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System Pillar T4 WP 3.1 - Train Integrity and Train Length

Proposal for a safe train length determination function:

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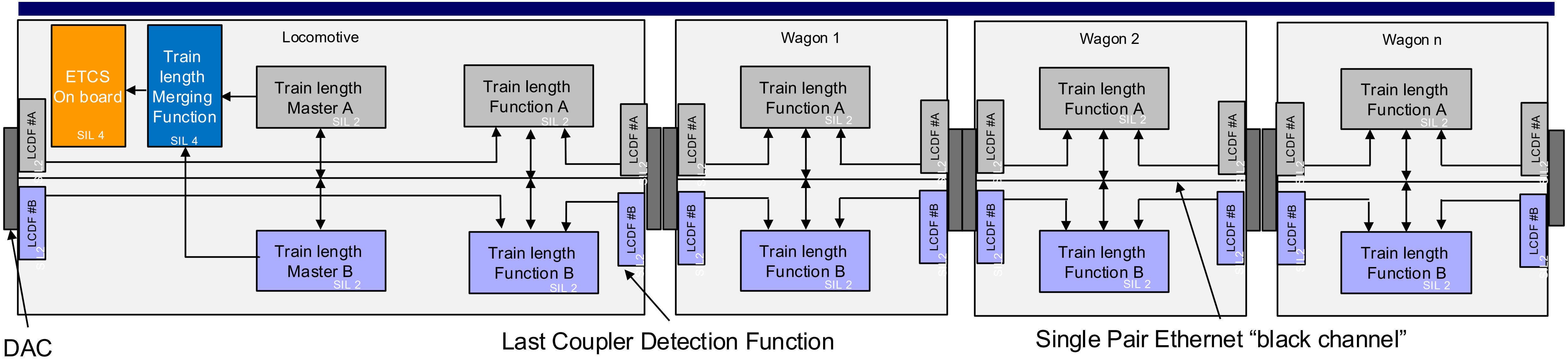
Previous proposal for Train Length Determination Function (2023)



- A first solution was identified in March 2023 by System Pillar Task 4 and approved by the PRAMS experts: said solution assumes possible the adoption of two "fully independent" SIL2 channels, said SIL2 channels being capable to obtain the information needed to determine the Train Length in an independent manner.
- A "Last Coupler Detection Function" LCDF per each DAC is requested to determine the DAC coupled/uncoupled condition at SIL4 level: according to the previous assumption, the SIL4 LCDF can be split in two independent SIL2 LCDF.
- A further function, named Merging Function, developed according SIL4 rules, is in charge to compare the information provided by the two SIL2 channels, to extract the Train Length at SIL4 level, and to provide it to the on-board ETCS
- Channel #A is part of the current FP5 development, embedded into the DAC basic system, using the Single Pair Ethernet communication in a "black channel" mode
- Based on these assumptions, after discussions with FP5, two more detailed solutions have been identified, shown in the next slides

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Sub-Systems in place that can be utilized for train length determination & confirmation

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Freight-ETB

- Redundant Single Pair Ethernet (SPE) lines provide train internal data connections
- A defect Freight ETB Node (F-ETBN) is bypassed.

Consist Control Unit (CCU)

- Control unit on each consist, incl. F-ETB connections as well as Ethernet interfaces inside the consist side (ECN), including end devices (e.g. DAC CU).

DAC Control Unit (DAC CU)

- Control Unit that controls and monitors the automatic coupler and connects to CCU via ECN.
- The DAC CU is located at either end of each consist and is seperate from the CCU.

Last Coupler Detection Function

- Relies on sensors in mechanical coupler to determine the state of the coupler on either end of the consist.
- Implementation is subject to supplier, however data connection runs via ECN/F-ETB to Master.
- The position/setting of the coupler is detected independently by the DAC CU and CCU.

Passive Consist Detection Function

- Relies on a current sink on the passive consist and a measurment unit on the adjacent (active) consists.
- The active consist is able to measure the current sunk on the passive consist side thus detecting it.

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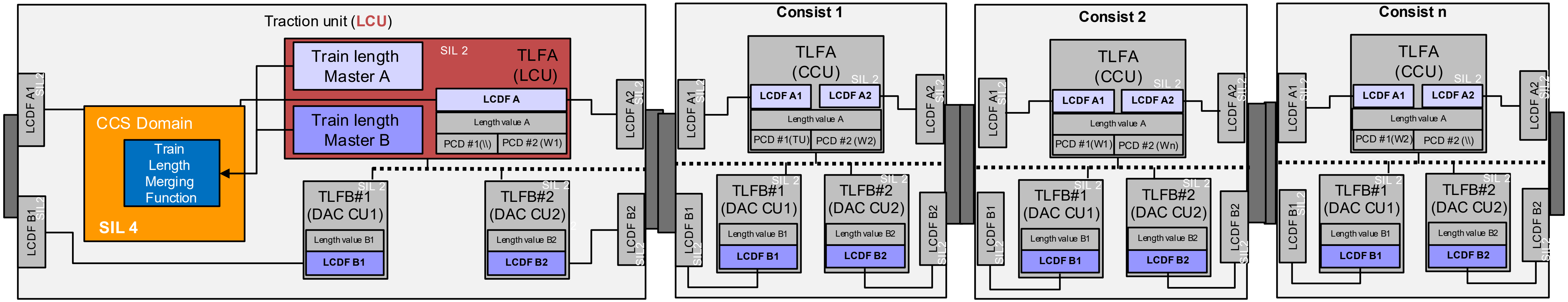
Train Length Determination: Distributed Approach



