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# Closer Running: Magic Potion or Deadly Poison?

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# ‘Closer Running’?



# Demand for Rail Transport is Growing

Railways require more capacity and flexibility:

- Better use of existing capacity;
- Improved reliability and availability;
- Better use of land, energy and staff.

Increasing cost of design, manufacture and installation of railway systems;

Increases in demand for rail travel and difficulty of adding infrastructure;

Environment affects systems more and more;

Railways' competitors improve performance:

- Efficiency and exhaust emissions of car / truck.

Availability of better technology and methods.

# Concept of Closer Running

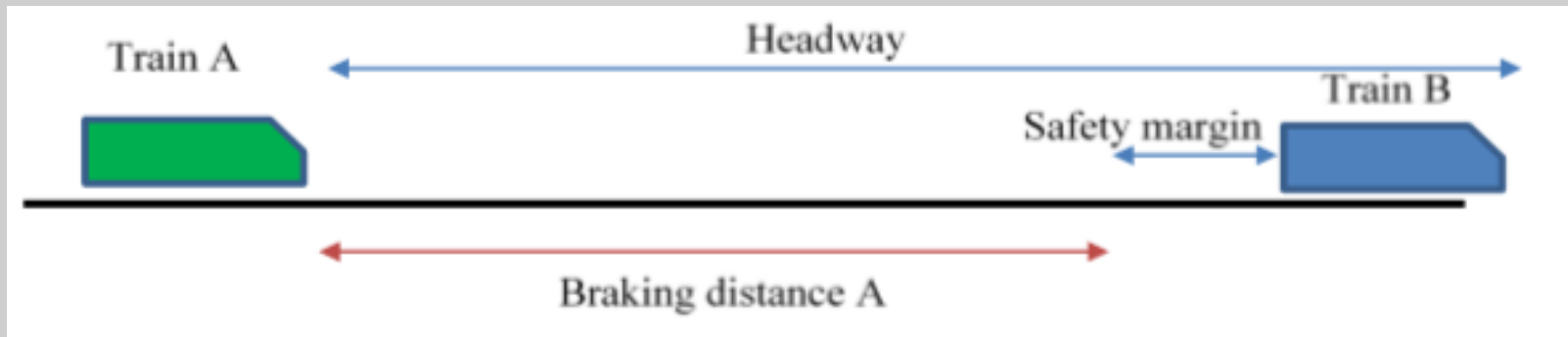
With this method of operation, trains can be brought closer together on the assumption that trains decelerate at a predictable rate;

In theory, this can lead to headway times that are close to the response times of the braking systems, with allowances for the accuracy of train location and the communication system latency;

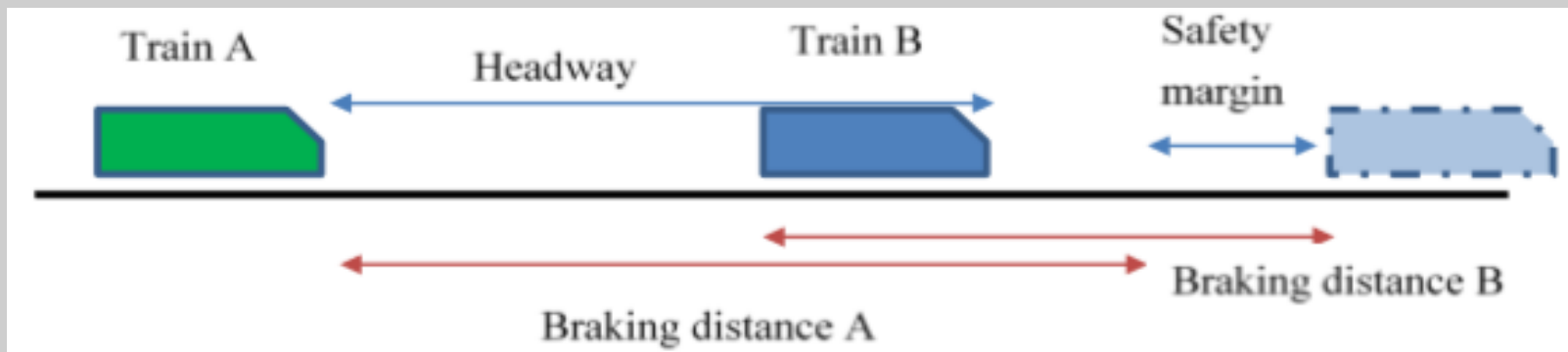
Implementing such a concept provides only a limited increase in capacity at junctions and in stations but great benefits on plain line.

