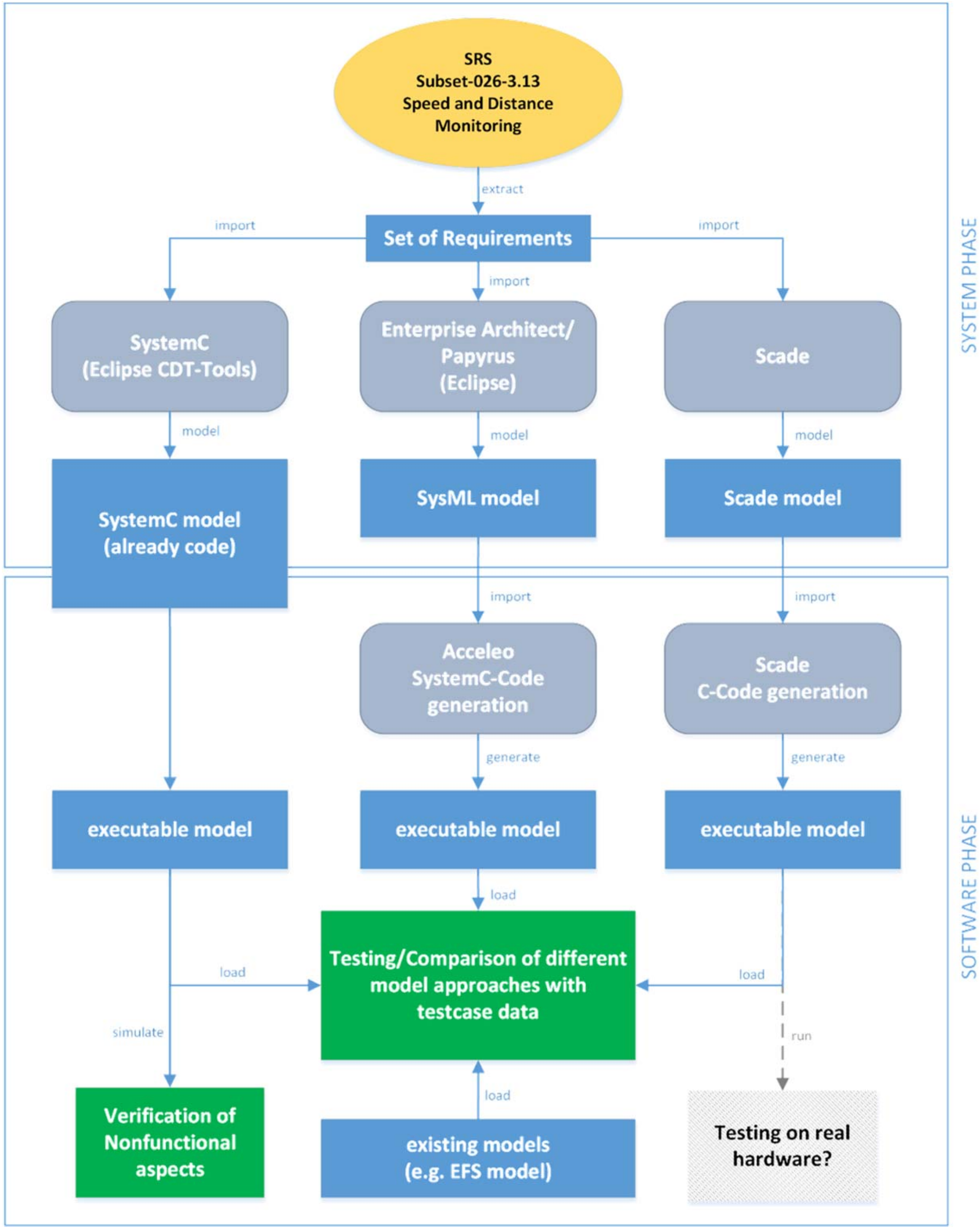
User Story:
University of Rostock

Introduction

- Which ONE tool/method will cover specification best?
- Hypothesis: There exists no ONE solution!