Last Coupler Detection Function: The LCDF is measured by the CCU (Ch. A) and DAC CU (Ch. B) on each consist

Passive Consist Detection Function: Each consist is equipped with a passive consist detection function which can detect adjacent passive consists (in both directions) as long as the physical data connection layer is uninterrupted, and all states provided to TLMF.

Three functions are independently implemented and information generated by each function to be provided to TLMF:

- **Last Coupler Detection Function** – determine if the "last" coupler is coupled or not through DAC CU and CCU → no unknown consist at tail
  - Provide states of each sensor of both couplers on each consist to TLMF (four states per consist)
- **Passive Consist Detection Function** – measure if a consist is passive and bypassed within the train → no unknown consist within train
  - Provide result of PCD detection for adjacent left or right consist to TLMF (two states per consist)
- **Train Length Determination Function** – providing the length value of each consist to TLMF → proving the resulting length
  - Provide length value stored in CCU and length value stored in DAC CU of each consist to TLMF (two values per consist)

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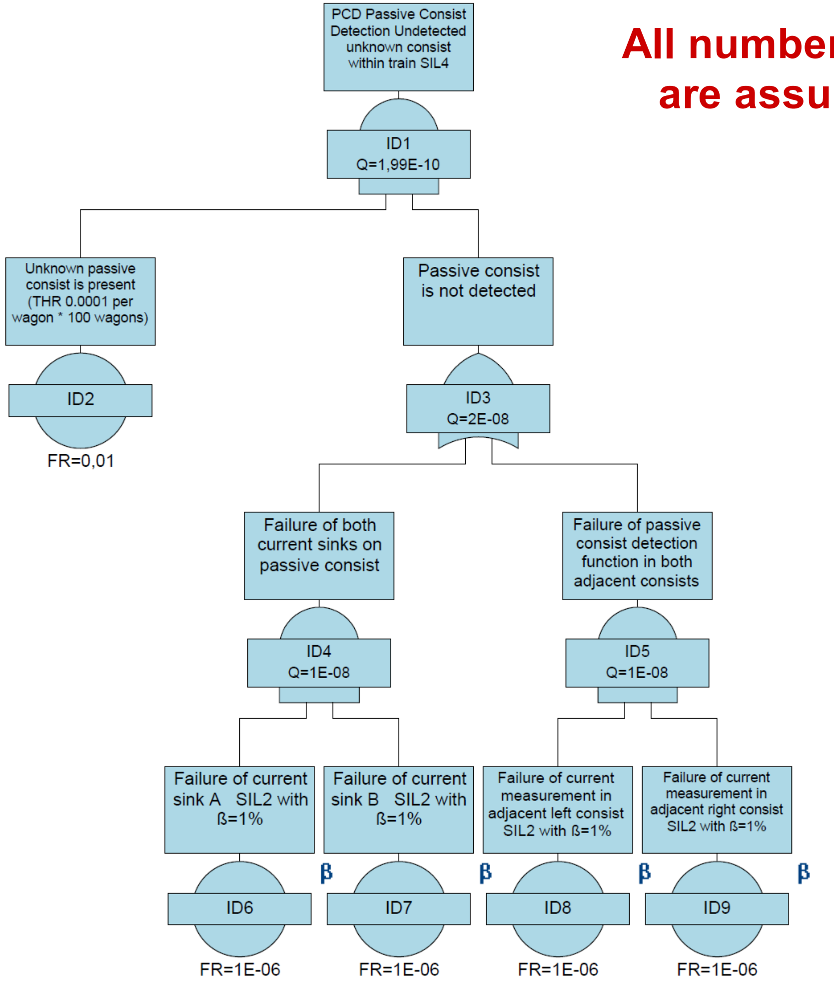
High Level Generic Fault Tree Examples for PCD

Passive Consist Detection is sufficiently safe, if implemented in both adjacent consist independently with SIL2 each and in combination with a low failure rate/high availability of ETBN (low occurrence of a passive consist)

Hazard
“Undetected consist within train”:
- ID2: Passive consist is present

AND
- ID3: Passive consist not detected by any of both adjacent consists

Mitigations:
- ID2: Limit expected occurrence of ETBN unavailability or failure (low occurrence of a passive consist)
- ID5: Redundant Passive Consist Detection on both F-ETB channels by both adjacent consists with SIL2 each



All numbers and SIL are assumptions

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High Level Generic Fault Tree Examples for LCDF

Last coupler detection function is sufficiently safe, if implemented with two independent evaluated sensors A and B each with SIL2 each and in combination with a low failure rate/high availability of successful electrical coupling

Hazard

"Undetected unknown consist at train tail":

- ID2 and ID3: Sensor A and Sensor B (on the mechanical part) indicate uncoupled, while coupler is in fact mechanically coupled

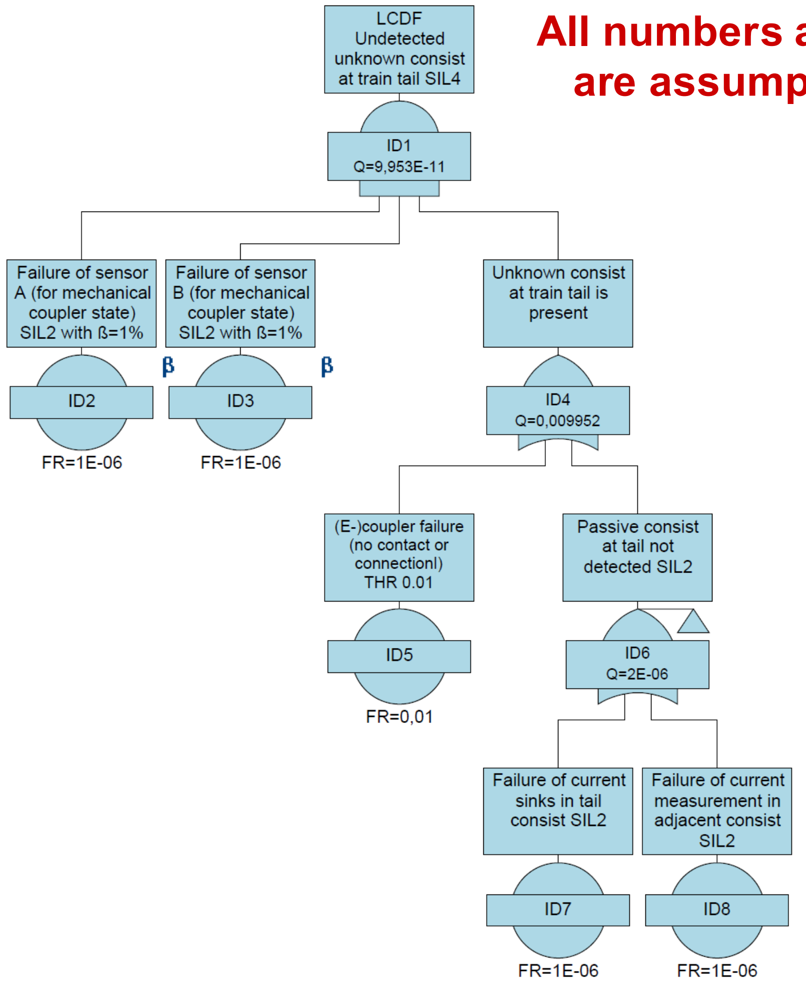
AND

- ID4: Undetected consist at train tail (e.g. E-Coupler not successfully coupled or PCD failure)

Mitigations:

- ID3: Second sensor is potentially required (ID3)
- ID5: Limit expected occurrence of failure on the electrical coupling

All numbers and SIL are assumptions



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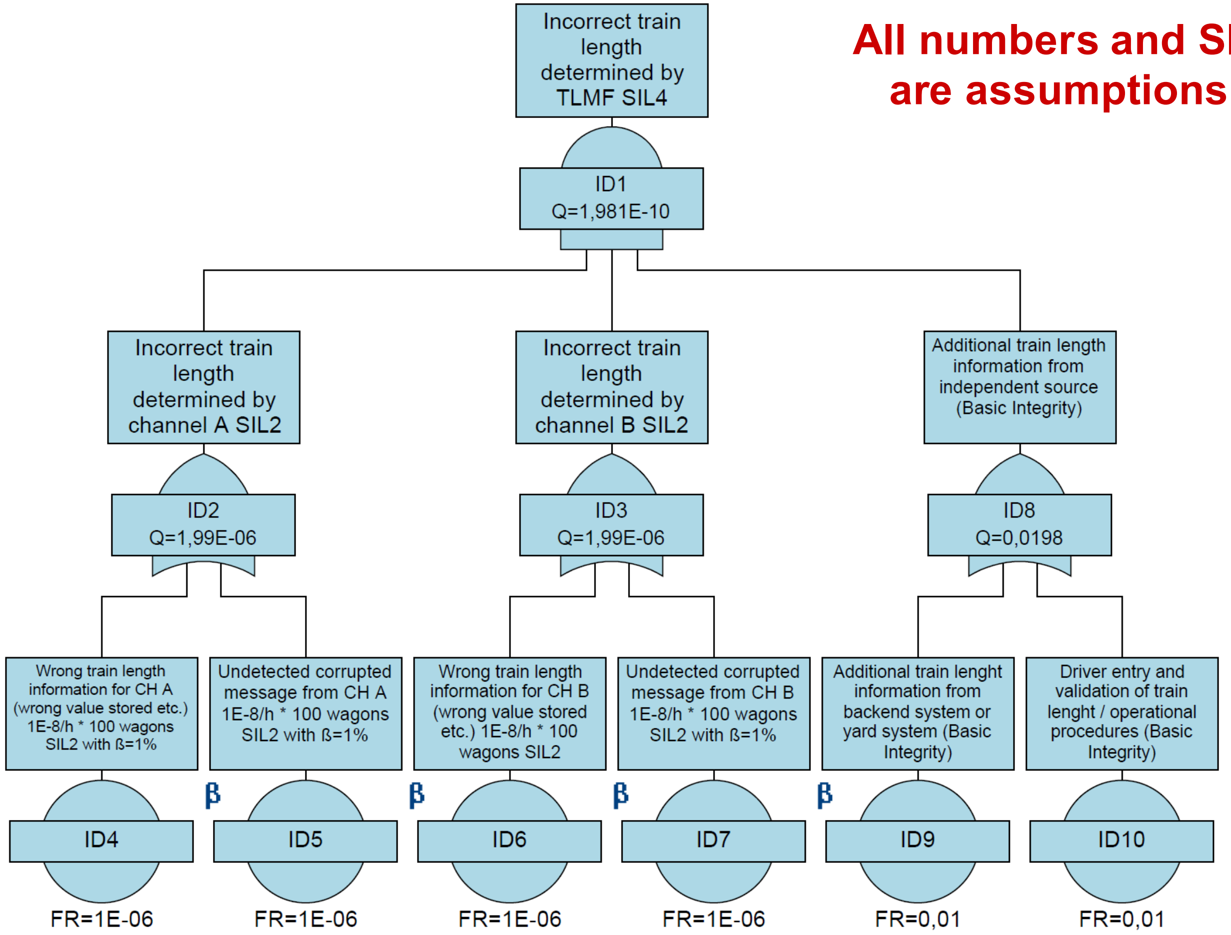
TLMF with two NOT fully-independent train length information (ß=1.0%) and additional external information

Aspects to be considered:

- Number of consists with equal failure rate each
- Each length provided on CH A and CH B needs to be independently determined and stored
- Overall, each channel needs to reach SIL2 overall, therefore higher requirement on each length stored on a single consist and channel
  - for 100 consists, per consist and channel failure rate of <=1E-07/h for each train length value
- Message transmission to be safely implemented, e.g. SIL4 Hash for stored value and SIL 4 CRC for transmission
- **Only if two fully-independent channels can be implemented and proven, SIL4 is reached**
- **For >=1% Beta/Common Cause Failures, SIL4 can not be reached by SIL2 & SIL2 only anymore**
- **Adding an independent additional information or validation of at least FR < 0.01 is sufficient to reach SIL4 overall**

All numbers and SIL are assumptions



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Conclusion and technical consequences of the solution proposal

Train Length Determination Function	• Requires additional **second** (independent) information on **train length**, e.g. **DAC-CU (SIL2)** • Sufficient **independence** to be proven or additional **mitigation** to be implemented
Last Coupler Detection Function	• **Sensors in each coupler** to determine state of a coupler on either end of the vehicle • **Additional second independent sensor/contact** in coupler required • **F-ETB data connection** of DAC-CUs required and **sensor states** to be transmitted to TLMF
Passive Consist Detection Function	• Relies on two **current sinks** on each consist • Passive consist detection (PCD) is performed by each adjacent consist independently by measuring a **current** due to a current sink in **each bypass** (redundant by both ETH lines) • **Failure rate of ETBN/CCU** (low occurence of a passive consist) to be **defined**
Train Length Merging Function Three functions above are generating information to be provided to TLMF	• Train Length Determination Function: **length value stored in CCU and length value stored in the two DAC CUs** of each consist to TLMF (**one value on channel A, two values on channel B, overall three values per consist**) • Last Coupler Consist Function: **states of each sensor of both couplers** on each consist to TLMF (**four states per consist**) • Passive Consist Detection Function: **result of PCD detection for adjacent left and right consist** to TLMF (**two states per consist**)