# Absolute BD vs. Relative BD

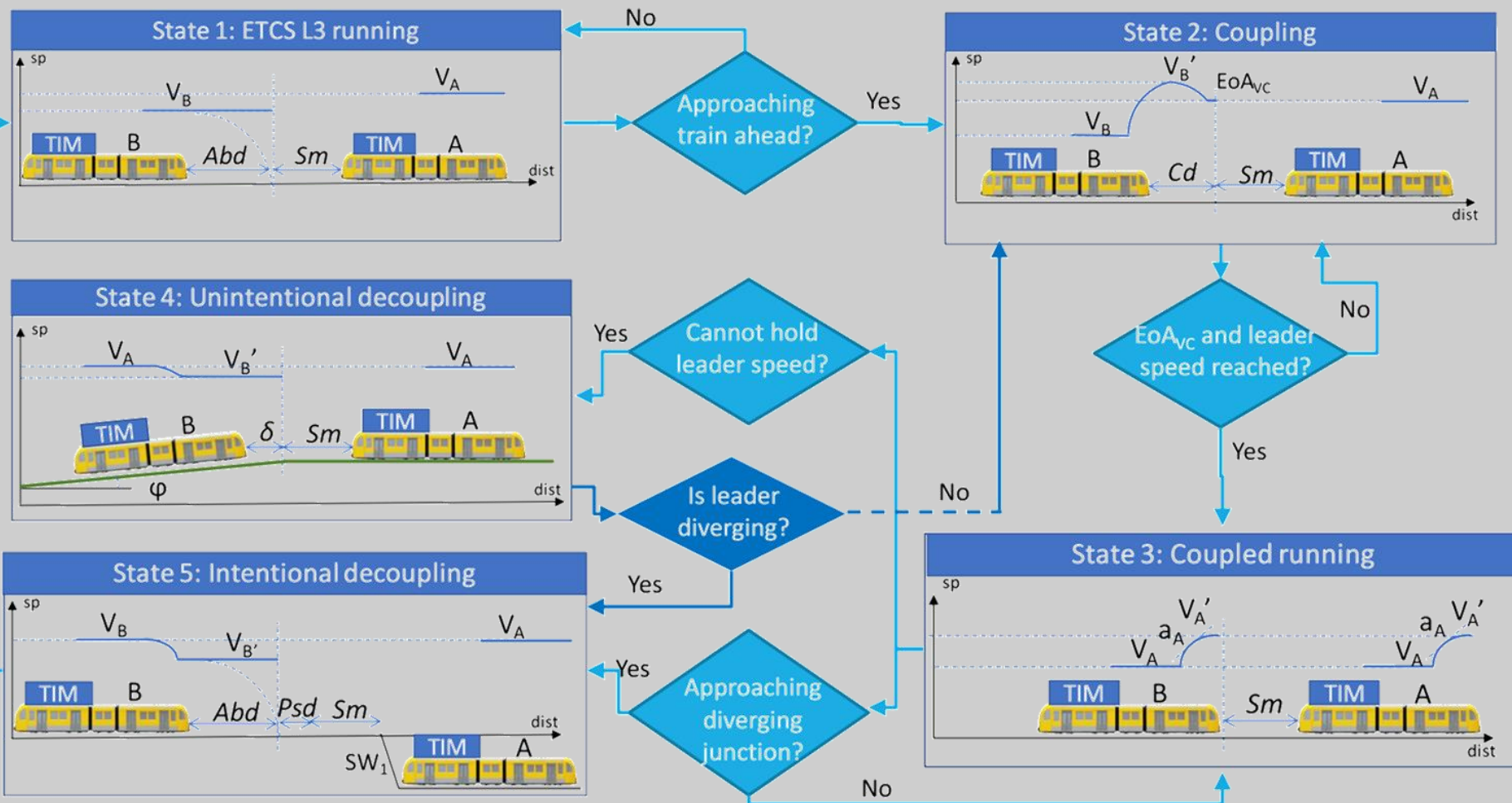
## Absolute Braking Distance



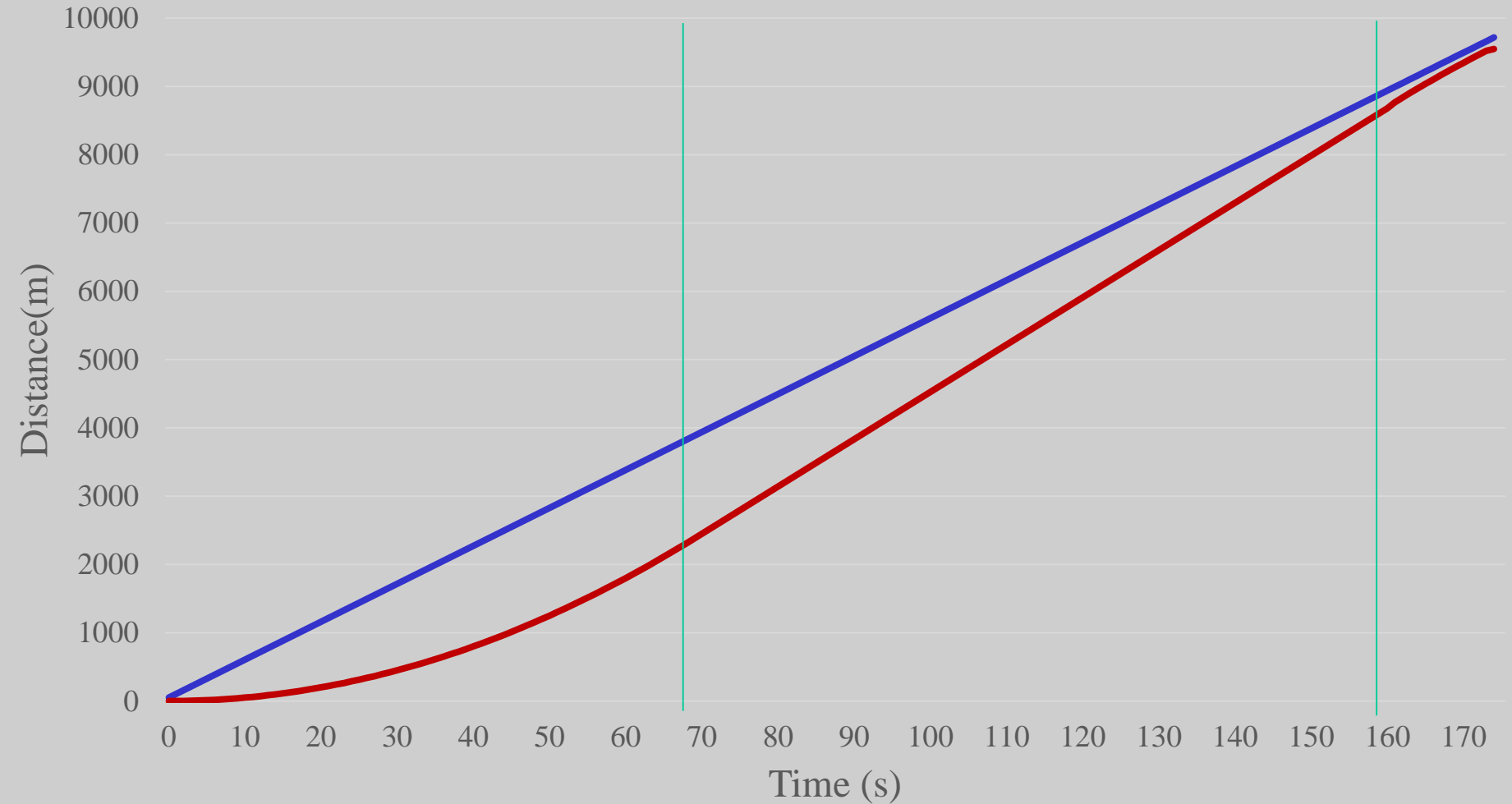
## Relative Braking Distance



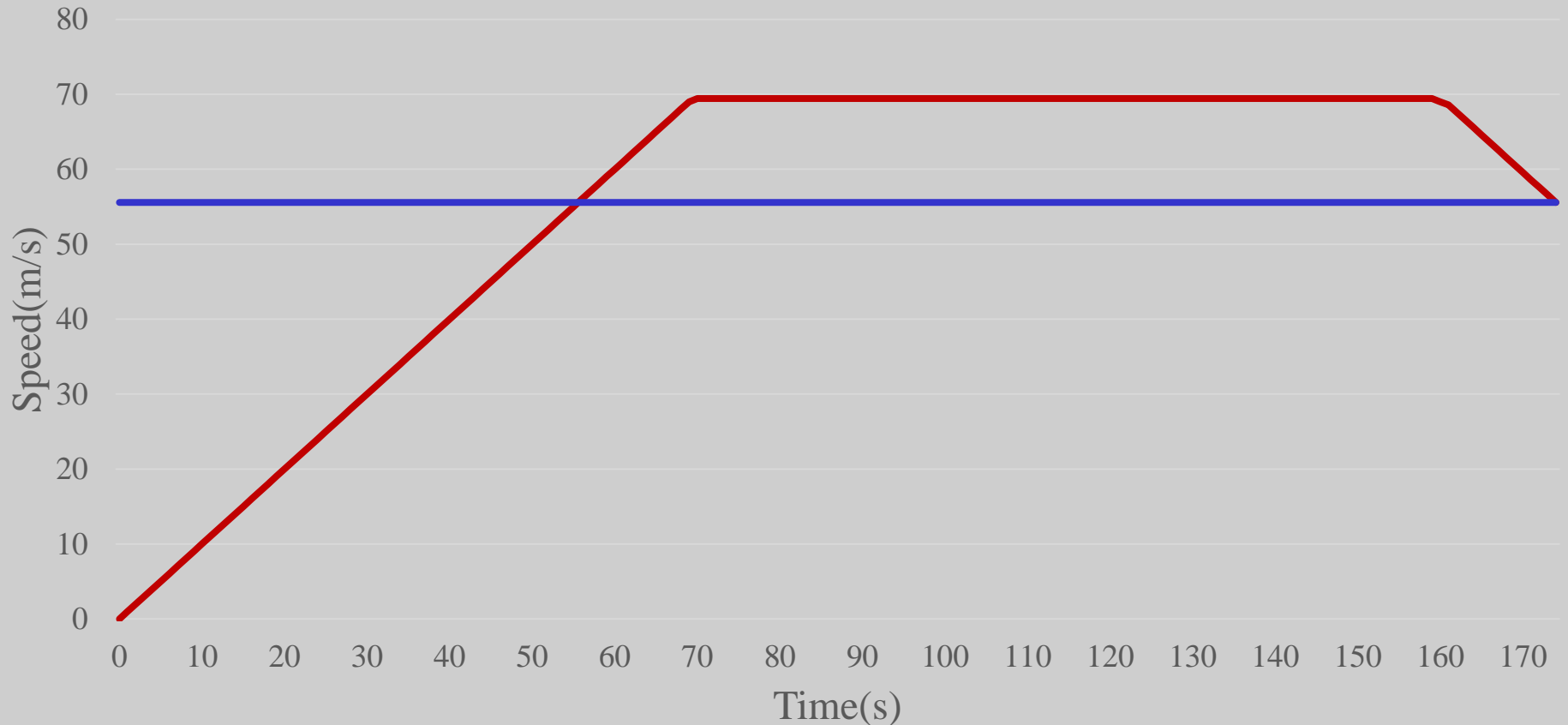
# States of Closer Running at $< BD$



# Example of Virtual Coupling: T/D Graph



# Example of Virtual Coupling: Speed



# Hazards for 'Closer Running'

Collapse of overbridges;

Collapse of underbridges / viaducts;

Incursions by heavy vehicles / objects;

Avalanches and rock-falls;

Flooding

Extreme adhesion issues;

Operations at stations;

Catastrophic points failures;

...