University of Rostock Approach:

- Example: Evaluating the best tool/method to model, verify and implement *“Speed and Distance Monitoring”* (Subset 026, Chapter 3.13, SRS)


SRS
Subset-026-3.13
Speed and Distance
Monitoring
extract
Set of Requirements
import
import
import
SystemC
(Eclipse CDT-Tools)
Enterprise Architect/
Papyrus
(Eclipse)
Scade
model
model
model
SystemC model
(already code)
SysML model
Scade model
SYSTEM PHASE
import
import
Acceleo
SystemC-Code
generation
Scade
C-Code generation
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executable model
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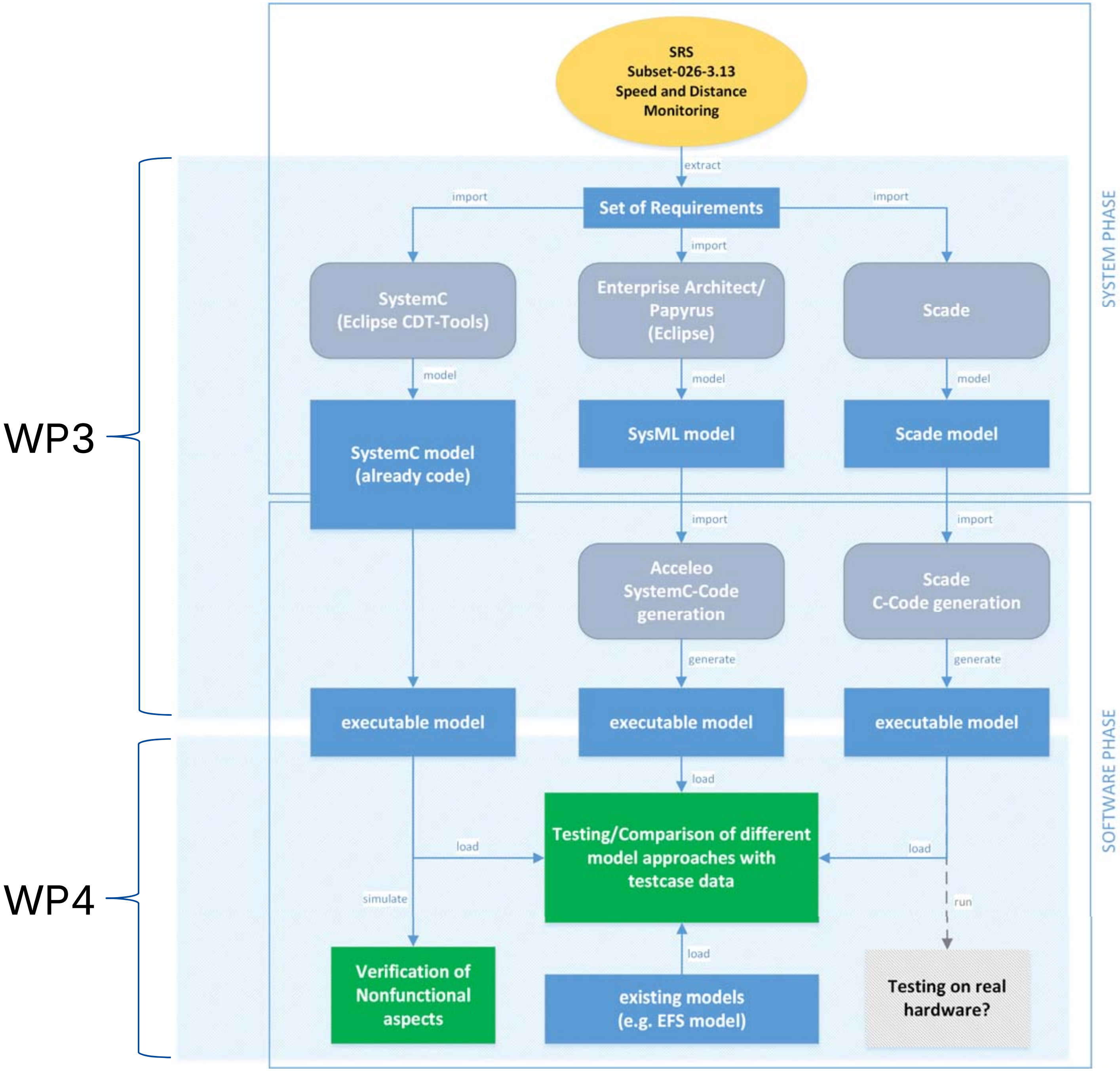
load
load
Testing/Comparison of different
model approaches with
testcase data
simulate
run
load
Verification of
Nonfunctional
aspects
existing models
(e.g. EFS model)
Testing on real
hardware?
SOFTWARE PHASE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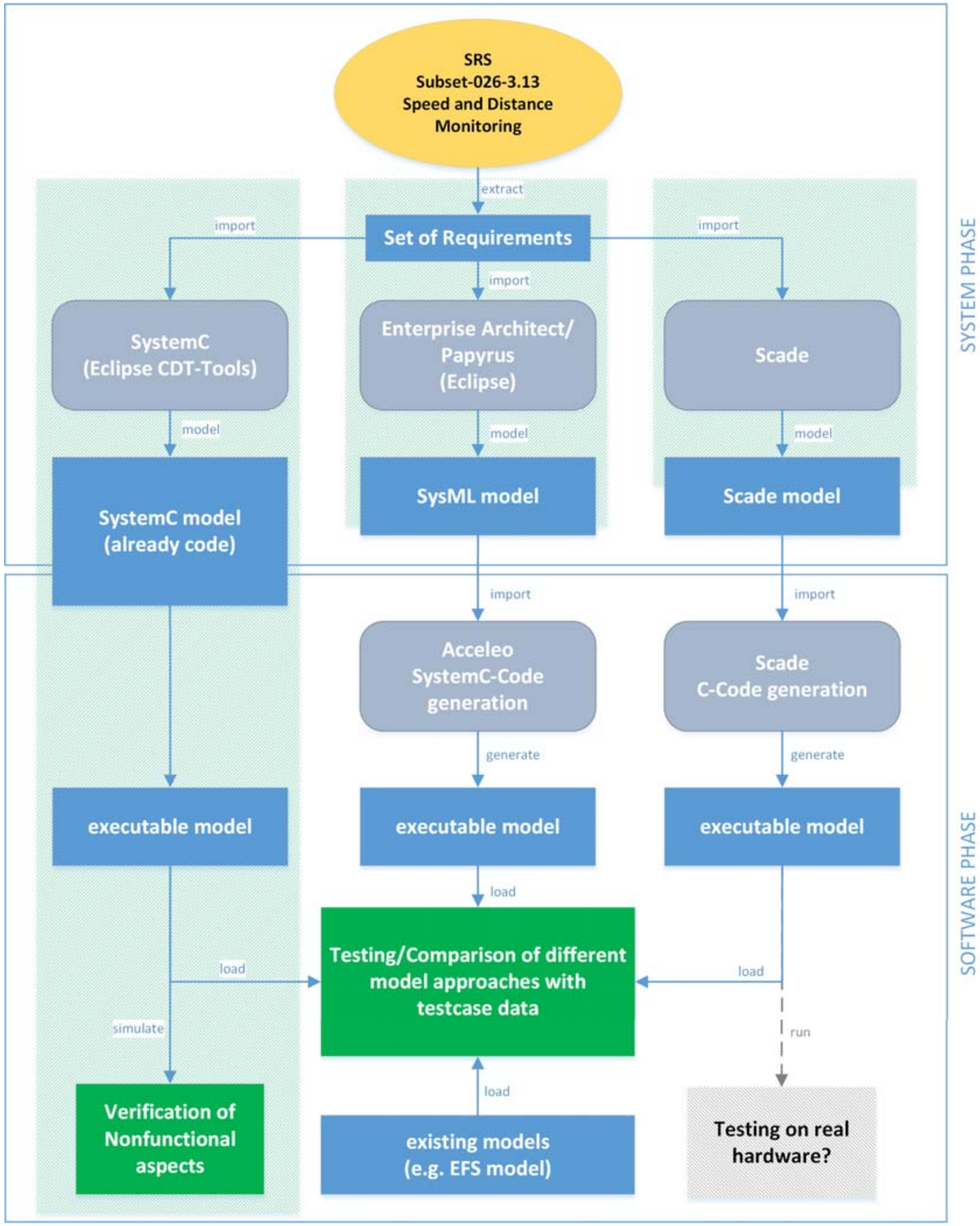
SOFTWARE PHASE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SOFTWARE PHASE