# Examples of Real-Life ‘Dead Stops’

Collision with cow at Polmont, Scotland, 1984-07-30;  
Derailment and bridge collapse, Eschede, Germany, 1998-06-03;  
Derailment at Hatfield, England, 2000-10-17;  
Ufton Nervet level crossing collision, England, 2004-11-06;  
Barrow upon Soar, England, 2008-02-01;  
Mudslide between Meran and Mals, Italy 2010-04-12;  
Sewage tanker on open level crossing, Sudbury, England, 2010-08-17  
Great Heck collision with Range Rover, England, 2011-02-28;  
Central line loss of traction motor near Holborn, 2013-01-25;  
Rockfall near Saint-Benoît on Chemins de fer de Provence, 2014-02-08;  
Barrow upon Soar, England, 2016-08-02;  
Great Belt collision in Denmark, 2019-01-02;  
Collision with avalanche Matterhorn Gotthard Bahn 2019-02-22.

# Information Loss in Railway Control

Line of sight operation: LMA not clearly visible:

- Reduce speed to re-register position of LMA.

Line side signalling: no update of LMA (by visual signal, balise or radio):

- Continue towards LMA and apply service brake to stop at LMA.

CBTC with absolute braking distance moving block:

- Apply service brake to stop before end of LMA, e.g., last known position of tail of train ahead.

No knock-on effect on following trains.

# Information Loss in Railway Control

CBTC with relative braking distance moving block:

- Apply emergency brake with jerk limit;
- Passengers are at risk of falling.

All following trains experience knock-on effect and have to apply emergency brake, with jerk limit:

- Passengers in all following trains are at limited risk.

Convoying and platooning with 'autonomous' trains:

- Apply emergency brake without jerk limit;
- All passengers at risk.

All trains in convoy / platoon have to apply brakes.

# Barrow-on-Soar: Footbridge Collapse



# Barrow-on-Soar: Impact Consequences



Running at 65 mph (104 km/h) and stopped in 170 m rather than  $BD=30*30/(2*0.8) = 900/1.6 = 562$  m, only 2 people hospitalised



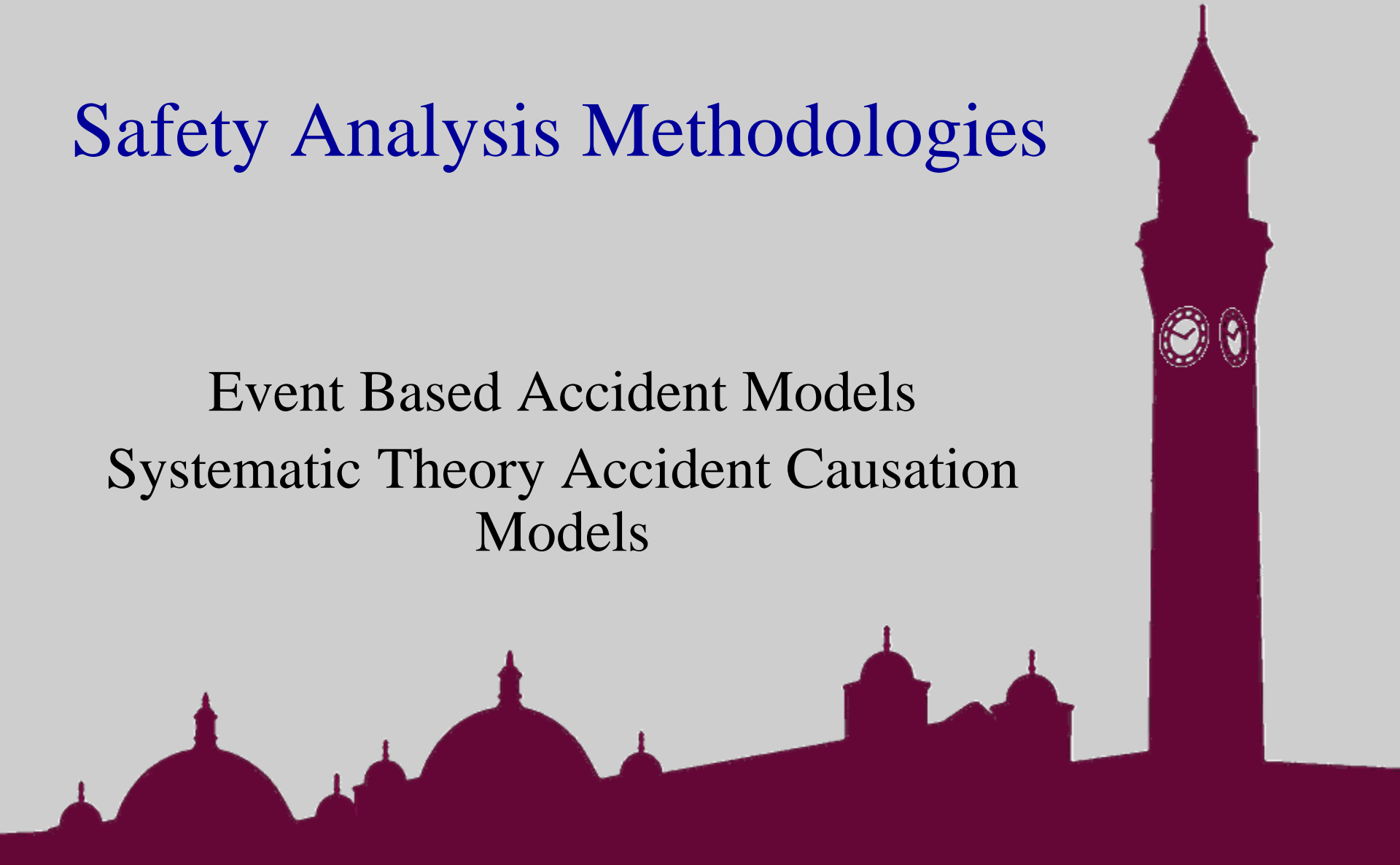
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# Safety Analysis Methodologies

Event Based Accident Models

Systematic Theory Accident Causation  
Models



# Two Safety Analysis Methods

## Event Based Accident Models:

- Choice of events and analysis end points are usually subjective;
- Relationships between causal factors are assumed to be linear;
- Social and organizational factors and software errors are not considered in this type of accident causation model;
- Work well for physical component failures as triggers;
- Method is limited to analysing basic interaction relationships;
- Poor traceability and coverage.

## Systematic Theory Accident Causation Model:

- Has been applied in aerospace, defence industry, transportation and chemical industry;
- Method is based on systems theory and considers interactions between system components;
- Offers a more comprehensive understanding of system safety and works well with software and design errors.

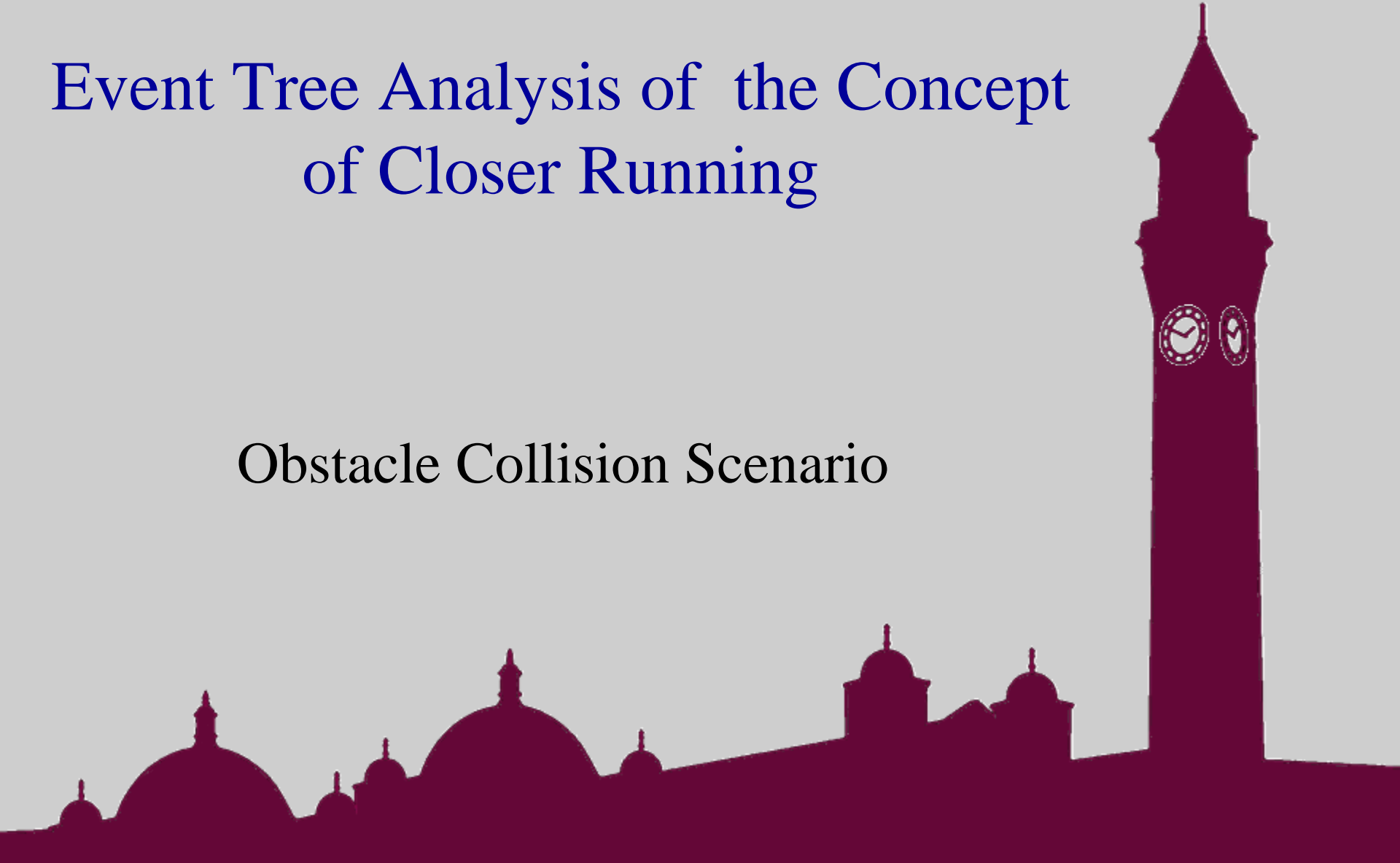


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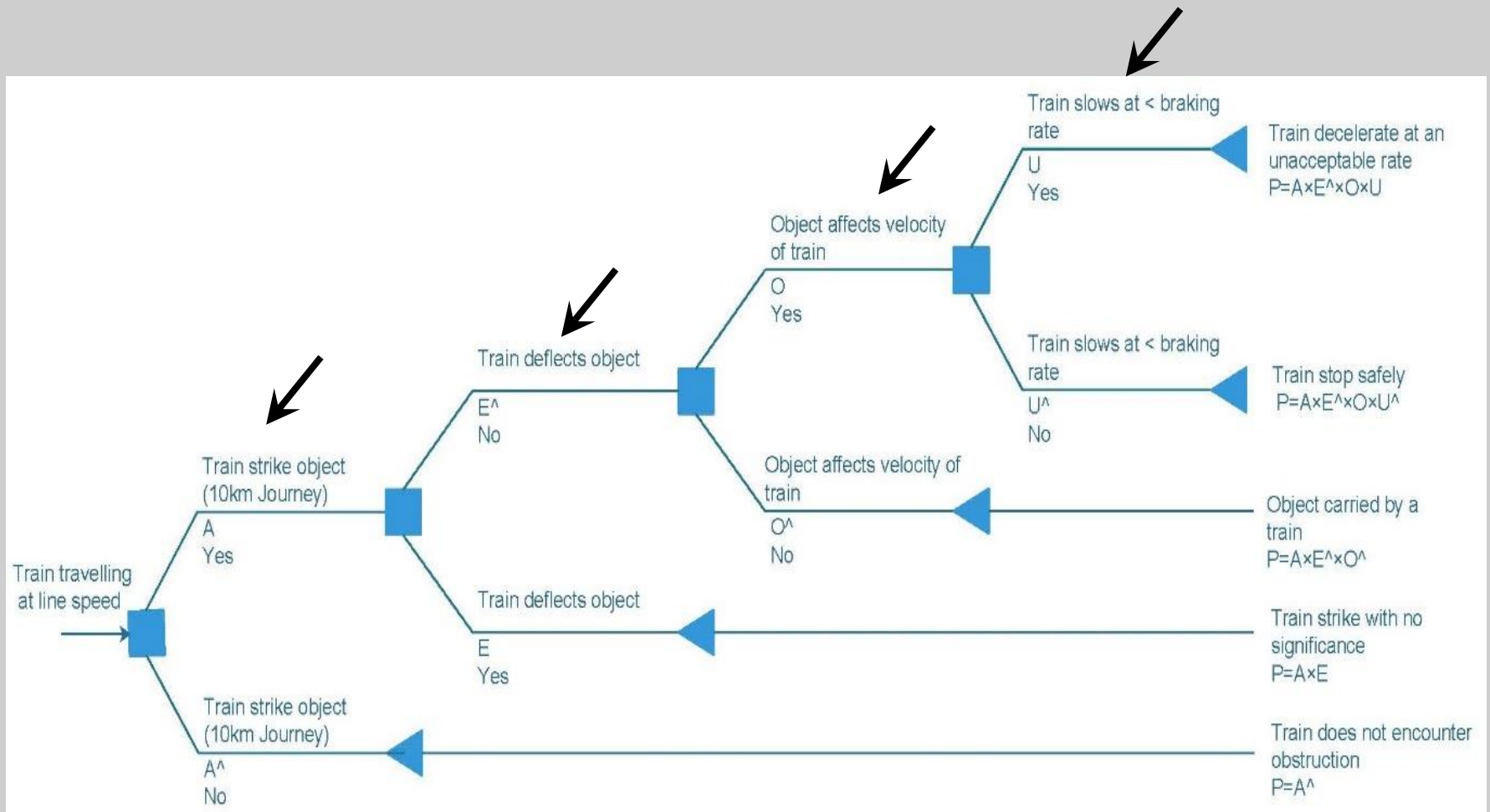
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# Event Tree Analysis of the Concept of Closer Running

## Obstacle Collision Scenario



# Event Tree Analysis of Obstacle Collision Scenario



# Probability of Encountering and Deflecting an Obstruction

Year	Passenger train kilometre (million)	Total number of incidents involving obstructions	Passenger train kilometres per accident (ptkm)
2011/12	509.9	391	1,304,092
2012/13	510.2	534	955,431
2013/14	510.6	509	1,003,143
2014/15	517.5	509	1,016,699
2015/16	521.8	473	1,103,171
		Mean	1,076,507

The probability of a train encountering an obstruction on the line during a theoretical **1 km** journey becomes:

$$\frac{1 \text{ km}}{\text{Mean value of Passenger train kilometres per accident}} = \frac{1}{1,076,507} = 9.29\text{E}-07$$

This data forms the basis for the **first decision node** in the event tree analysis.

making a **2000 km journey**, the probability of encountering an obstruction increases to 1.86E-03 per journey

## Probability of Deflection and Consequences

Category of Obstruction	Number of collisions	Number deflected	% chance of obstacle being deflected
Payload dislodged from train	0	0	N/A
Failed infrastructure component	4	4	100
Snow	1	0	0
Landslide	9	0	0
Fallen tree	1	0	0
Road vehicles	2	1	50
Animals	1456	1455	99.93
Vandalism	108	108	100
Equipment from engineering work	3	1	33.33
Debris or rubbish	3	0	0
Engineering plant	3	1	33.33

The hazards are determined by the likelihood of an object being deflected upon impact, based on the records of previous incidents so the values are not representative for other countries and situations;

This data forms the basis for the **2nd decision node** in the event tree analysis.