What is the benefit of this approach?

- each Partner use existing tool/method (know how)
- Interoperability of executable models implemented with different tools/methods
- Higher coverage of specification

Additional benefits

- Decreased development (modelling) time
- Early estimation of model capabilities
- Early testing/verification

Questions?

Back up

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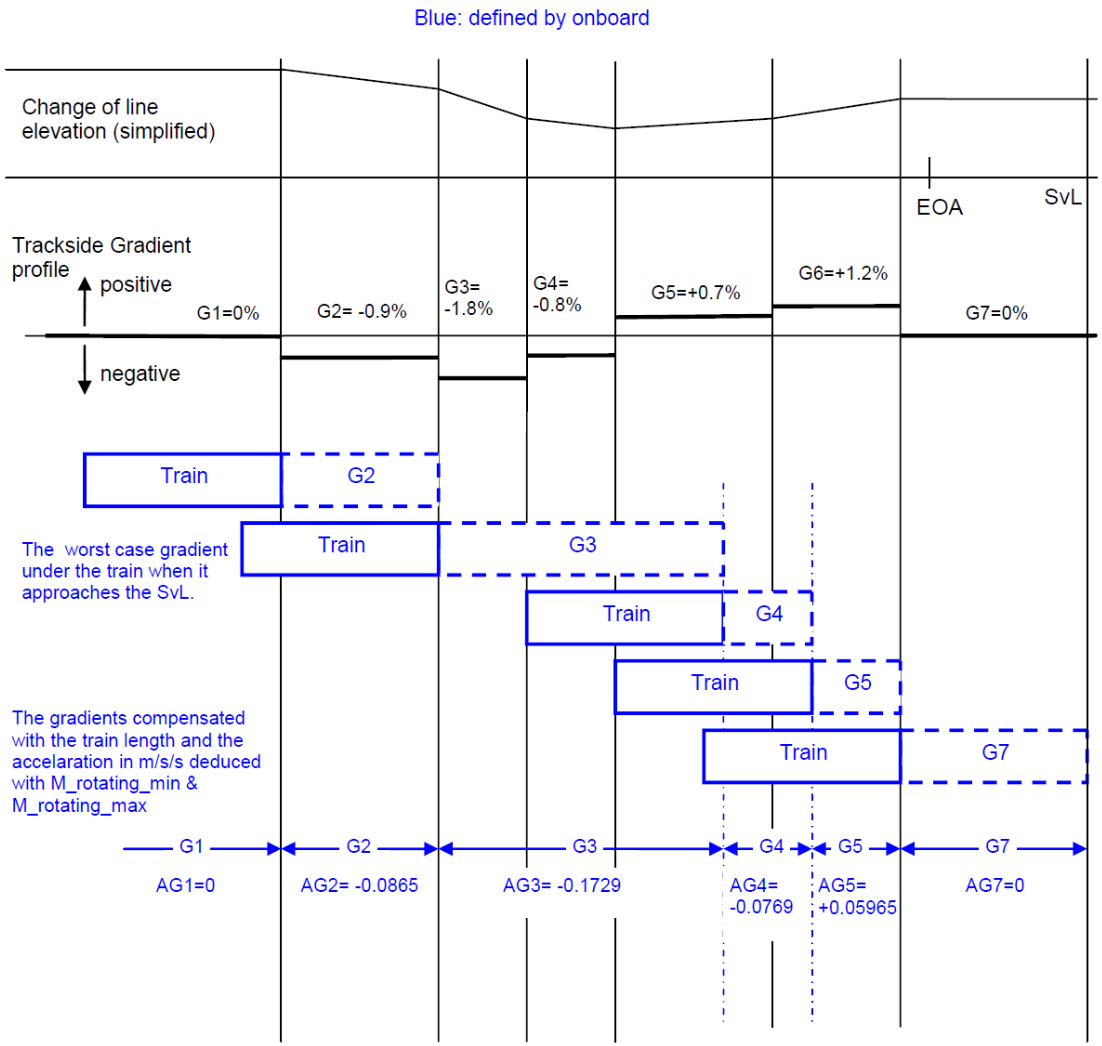
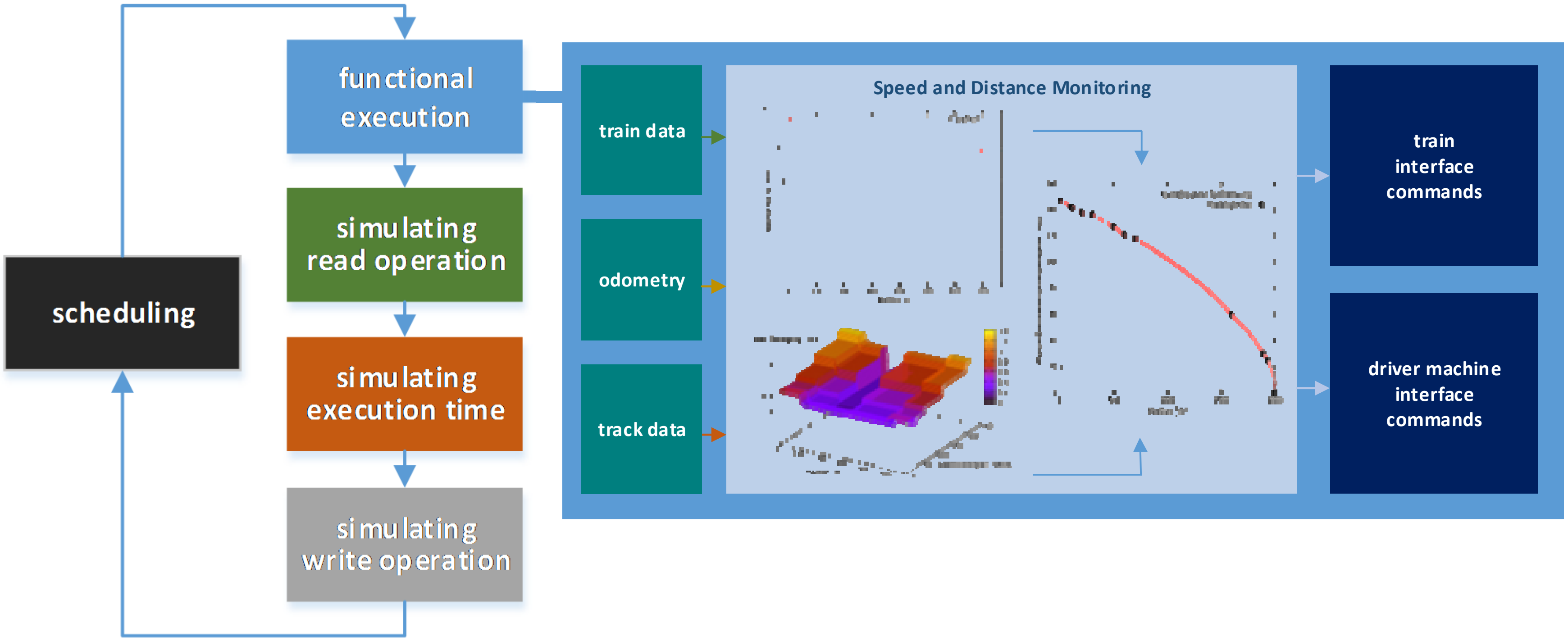
Accel./Decel. due to Gradient



Implementation of the specification with SystemC
Progress of work:

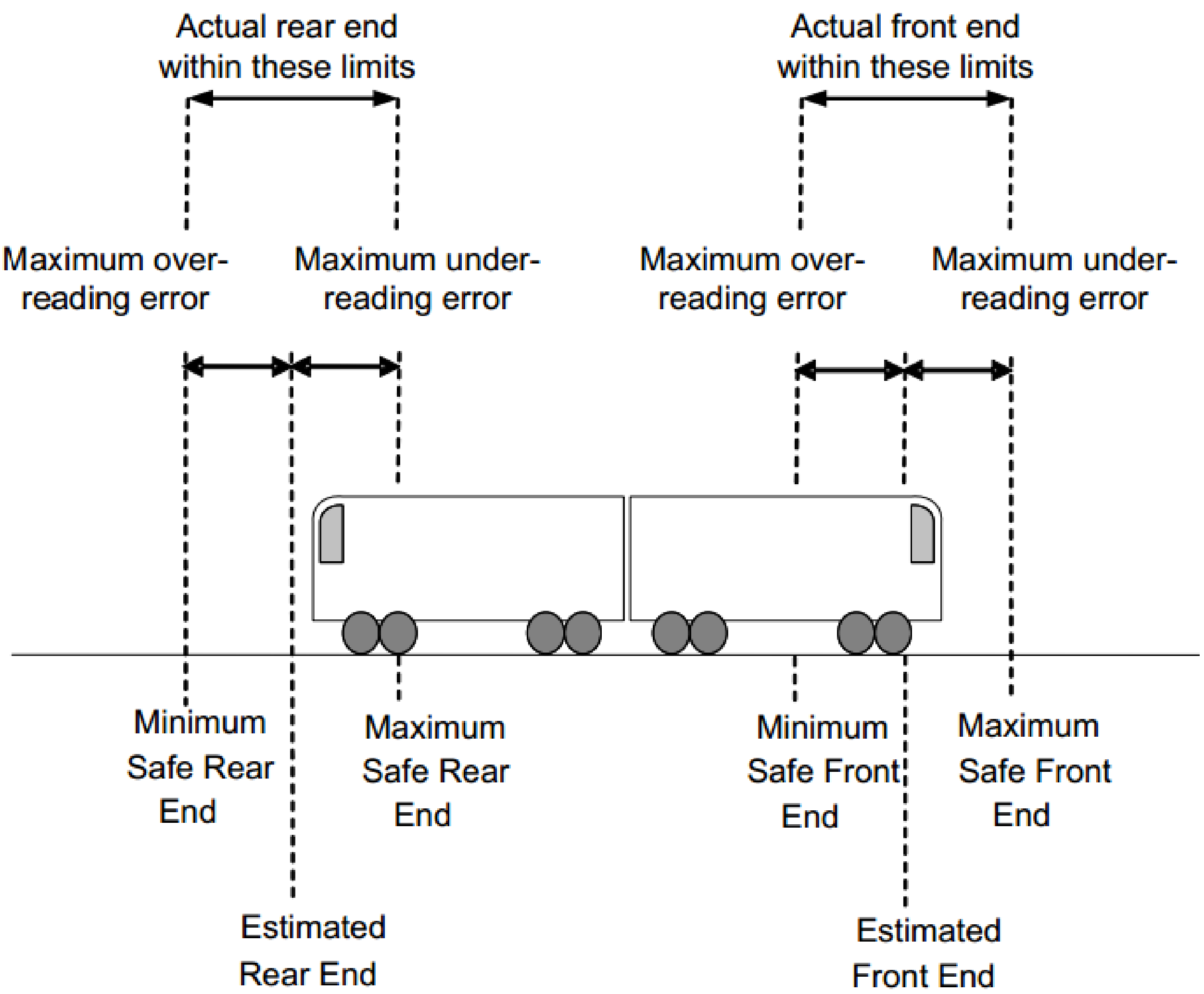


Calculation of decelerations and brake build up time

$$
\begin{aligned}
A_{brake\,safe}(v,d) &= Kdry_{rst}(v, M_{NV\,EBCL}) \cdot \\
&\quad (Kwet_{rst}(v) + M_{NV\,AVADH} \cdot (1 - Kwet_{rst}(v))) \cdot \\
&\quad A_{brake\,emergency}(v,d)
\end{aligned}
$$

$$
A_{safe}(v,d) = \begin{cases} min\{A_{brake\,safe}(v,d); A_{MAX\,REDADH}\} + A_{Gradient}(d) & \textit{for reduced Adhesion} \\ A_{brake\,safe}(v,d) + A_{Gradient}(d) & \textit{else} \end{cases}
$$

Max/Min Safe Front/Rear End



Implementation of the specification with SystemC
Why using SystemC?