## Likelihood of different Obstructions affecting Train Speed

Type of Obstruction	Number of collisions during review period	Number which affected train speed	% chance of affecting speed
Payload shifted / fallen from train	0	0	N/A
Broken infrastructure component	4	0	0
Snow	1	1	100
Landslide	9	9	100
Fallen tree	1	1	100
Road vehicles	2	2	100
Animals	1456	1	0.07
Vandalism	108	0	0
Materials from engineering work	3	2	66.66
Debris or rubbish	3	3	100
Engineering plant	3	2	66.66

This data forms the basis for the **3rd decision node** in the event tree analysis.

# Landslip Collisions and Analysis of Deceleration Events

Incidents (Year of accident)	Merstham Tunnel (2017)	Kemble (2007)	Gillingham Tunnel (2010)	St Bee's (2012)	Rosyth (2012)	Falls of Cruachan (2012)	Bargoed (2013)
Line speed (mph)	82	90	85	60	65	30	30
Train speed on impact (mph)	70	51	64	47	45	30	30
Stopping distance (m)	320	243	404	121	160	N.A.	15
Recommended braking distance (m)	351	189	306	156	156		76
Evidence of train decelerating at an unacceptable rate	Yes	No	No	Yes	No	Yes	Yes

The probability of a train slowing at an unacceptable rate when obstructed by a landslide can be expressed as:

$$\frac{\text{The number of unacceptable decelerations}}{\text{The number of instances of hitting landslides}} = \frac{4}{7} = 0.57$$

## Likelihood of Unacceptable Deceleration Events

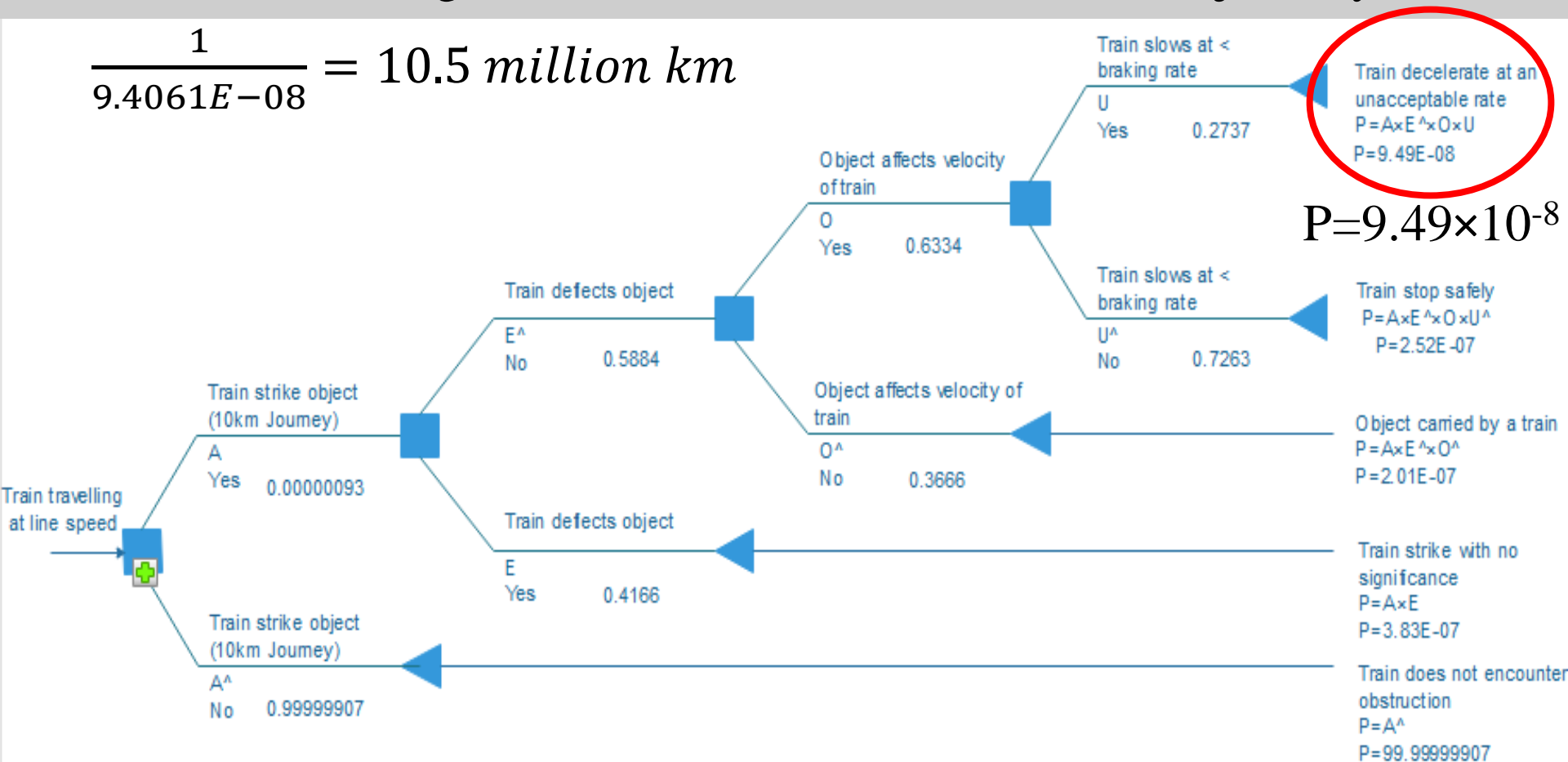
Type of Obstruction	Number of collisions occurred	Number of unacceptable decelerations	% chance of unacceptable deceleration
Payload shifted / fallen from train	0	0	-
Broken infrastructure component	3	0	0
Snow	1	1	100
Landslide	7	4	57
Fallen tree	1	0	0
Road vehicles	2	0	0
Animals	1456	0	0
Vandalism	108	0	0
Materials from engineering work	3	0	0
Debris or rubbish	3	2	66.66
Engineering plant	3	1	50

This data forms the basis for the **4th decision node** in the event tree analysis.

# Event Tree Analysis

Based on a 1 km journey, a train will decelerate at an unacceptable rate due to hitting an obstruction once in 10.5 million journeys:

$$\frac{1}{9.4061E-08} = 10.5 \text{ million km}$$



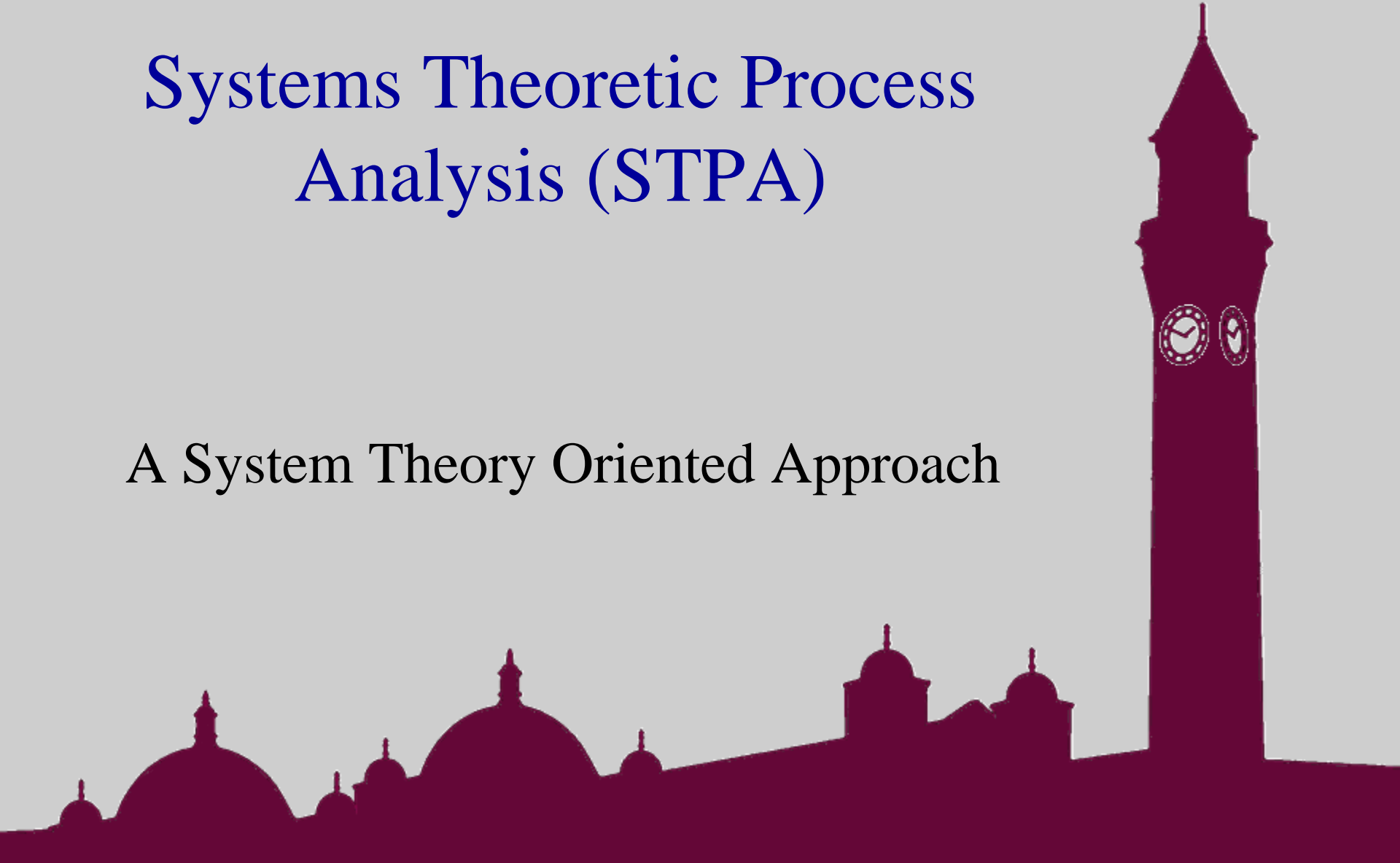


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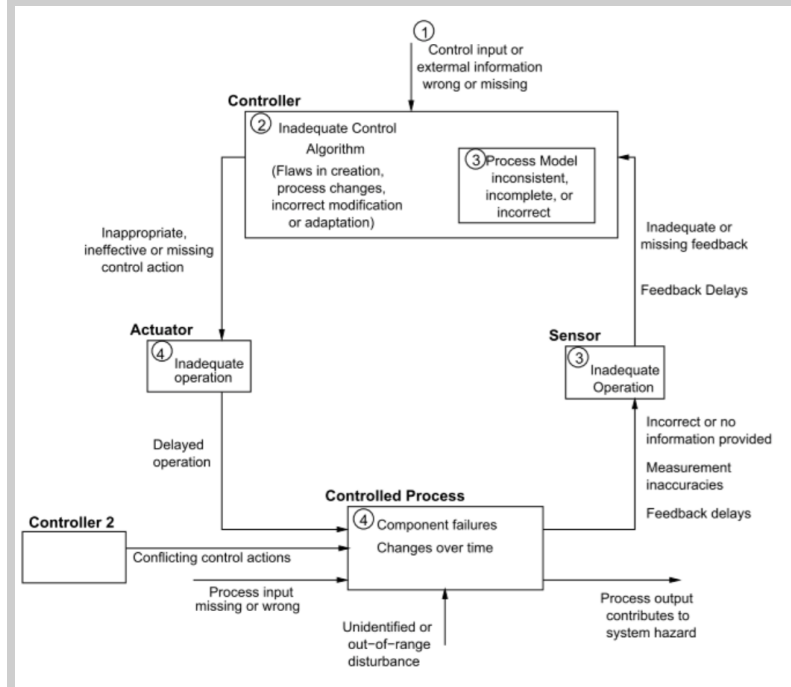
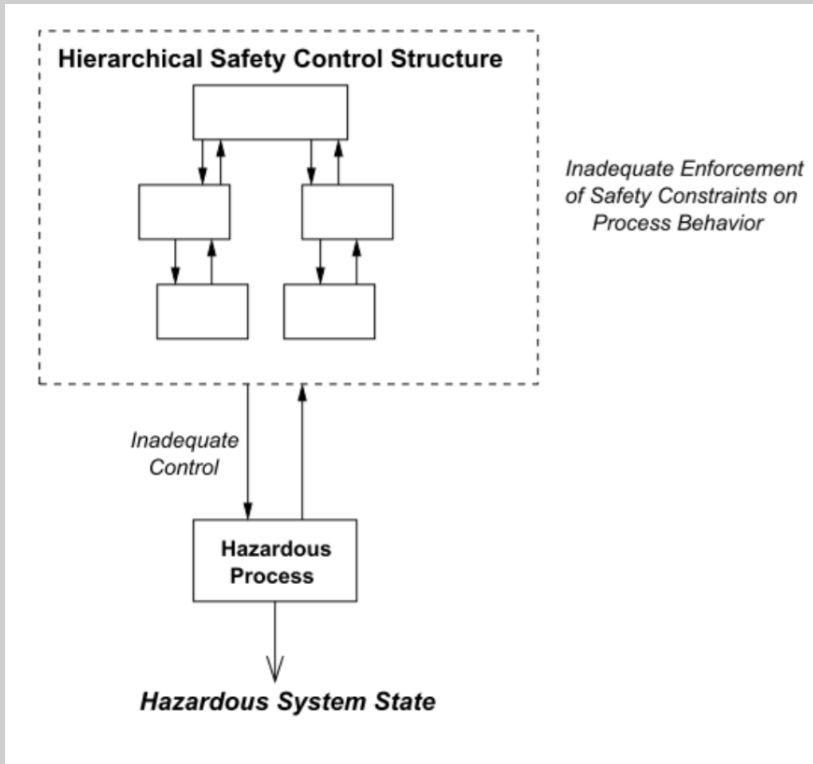
# Systems Theoretic Process Analysis (STPA)

A System Theory Oriented Approach



# System-Theoretic Process Analysis (STPA)

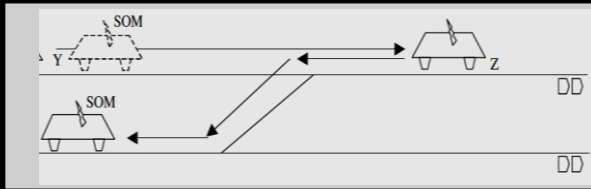
- Systems-theoretic view
- Hierarchy of control based on adaptive feedback mechanisms
- Inadequate controls lead to hazardous system state



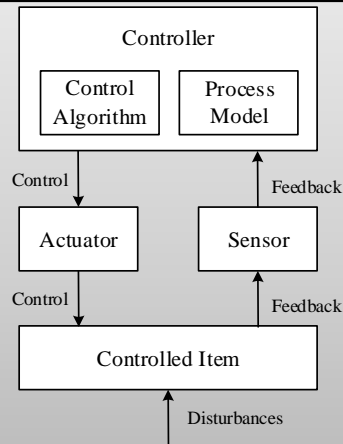
# STPA Process

## What is the system?

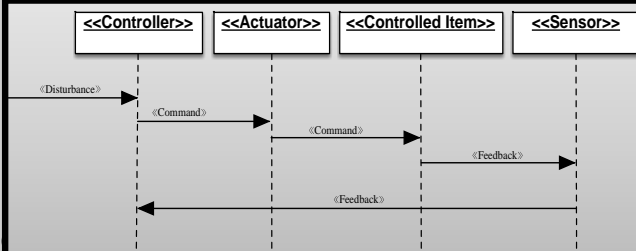
### 1. Identify Operational Scenarios



### 2.1 Identify Control Structures



### 2.2 Extended UML Sequence Diagram



## When things go wrong?

**3 Hazards—system constraints**

**4 Unsafe Control Actions**

On which situation,

provide

not provide

controller

provide too early

provide too late

stop too soon

apply too long

control action

# STPA Process

When things go wrong?

**3 Hazards—system constraints**



**4 Unsafe Control Actions**

On which situation,

provide

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controller provide too early

provide too late

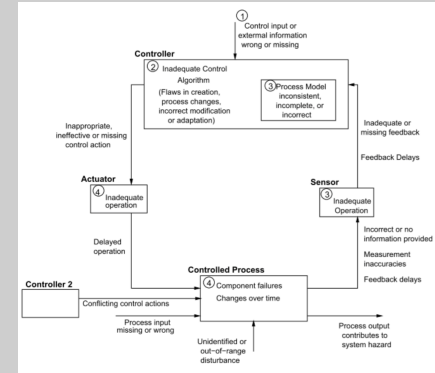
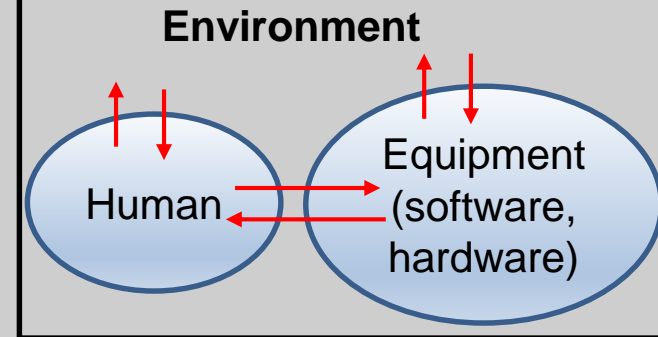
stop too soon

apply too long

control action

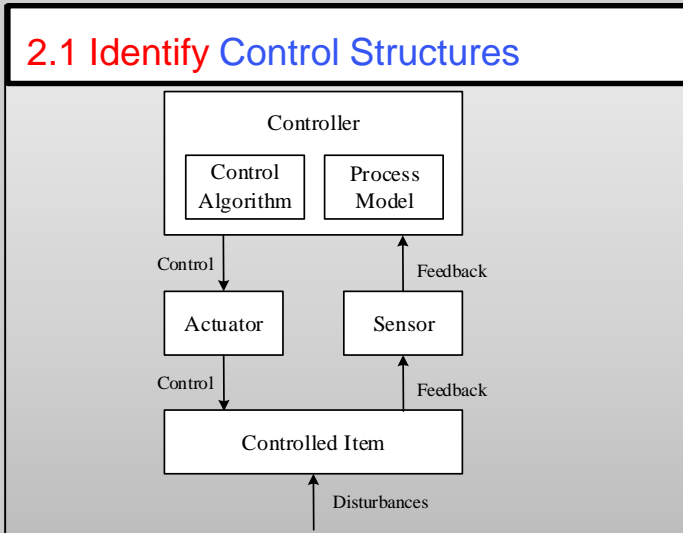
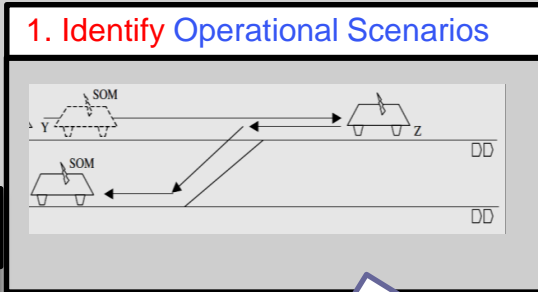
Why it would happen?

**5. Identify Causal Scenarios**

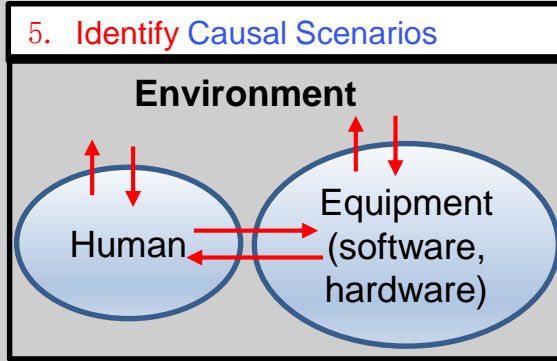
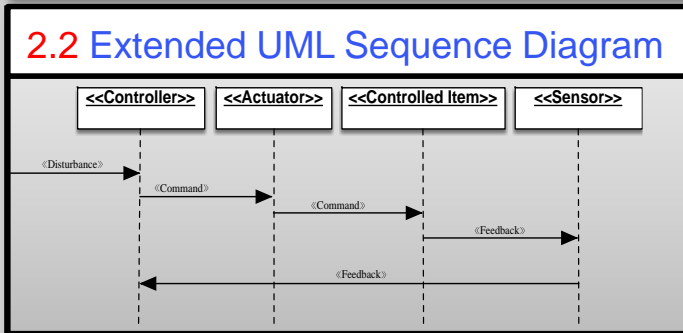


- How environmental conditions contribute?
- How human actions contribute?
- Why this situation could happen?

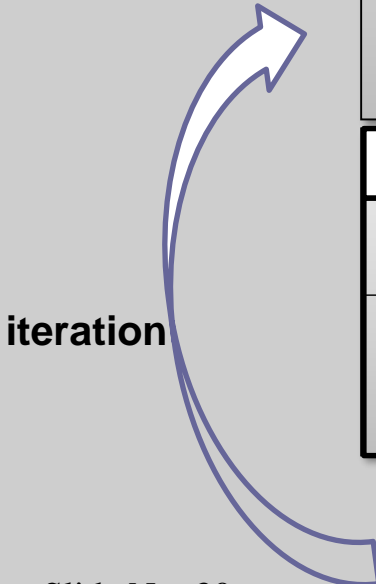
# STPA Process



- 3 Hazards—system constraints**
- 4 Unsafe Control Actions**



**6 Safety Requirements**



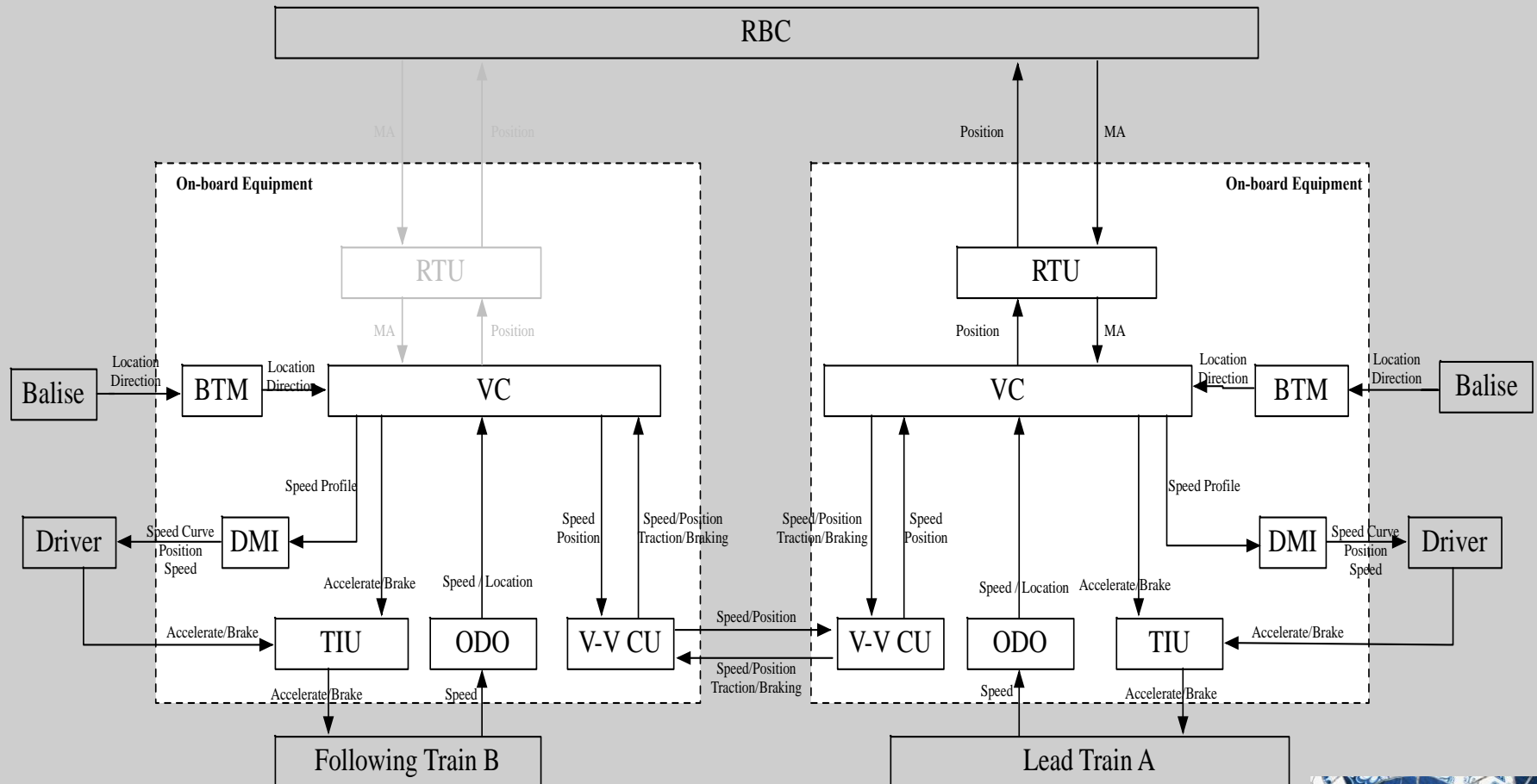
# STPA for Closer Running (Step 1&2)

Based on the scenario, i.e., ‘a train convoy runs on plain line’, seven hazards are identified:

- Hazard 1: A following train collides with the leading train on plain line;
- Hazard 2: A train convoy collides with a train on plain line;
- Hazard 3: A train convoy exceeds the safe speed and derails on plain line;
- Hazard 4: A following train exceeds the safe speed and derails on plain line;
- Hazard 5: A leading train exceeds the safe speed and derails on plain line;
- Hazard 6: A leading train collides with an obstruction on plain line;
- Hazard 7: A following train collides with an obstruction on plain line.

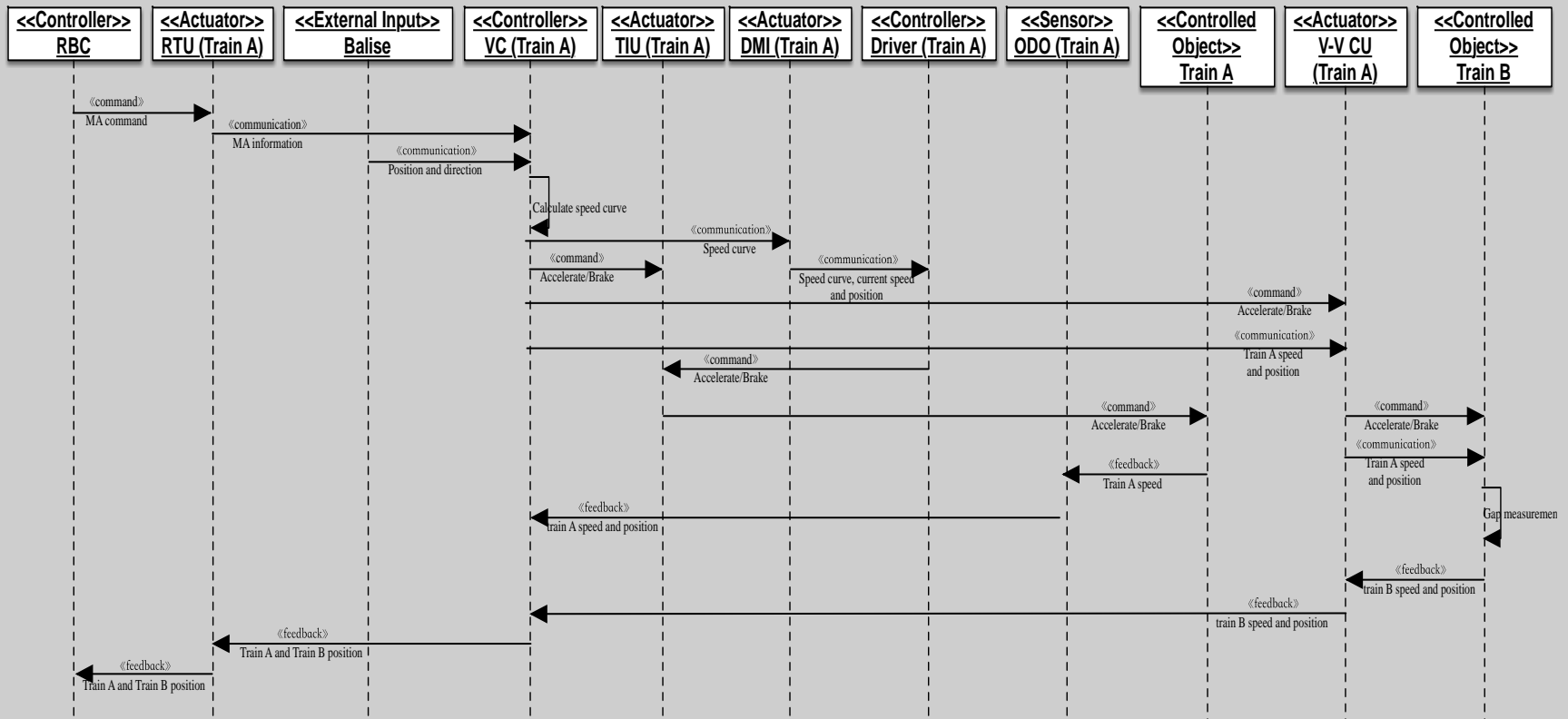
# STPA for Closer Running (Step 3)

Hierarchical control structure for the scenario of ‘train convoy runs on plain line’



# Extended UML Diagram

Information flow in the hierarchical control structure using the extended UML



# Unsafe Control Action Identification (Step 4)

<b>Hazard 1:</b> The following train (Train B) collides with the leading train (Train A) on plain line track				
<b>Control Action</b>	<b>*Not providing causes hazard</b>	<b>*Providing causes hazard</b>	<b>*Too early / too late, wrong order causes hazard</b>	<b>*Stopping too soon / applying for too long causes hazard</b>
Accelerate (to TIU)	UCA 1: Accelerate command is not provided to Train A when train B accelerates.	-	UCA 2: Accelerate command is provided too late to Train A.	UCA 3: Accelerate command stops too soon for Train A.
Brake (to TIU)	-	UCA 4: Brake command is provided to train A when it is not needed.	-	-

\*Associating with the four types of unsafe control actions that proposed by Leveson (2011b)



# STPA for Closer Running (Steps 5 & 6)

UCA 1: The accelerate command is not provided to Train A when train B accelerates.	
Causal Scenario (CS)	CS1-1: TIU does not receive accelerate command from VC because of the communication between VC and TIU being broken.
Safety Requirement (SaR)	SaR 1-1-1: VC shall monitor train's acceleration. If it does not satisfy the standard acceleration, VC cuts down acceleration of following trains and report faults.
	SaR 1-1-2: VC shall monitor the communication with TIU. If it is interrupted, VC reports to driver and applies the emergency brake to all trains.
	SaR 1-1-3: Redundant communication line between VC and TIU.

# Discussion (1)

The result indicates that the risk associated with the scenario on the UK mainline railway falls into the region of negligible / tolerable;

Based on historic data, the probability of a train not deflecting an obstruction and causing unacceptable deceleration events are very low;

However, the risk exists!

There have been instances with catastrophic outcomes...

## Discussion (2)

Approaches based on the STPA philosophy are often viewed as highly theoretical, our study shows that it can be applied to practical situations, such as the safety analysis of ‘closer running’ or ETCS Level 4.

Applying both methodologies together makes it possible to take informed decisions on the implementation of ‘closer running’ and the risks involved.



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# Any Questions?

## Thank you for Listening!