- SystemC = modelling language initially developed to build hardware
- developed as a language to model the behavior of a system independent of implementation
- at an very early stage of system design: possible by means of this language to evaluate the system
  - Specification / Timing / Scheduling / Performance
  - Estimation of hardware resources (single core, multi core, quad core)
  - Software structure (moduls)
  - Type of onboard unit (OBU)

Implementation of the specification with SystemC Solutions:

- formalized specification and executable model (calculating braking curves with real input data)
- found and reported specification issues
- successful graduation of students
- first submitted publication

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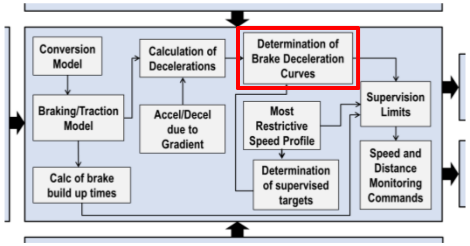
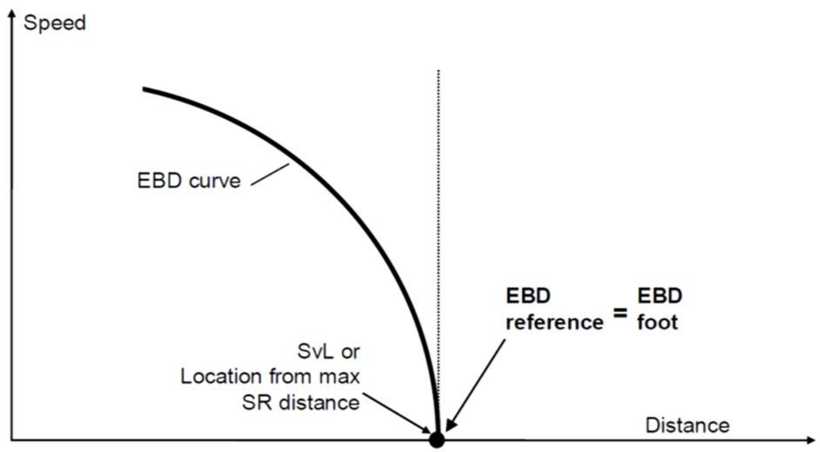


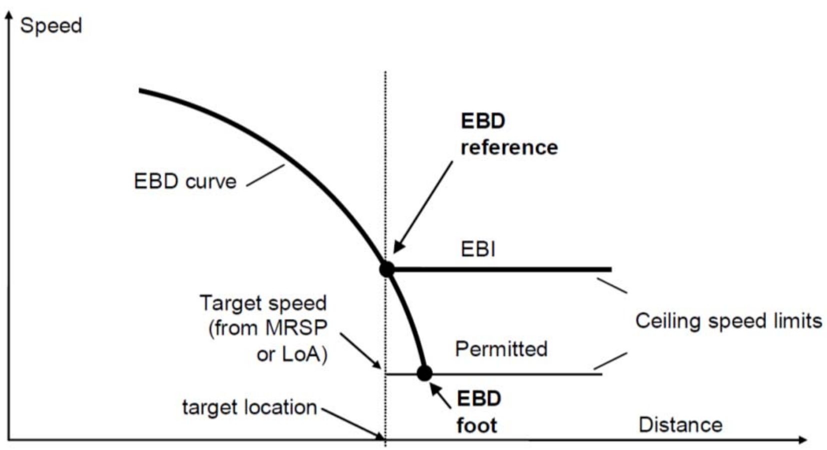
Determination of brake deceleration curves

- EBD curve:

→ Target = SvL (Stop location)
→ EBD based on A_safe(V,d) and V = 0 at the SvL
→ Target location = EBD foot

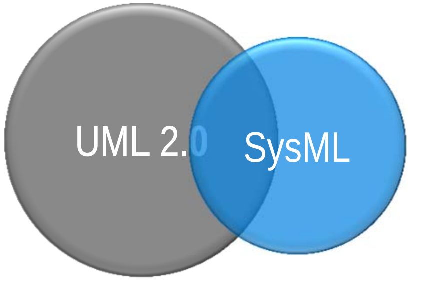
→ Target = MRSP (speed reduction)
→ EBD based on A_safe(V,d)
→ crosses ceiling speed EBI (Emergency Brake Intervention)
→ EBD foot is shifted





Implementation of the specification with SysML
What is SysML and why using?

- graphical modeling language suitable to needs of system engineering
- helps modeling system within a broad range of system variety that may include hardware, software, data, personnel and facilities
- supports the specification, analysis design, verification and validation of complex systems
- SysML supports system modeling in a (semi-) formal way:
  - architecture (statics)
  - behavior (dynamics)
  - requirements
- formal representation allows the automatic transformation into:
  - Code, Test cases



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Implementation of the specification with SysML Progress of Work: