

A Comparison of Event-Based Root Cause Analysis Methods

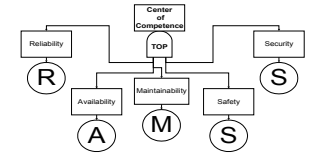
Jens Braband, Ernesto de Stefano – Siemens Transportation Systems

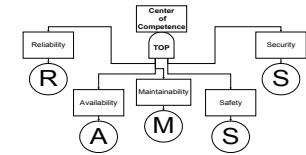
Sonja-Lara Kurz – Technical University, Braunschweig, Germany

{jens.braband|ernesto.destefano}@siemens.com, s-l.kurz@tu-bs.de

Overview

- Introduction
- Case Study: Herald of Free Enterprise (HoFE)
 - SOL analysis
 - Multilinear Events Sequencing
 - Events and Causal Factors analysis
- Case Study: Warngau
 - SOL analysis
 - Multilinear Events Sequencing
 - Events and Causal Factors analysis
- Comparison and Evaluation
- Conclusion and Way Forward





Introduction

- Recent increased interest in causal analysis methods
 - IRIA2002&IRIA2003
 - Bieleschweig Workshops, 2002&2003
 - IMTP2003 ...
- Several different approaches available
 - Multilinear Events Sequencing (MES, Benner, Chicago)
 - Safety by Organizational Learning (SOL, Wilpert/Fahlbruch, Berlin Tech. Univ.)
 - Events and Causal Factors (ECF) analysis
 - Why-Because Analysis (WBA, Ladkin, Univ. of Bielefeld)
 - Systems Theoretic Accident Model and Processes (STAMP, Leveson, MIT, Boston)
 - Theory of Constraints (TOC, Zotov, ...)
- Event-based methods are used as stand-alone methods, but it could be they contribute more as an initial stage in causal analysis.

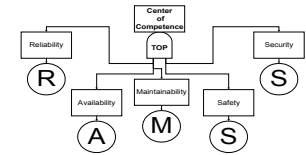
Case Study: Herald of Free Enterprise

- The ferry left with her bow doors open and as she passed the outer mole and increased speed, water flooded onto the lower car deck. The ship became destabilised and capsized.
- Factors identified in the investigation:
 - The Assistant Bosun, whose immediate responsibility it was to close the bow doors upon departure, was asleep in his cabin.
 - The Bosun noticed that the bow doors were still open, but did not close them as he did not consider this to be one of his duties.
 - The Chief Officer, responsible for ensuring door closure, thought he saw the Assistant Bosun going to close the doors.
 - The Captain assumed that the doors were properly closed unless told otherwise.



SOL Analysis

- The starting point is a “mental movie” based on index cards (called event building blocks, EBBs).
- The rules concerning what has to be included, and in what form and detail, are less formal than in similar approaches, e.g. Benner’s MES.
- Then direct and indirect factors are attached to the event building blocks.
- The results in our case become quite extensive and cannot be presented here.
- For this reason the results for each actor were placed on a separate sheet.



Nr.:	
Time:	
Location:	
Actor:	
Action:	
Remarks:	

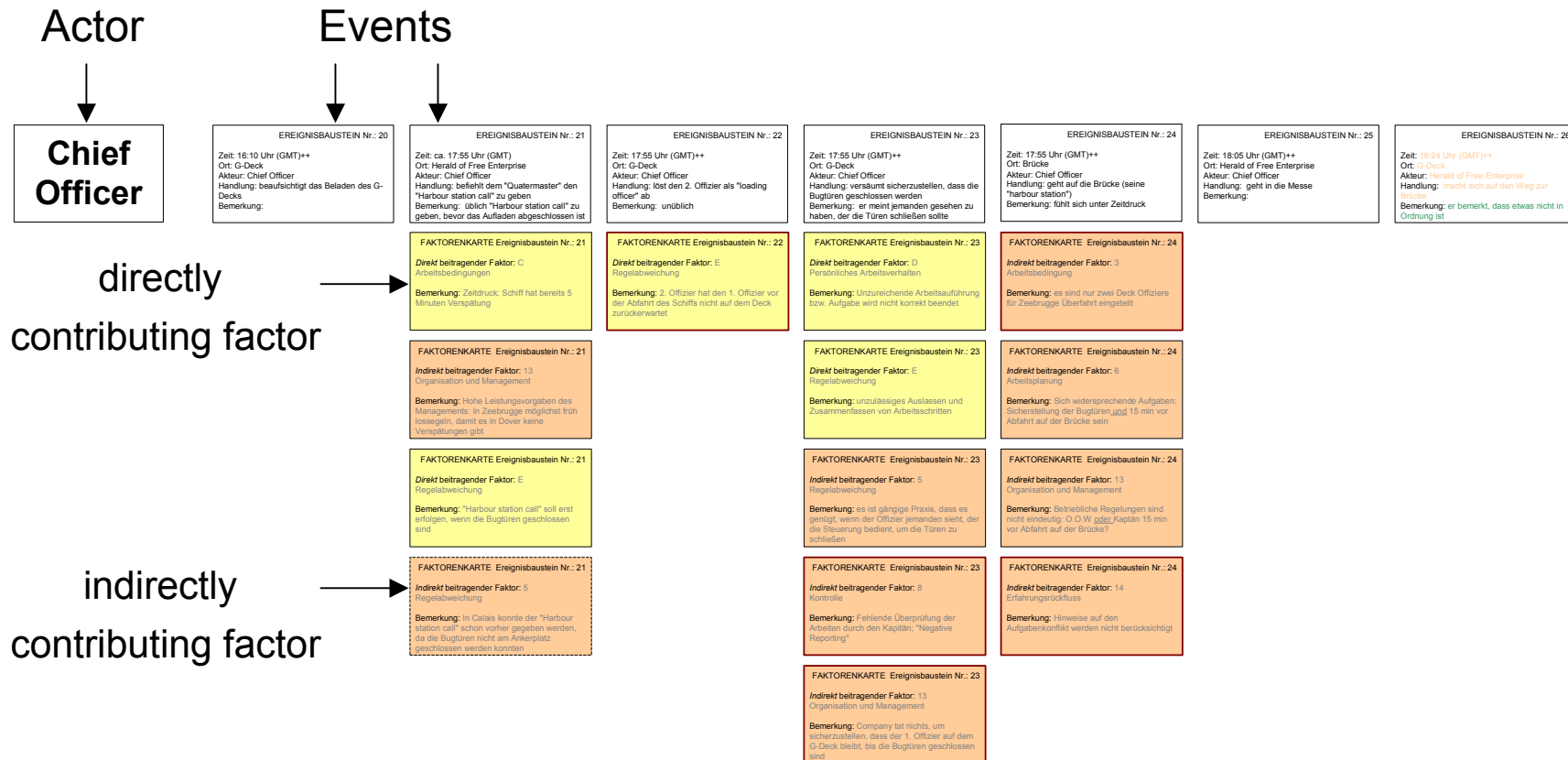
Herald of Free Enterprise, March 6th, 1987

March 6th, 1987

16:10	17:40	17:55	18:05	18:24	18:28

TIME

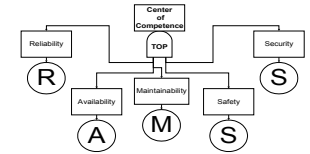
SOL Analysis Detail for Chief Officer



SOL Analysis Contributing Factors

	Number of		Directly contributing Factor							Indirectly contributing Factor																			
Akteur	EBBs	CFs	A	B	C	D	E	F	Σ	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Σ
Captain	2	9		1	1	1	1		4		1						1		1			1	1						5
Chief Officer	7	14			1	1	3		5			1		2	1		1					3	1						9
Second Officer	2	4		2					2				1									1							2
Bosun	3	3			1				1				1				1												2
Assistant Bosun	7	12					1		1			1		2			2		1				3	2					11
Ship	7	23	2		3		1		6	1	1		1	1			2		1			1	5	4					17
total	28	65	2	3	5	2	6	0	19	1	2	2	3	5	1	0	7	0	3	0	0	6	10	6	0	0	0	0	46

MES Analysis

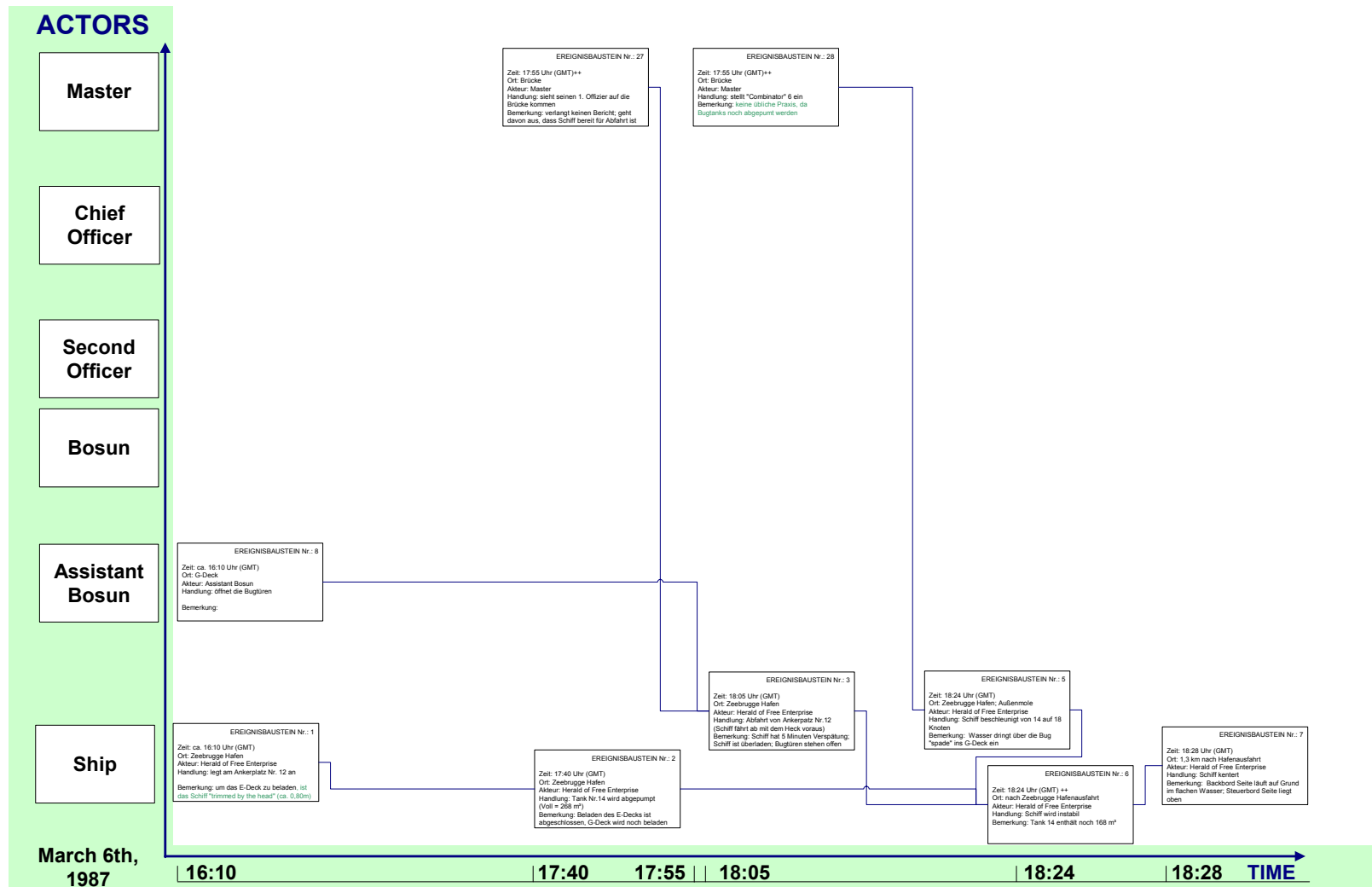


- Similar approach to SOL “mental movie”, but has very restrictive rules for construction of event building blocks to avoid judgmental bias, e.g.
 - Non-events or passive voice not allowed
 - Plural actors, e.g. crew or passengers, not allowed
 - Explicit list of so-called “poison words”
 - Only one action per EBB
- EBBs are causally linked due to similar reasoning as in WBA.
- Recommendations are based on a kind of deviation analysis, which is performed for each causally linked EBB pair.

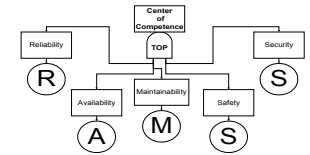
N.B. While the first version of this approach was labelled MES, its successor was called STEP and the latest version (2002) MES again. We refer here only to the latest version.

MES Chart

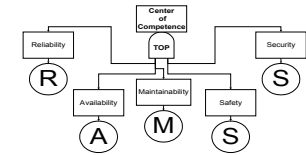
Herald of Free Enterprise, March 6th, 1987



Experience with MES Based on HoFE



- Detail in resulting chart is sparse and almost trivial (compared to SOL) because major events or causes cannot be shown, e.g.
 - Assistant Bosun DOES NOT close bow doors.
 - First Officer DOES NOT supervise closing of doors.
 - Master DOES NOT receive a report.
 - etc.
- It seems unclear how organisational causes can be found systematically by MES.
- Judgmental bias, which is apparently avoided by strict rules for construction of MES chart, seems to return when it comes to definition of recommendations.

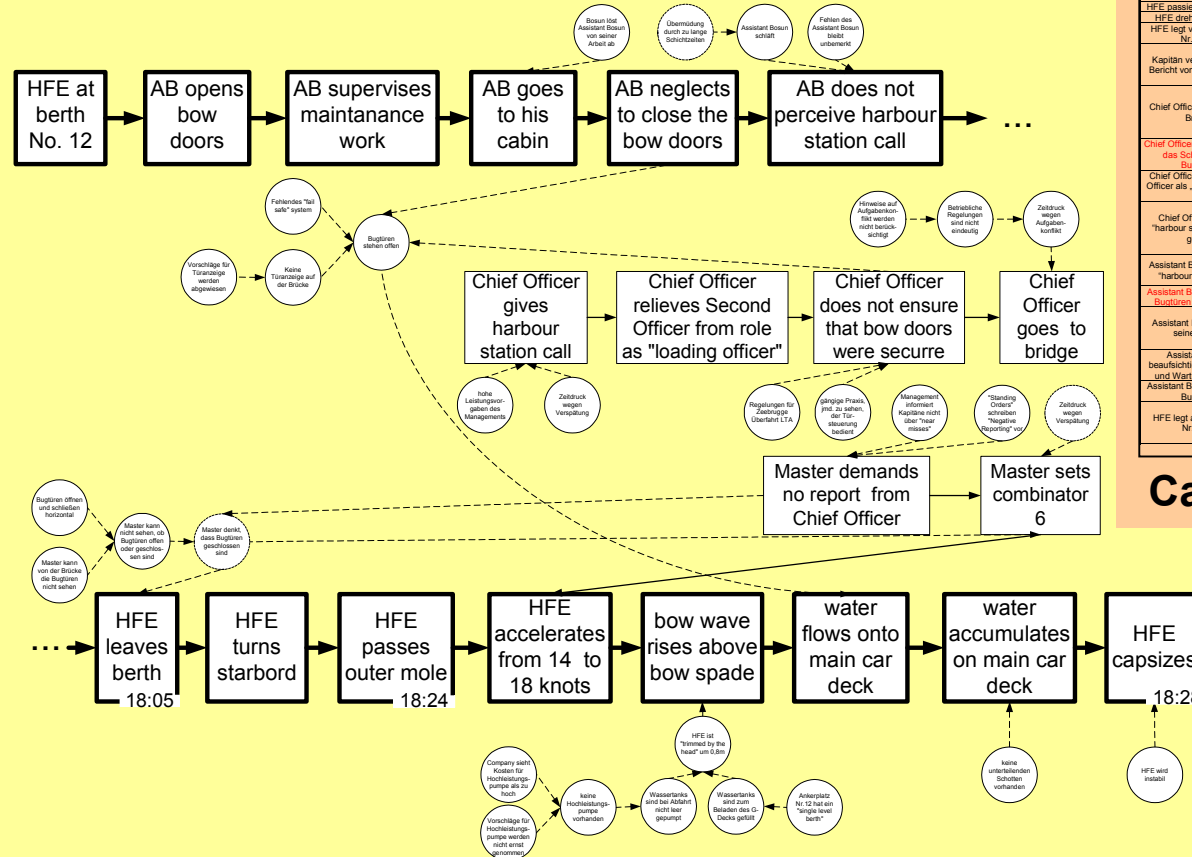


ECF Analysis

- Starts with timeline similar to SOL's "mental movie", but offers more restrictive rules for list of events and conditions, e.g.
 - Events should be described by a short sentence with one subject and one active verb.
 - Events should describe a single discrete occurrence.
 - Events should be derived directly from the event and conditions preceding it.
 - Conditions should be connected to each other and to events.
 - Conditions should be derived directly from the conditions immediately preceding them.
- Conditions differ from events in that they
 - describe states or circumstances rather than happenings or occurrences.
 - are passive rather than active.
- Causal Counterfactual Reasoning distinguishes potential causal factors from more contextual information (applied only to events).

ECF Chart

Herald of Free Enterprise, March 6th, 1987

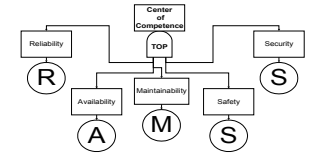


Ereignis	Kausaler/ Kontextabhängiger Faktor	Begründung
Wasser sammelt sich im G-Deck an	Kausal	Wäre nicht so eine große Menge an Wasser eindringen, wäre die HFE nicht instabil geworden
Wasser dringt über die Bugspade in G-Deck ein	Kausal	Wäre das Wasser nicht eingedrungen, hätte die HFE nicht so stabil verfahren
Bugwelle steigt über die Bugspade	Kausal	Wenn die Bugwelle nicht so hoch gewesen wäre, hätte das Wasser nicht eindringen können
HFE beschleunigt von 14 auf 18 Knoten	Kausal	Durch die Beschleunigung stieg die Bugwelle an und die HFE ging in die "Hocke"
Kapitän stellt "combinator 6" ein	Kausal	Bei niedrigerer Geschwindigkeit wäre die Bugwelle nicht so hoch gewesen
HFE passiert "Outer Mole"	Kontext	Üblicher Weg aus dem Zeebruggen Hafenbereich
HFE dreht Steuerbord	Kontext	s.o.
HFE legt von Ankerplatz Nr. 12 ab	Kontext	s.o.
Kapitän verlangt keinen Bericht vom Chief Officer	Kontext	Wenn er einen Bericht verlangt hätte, hätte ihm der Chief Officer berichtet, dass er ihm gesehen hat, für die Bugtüren zuständig ist. Es war gängige Praxis, dass dies ausreicht
Chief Officer geht auf die Brücke	Kontext	Wenn er nicht unter Zeitdruck gewesen wäre auf die Brücke zu gehen, dann wäre er vielleicht länger auf dem G-Deck geblieben. Das heißt aber nicht, dass er zwangsläufig dafür gesorgt hätte, dass die Bugtüren geschlossen werden
Chief Officer überprüft nicht das Schließen der Bugtüren	Kausal	Wenn er sicherge stellt hätte, dass die Bugtüren geschlossen sind, hätte kein Wasser ins Schiff eindringen können
Chief Officer ist Second Officer als "loading officer" ab	Kontext	Wenn der Second Officer "loading officer" geblieben wäre, ist nicht sicher, ob er dafür gesorgt hätte, dass die Bugtüren geschlossen werden
Chief Officer befiehlt "harbour station call" zu geben	Kontext	Wenn "harbour station call" erst nach Beenden des Beladens gegeben worden wäre, dann wäre der Chief Officer trotzdem unter Zeitdruck gewesen auf die Brücke zu gehen und der Assistant Bosun hätte den "call" trotzdem überhört
Assistant Bosun überhört "harbour station call"	Kontext	Wenn er den "harbour station call" nicht überhört hätte, dann ist es nicht sicher, ob er danach doch die Bugtüren geschlossen hätte
Assistant Bosun versäumt Bugtüren zu schließen	Kausal	Wenn er das nicht vergessen hätte, wäre kein Wasser eindringen
Assistant Bosun geht in seine Kabine	Kontext	Wenn er nicht in seine Kabine gegangen wäre, dann wäre er vielleicht nicht eingeschlafen, aber das heißt nicht zwangsläufig, dass er daran gedacht hätte die Bugtüren zu schließen
Assistant Bosun beaufsichtigt Reinigungs- und Wartungsarbeiten	Kontext	Normale Arbeiten
Assistant Bosun öffnet die Bugtüren	Kontext	s.o.
HFE legt an Ankerplatz Nr. 12 an	Kontext	Wäre es ein anderer Ankerplatz gewesen, dann wäre das Schiff vielleicht nicht "rimmed by the head" gewesen, aber die hohe Bugwelle hätte vielleicht auch ausgereicht, damit Wasser über die "spade" kommt

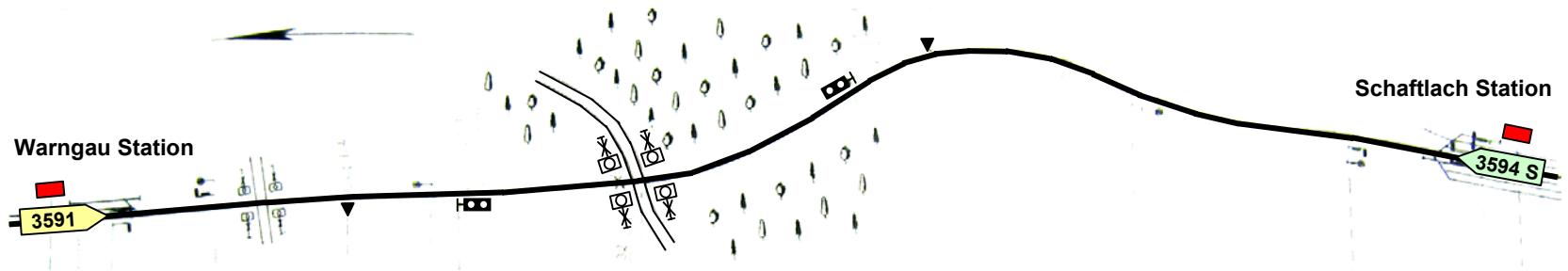
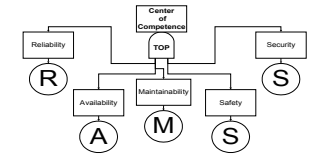
Cause/context chart

Overview

- Introduction
- Case Study: Herald of Free Enterprise (HoFE)
 - SOL analysis
 - Multilinear Events Sequencing
 - Events and Causal Factors analysis
- Case Study: Warngau
 - SOL analysis
 - Multilinear Events Sequencing
 - Events and Causal Factors analysis
- Comparison and Evaluation
- Conclusion and Way Forward



Warngau – telephone block



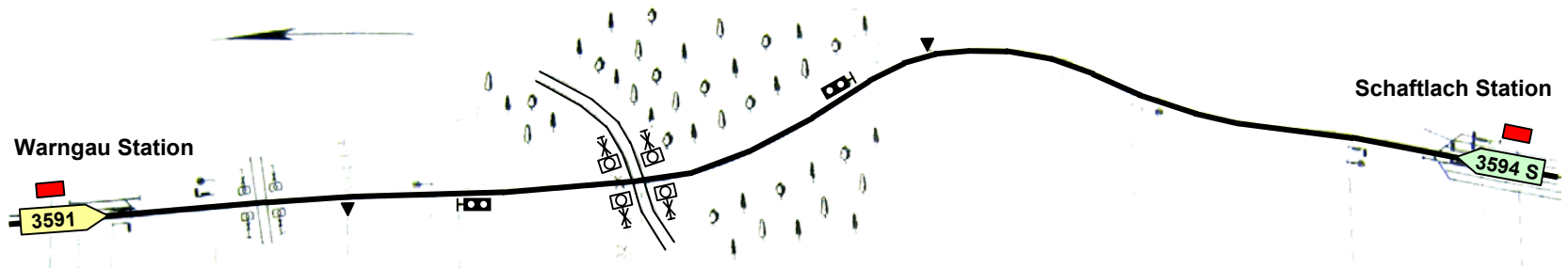
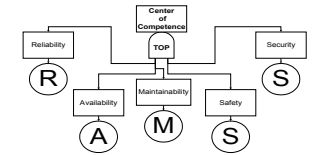
Warngau Station

Train **3591** about to
depart

Schaftlach Station

Train **3594 S** about to
depart

Warngau – telephone block



Warngau Station

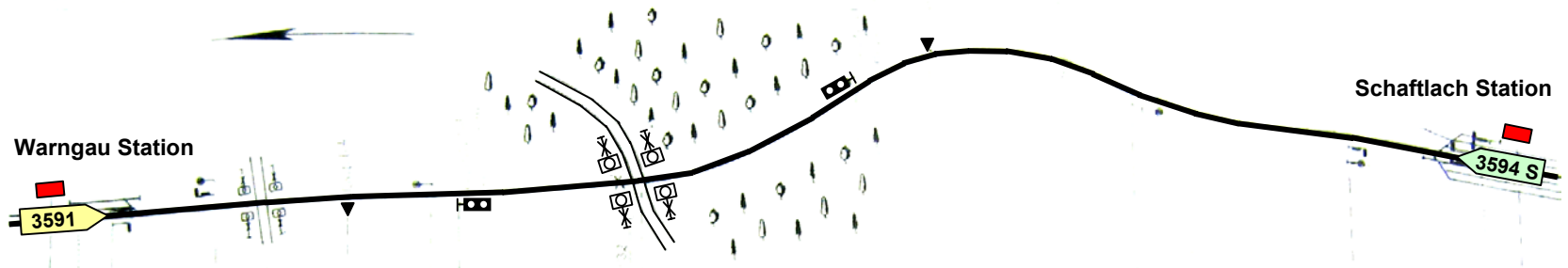
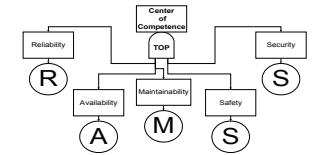
Train **3591** about to depart

Schaftlach Station

Train **3594 S** about to depart

← Offering of the train

Warngau – telephone block

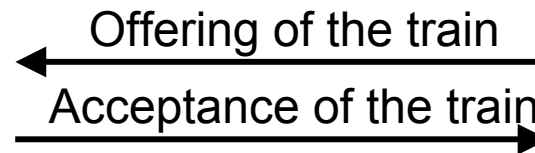


Warngau Station

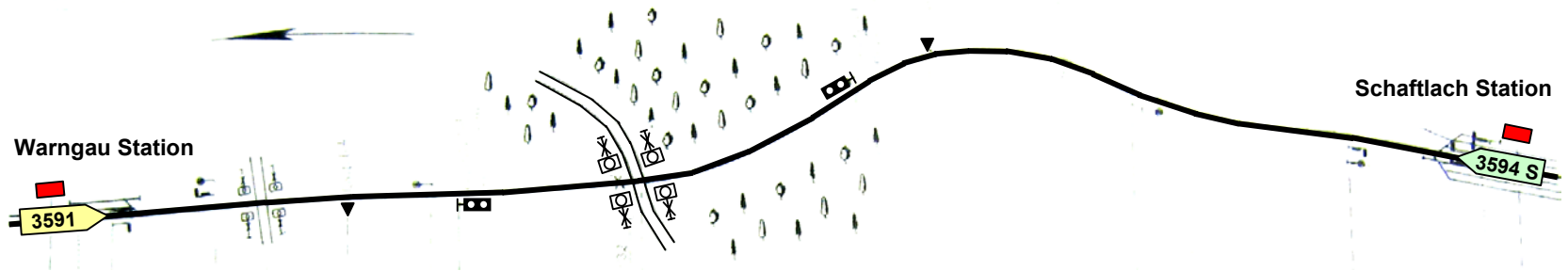
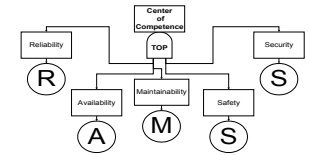
Train **3591** about to depart

Schaftlach Station

Train **3594 S** about to depart



Warngau – telephone block

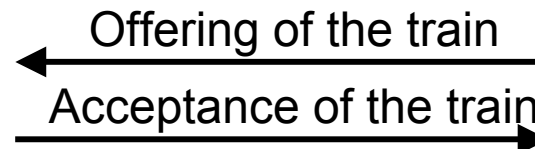


Warngau Station

Train **3591** about to depart

Schaftlach Station

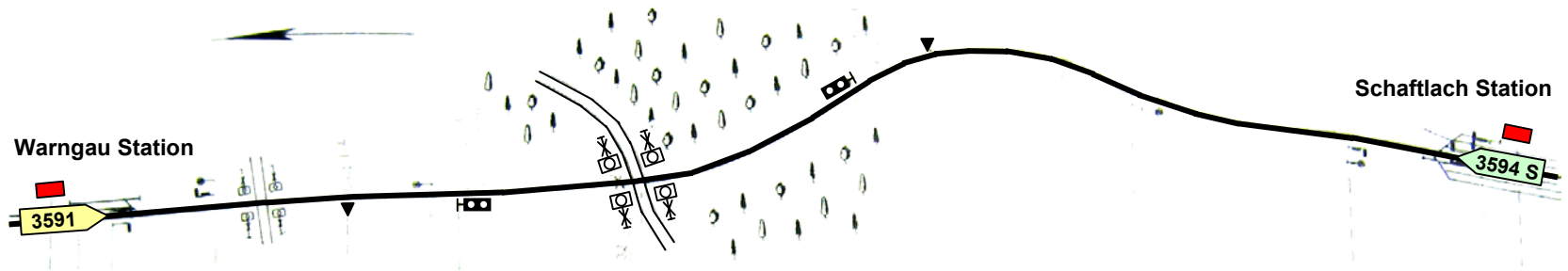
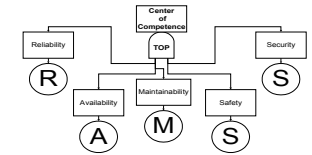
Train **3594 S** about to depart



Train **3591** is waiting

Departure Train **3594 S**

Warngau – telephone block

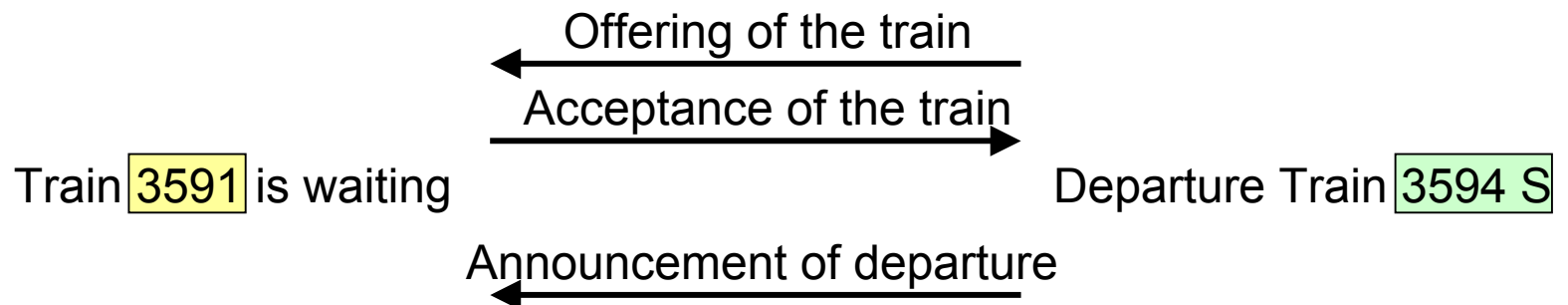


Warngau Station

Train **3591** about to depart

Schaftlach Station

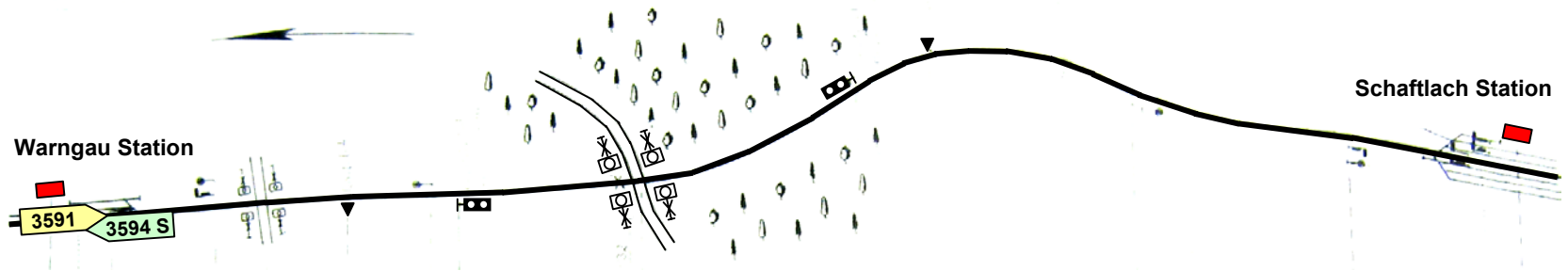
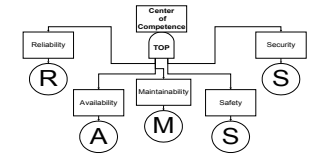
Train **3594 S** about to depart



Train **3591** is waiting

Departure Train **3594 S**

Warngau – telephone block

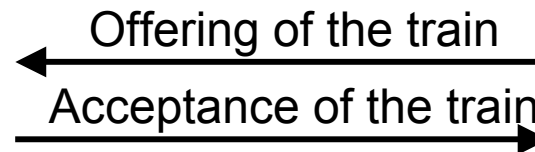


Warngau Station

Train **3591** about to depart

Schaftlach Station

Train **3594 S** about to depart



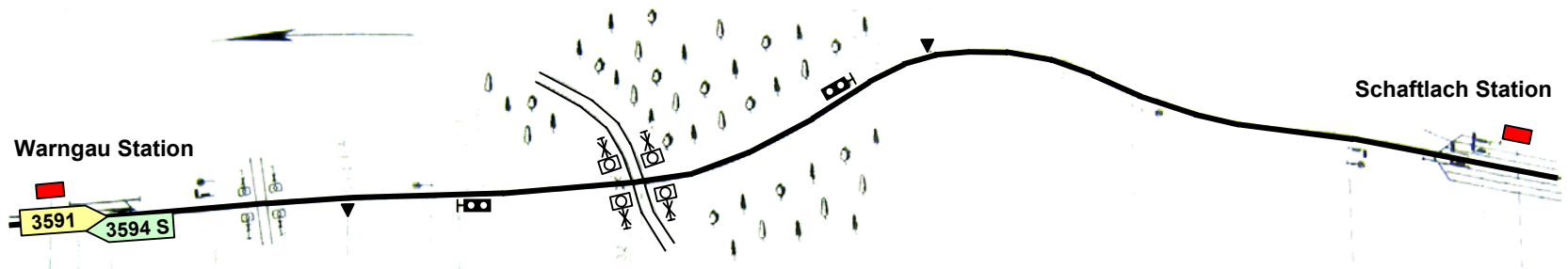
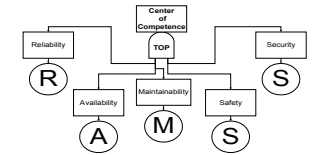
Train **3591** is waiting

Departure Train **3594 S**



Arrival Train **3594 S**

Warngau – telephone block

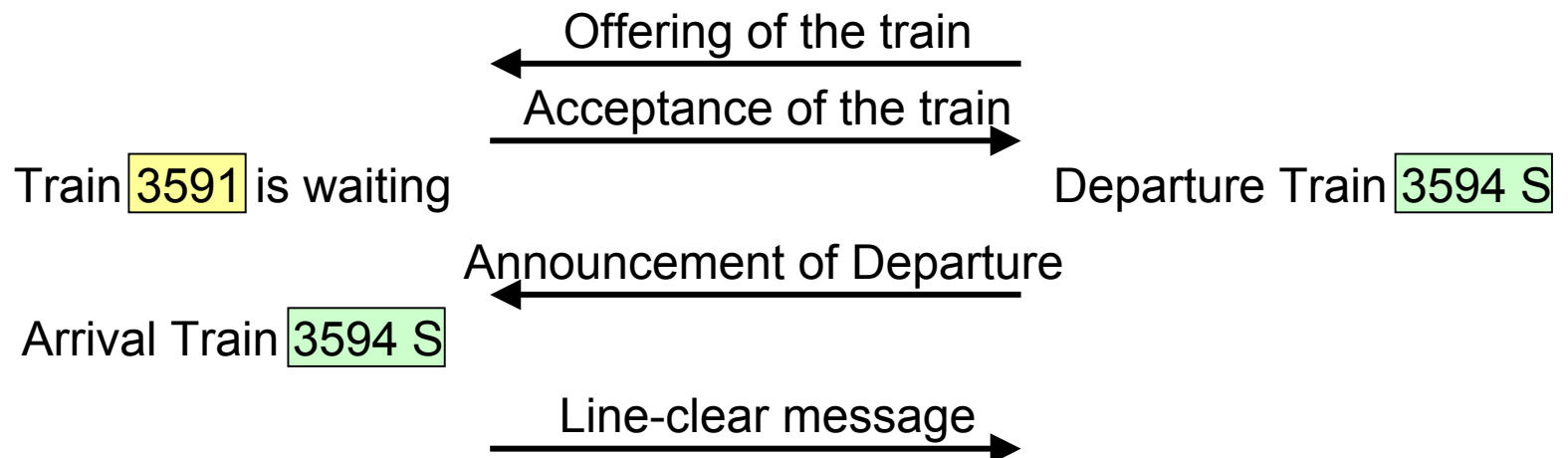


Warngau Station

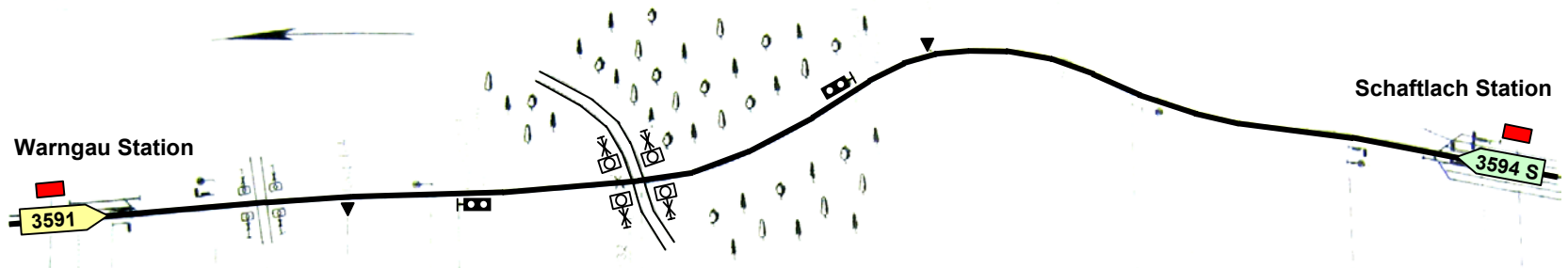
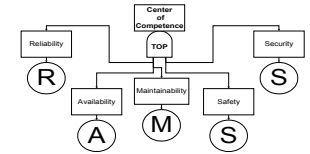
Train 3591 about to depart

Schaftlach Station

Train 3594 S about to depart



Warngau – telephone block 06-08-1975



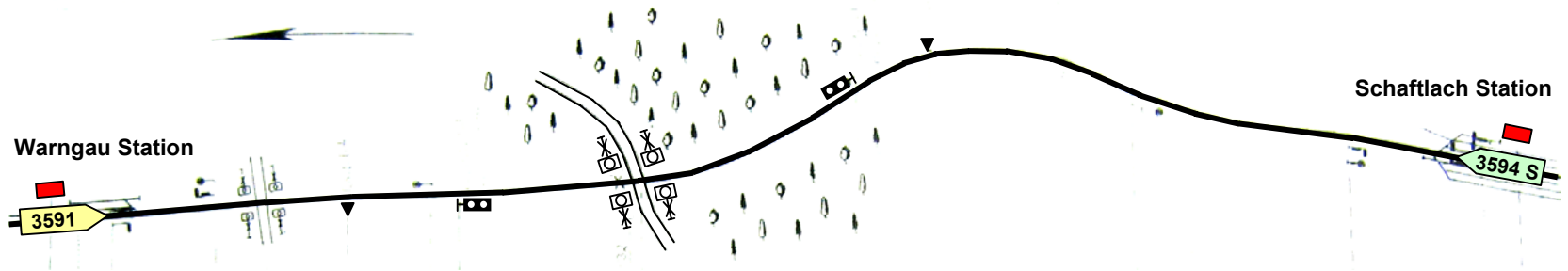
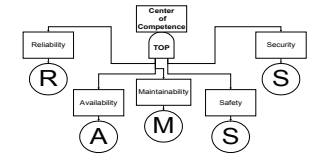
Warngau Station

Train **3591** about to depart

Schaftlach Station

Train **3594 S** about to depart

Warngau – telephone block 06-08-1975



Warngau Station

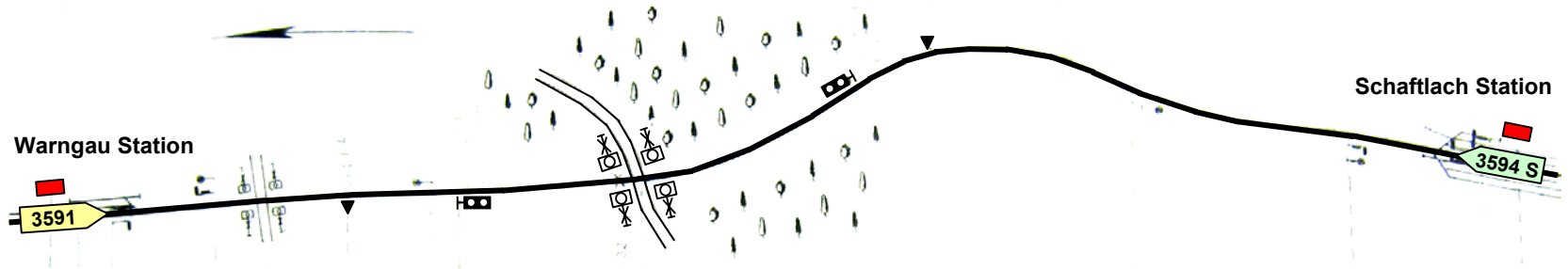
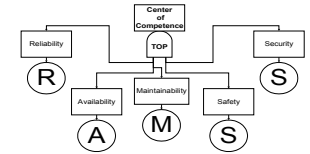
Train **3591** about to depart

Schaftlach Station

Train **3594 S** about to depart

Offering of train **3594 S**

Warngau – telephone block 06-08-1975

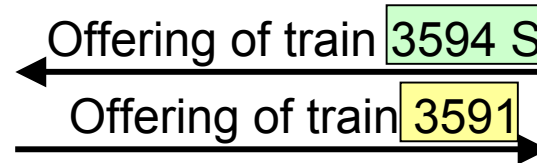


Warngau Station

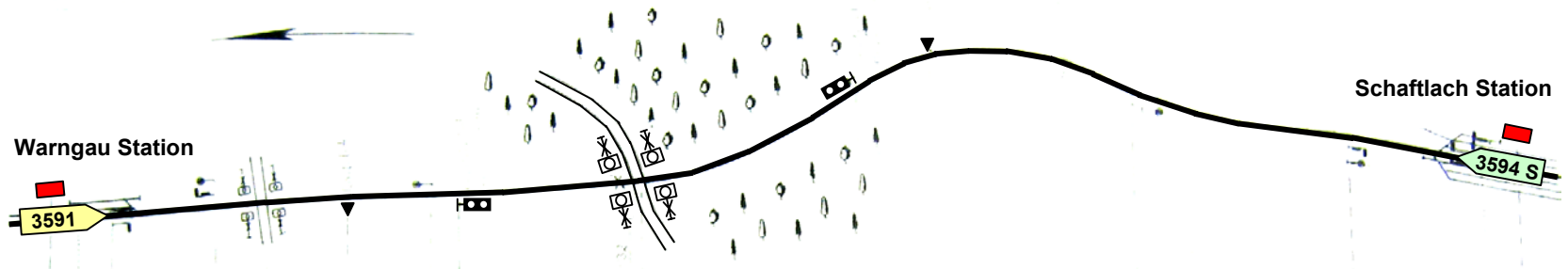
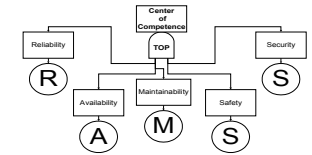
Train **3591** about to depart

Schaftlach Station

Train **3594 S** about to depart



Warngau – telephone block 06-08-1975

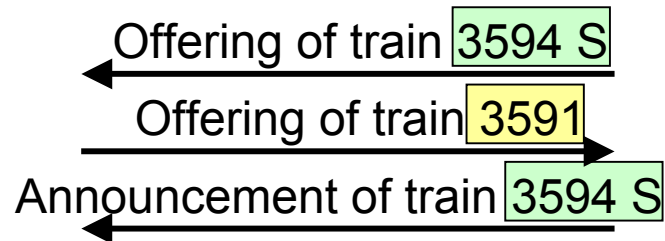


Warngau Station

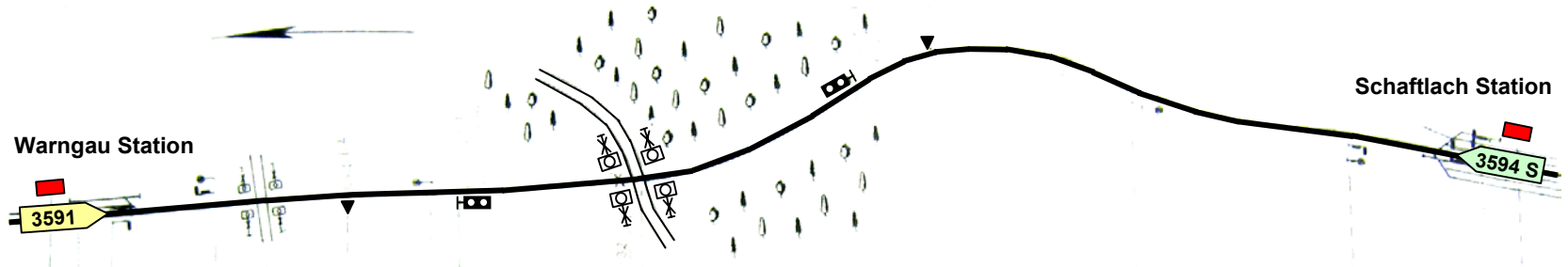
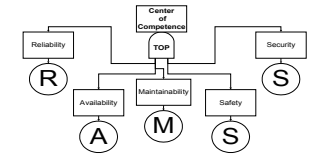
Train **3591** about to depart

Schaftlach Station

Train **3594 S** about to depart



Warngau – telephone block 06-08-1975

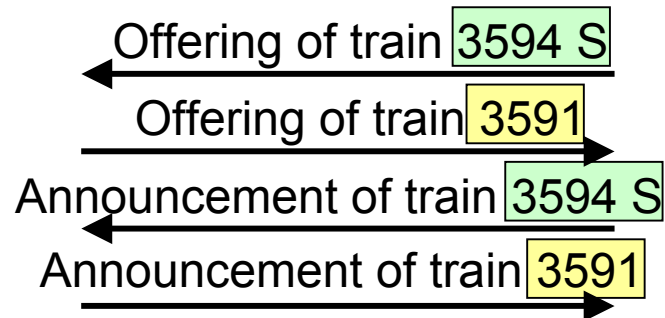


Warngau Station

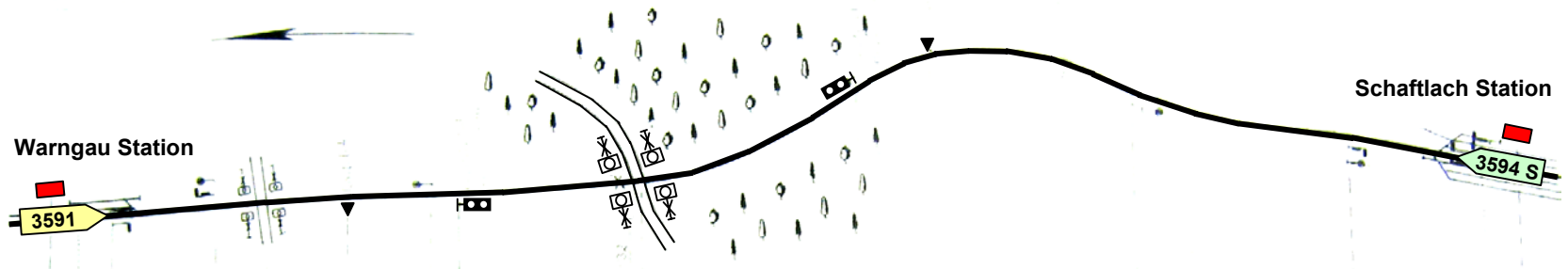
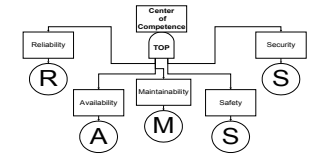
Train **3591** about to depart

Schaftlach Station

Train **3594 S** about to depart



Warngau – telephone block 06-08-1975

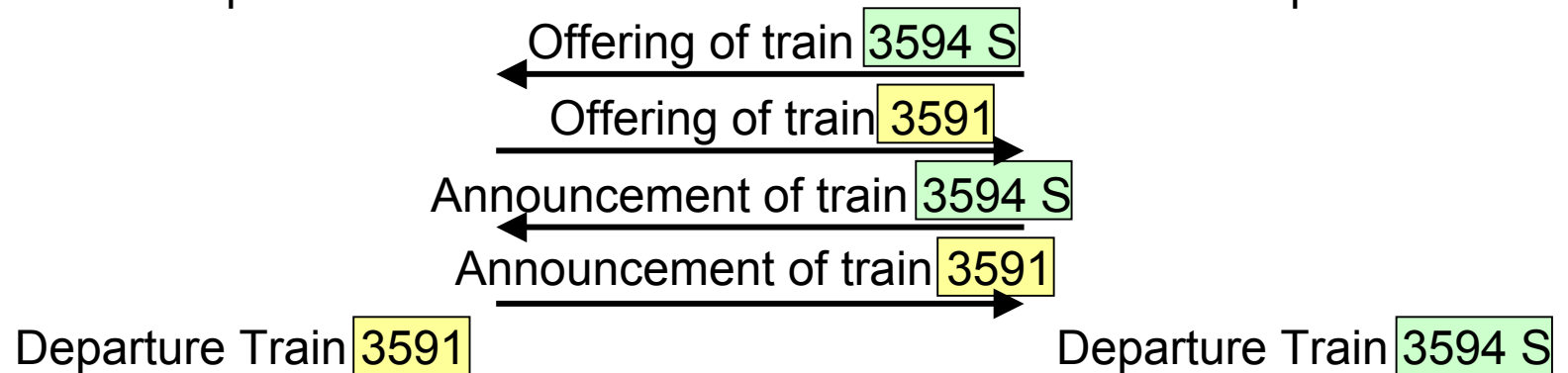


Warngau Station

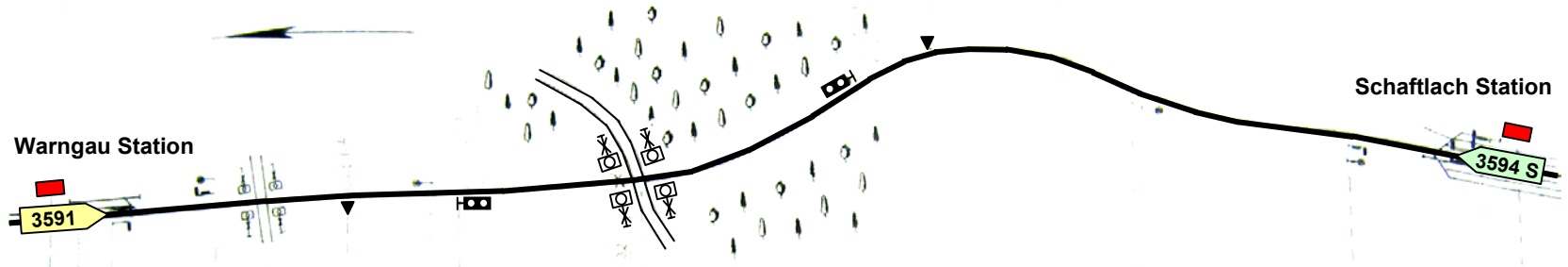
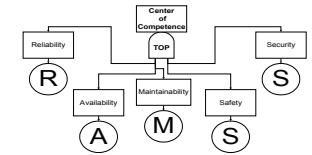
Train **3591** about to depart

Schaftlach Station

Train **3594 S** about to depart



Warngau – 06-08-1975



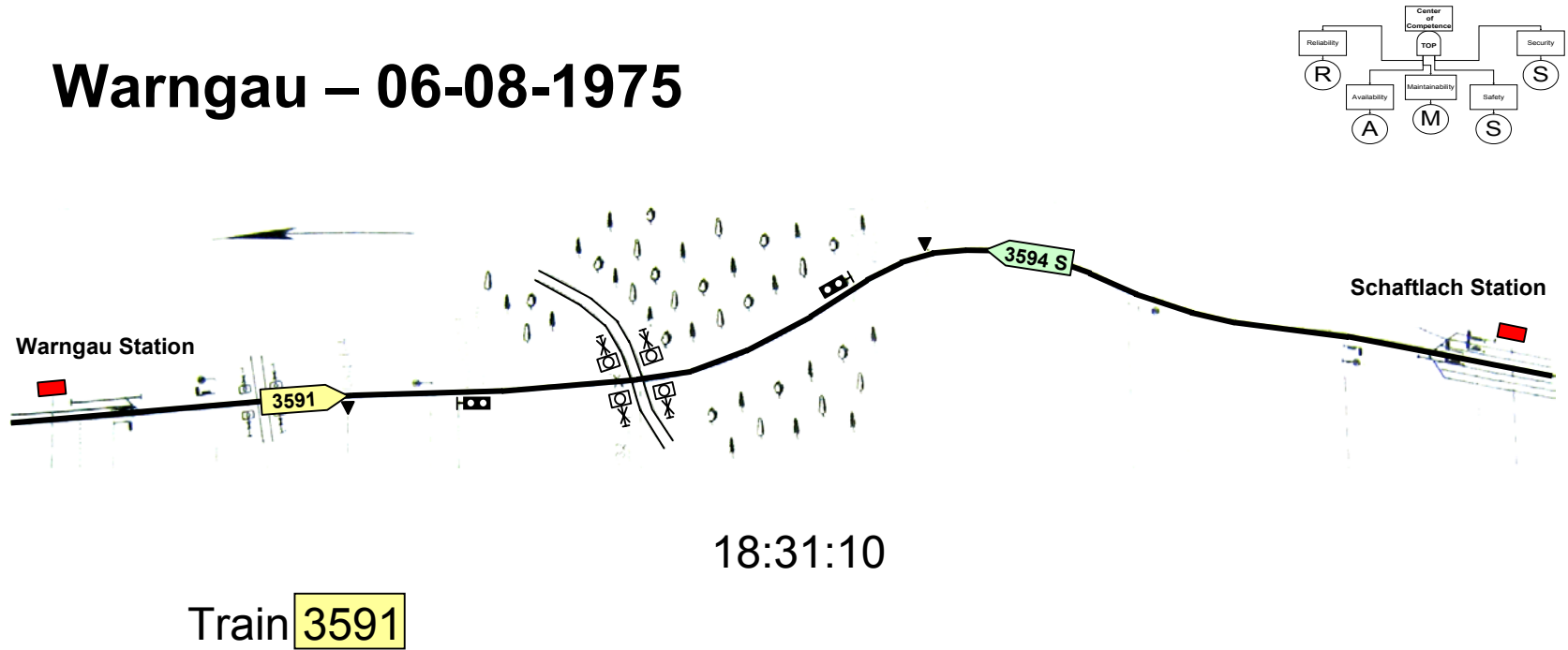
18:29

Train 3591

Train 3594 S

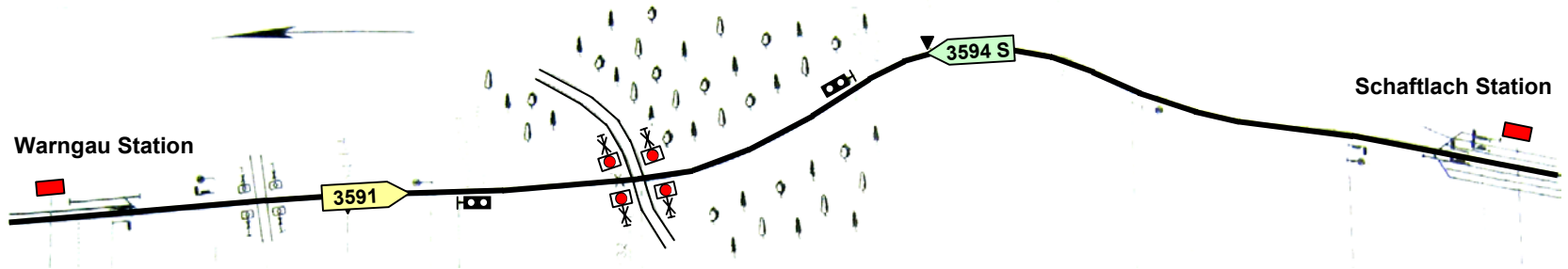
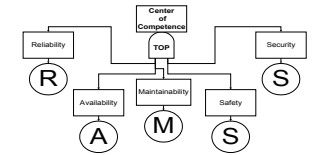
Departing from
Warngau StationDeparting from
Schaftlach Station

Warngau – 06-08-1975



Passing the contact for
activating the LC

Warngau – 06-08-1975

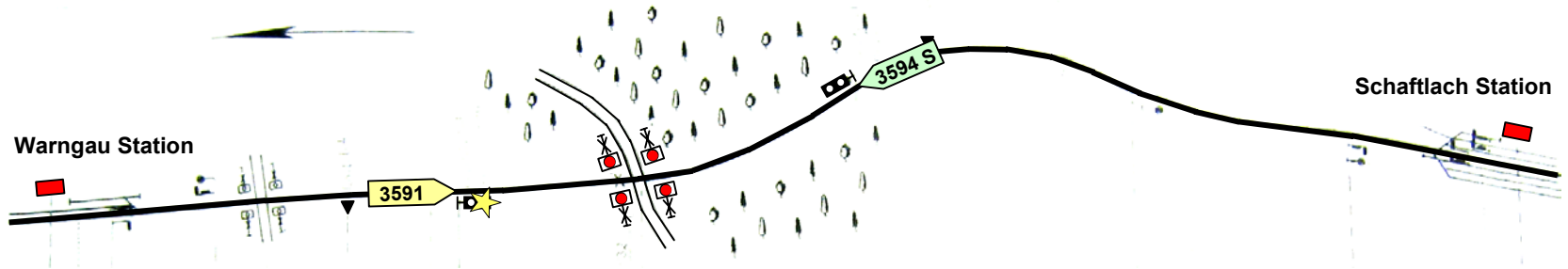
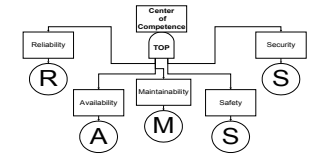


18:31:20

Train 3594 S

Passing the contact for
activating the LC

Warngau – 06-08-1975



18:31:30

Train **3591**

Passing Ü-Signal

Flashing light signal



LC protected



Passing LC



Train **3594 S**

Passing Ü-Signal

No flashing light signal



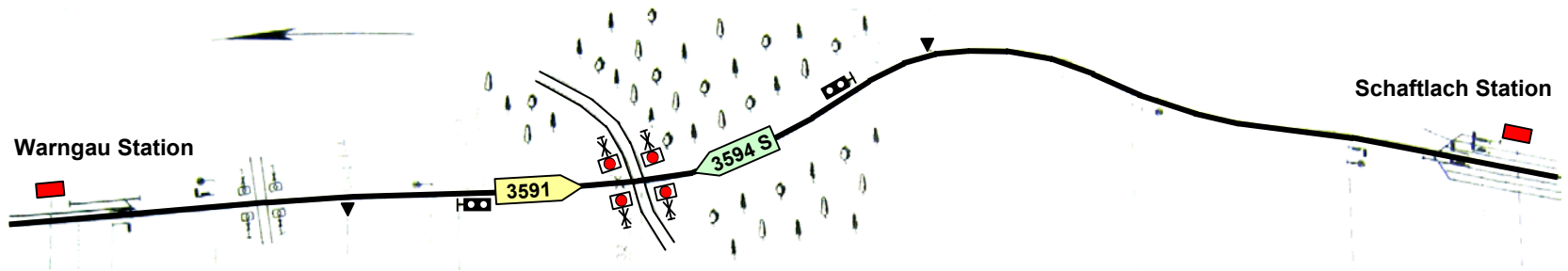
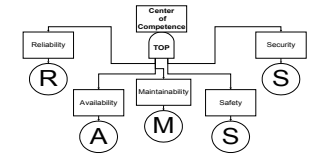
LC not protected



Stop in front of LC !



Warngau – 06-08-1975



18:31:53

Train **3591**

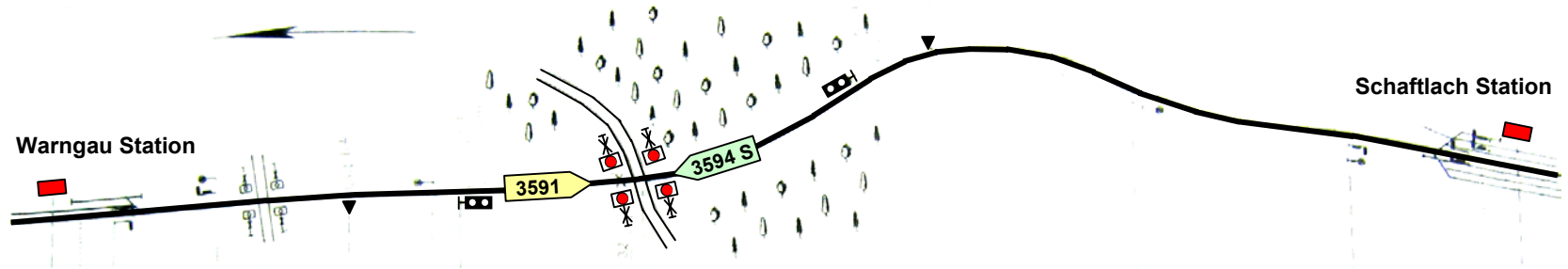
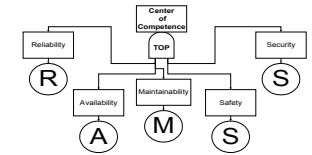
Recognizes oncoming
train



Full brake application



Warngau – 06-08-1975



18:31:54



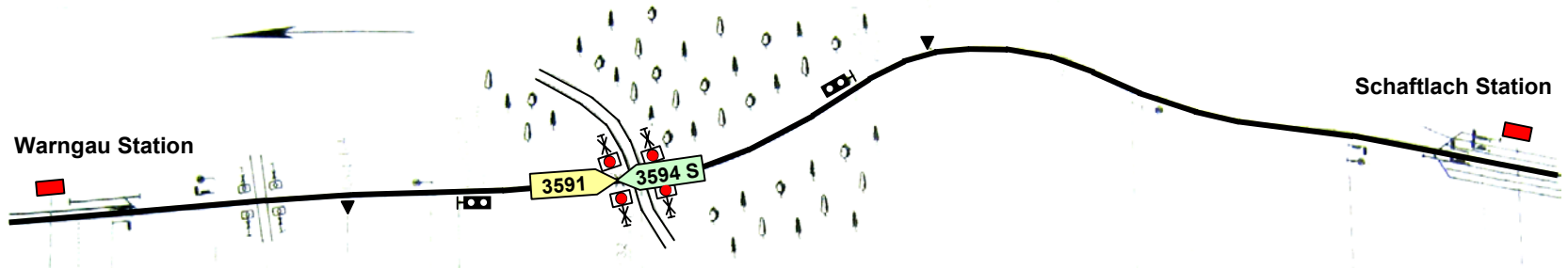
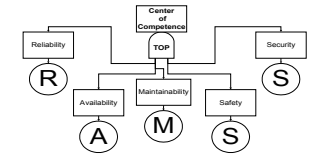
Train **3594 S**

Recognizes oncoming
train



Full brake application

Warngau – 06-08-1975



18:32

Train **3591**

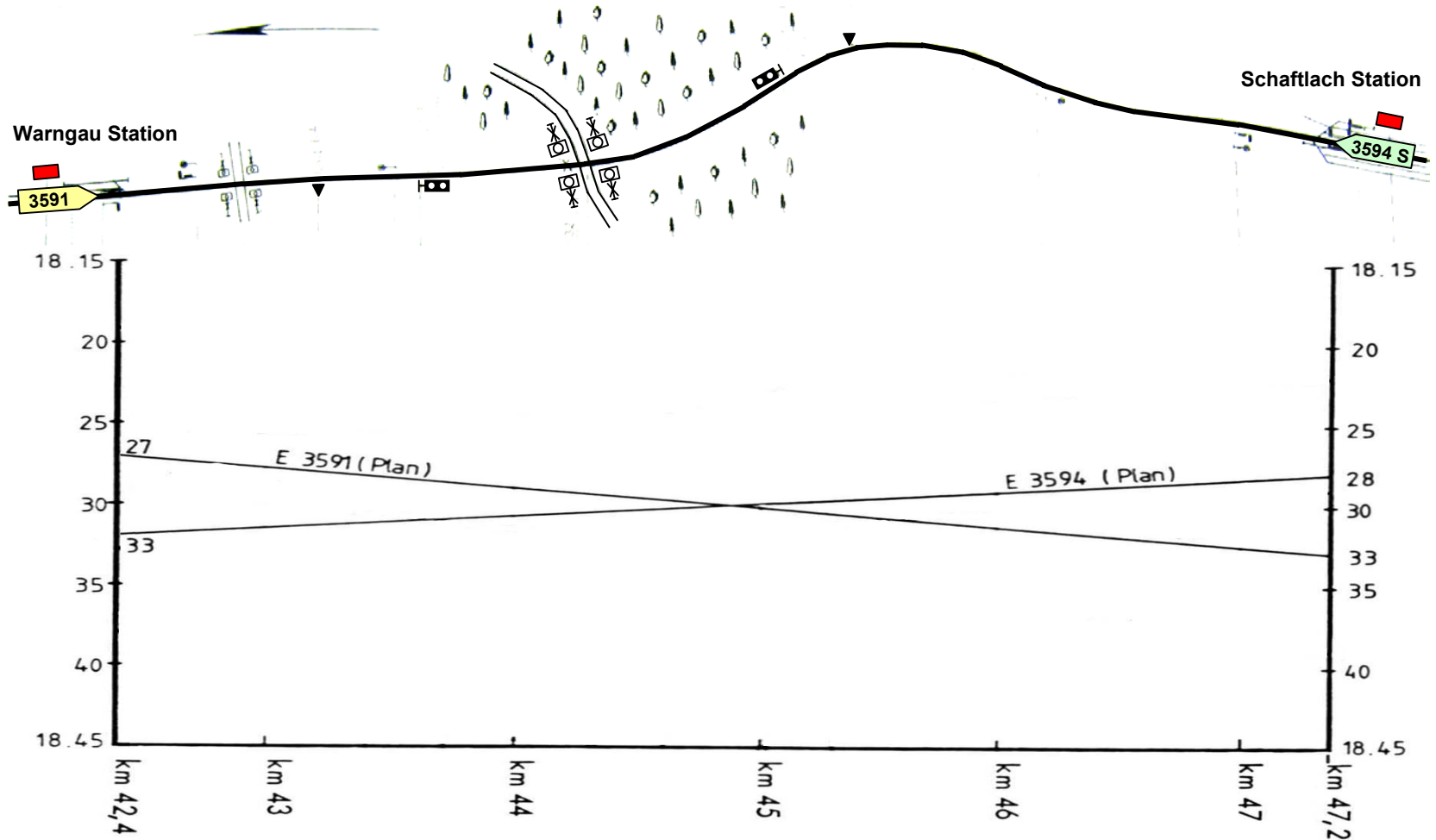
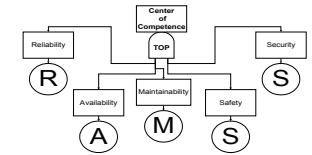
Head-on
collision



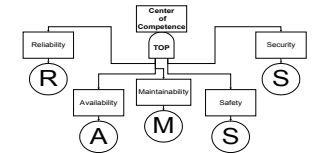
Train **3594 S**

Head-on
collision

Warngau – train diagram



Warngau, June 8th, 1975



Driver
3594 S

Drive
359Train
3594 STrain
359Trai
359

Operator
Schaftlach

Operator
Warngau 2

Operator
Warngau 1

June 8th
1975

12:00

18:20

18:28

18:29

18:32

TIME

SOL Analysis Contributing Factors

	Number of		Directly contributing Factor							Indirectly contributing Factor																			
Actor	EBBs	CFs	A	B	C	D	E	F	Σ	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Σ
Operator Warngau 1	1	2		1					1		1																		1
Operator Warngau 2	6	72 (29)	2	4	2	3	7		18	4	5	1	6	12	3		10		5	3			5						54
Operator Schaftlach	4	23 (6)		3		2	2		7				1	6			4		1	1			3						16
Train 3592	3	0							0																				0
Train 3591	5	8							0		1		1	2			1		1	1			1						8
Train 3594 S	3	7							0				1	2			1		1	1			1						7
Driver 3591	2	2					1		1														1						1
Driver 3594 S	3	0							0																				0
total	27	114	2	8	2	5	10	0	27	4	7	1	9	22	3	0	16	0	8	6	0	0	10	1	0	0	0	0	87
			Information	Communication	Working Conditions	Personal Performance	Violation	Technical Component		Information	Communication	Working Conditions	Personal Performance	Violation	Operation Scheduling	Responsibility	Control and Supervision	Group Influence	Rules, Procedures and Documents	Qualification	Training	Organization and Management	Feedback of Experience	Safety Principles	Quality Management	Maintenance	Bodies	Regulatory and Consulting	Environmental Influence

MES Chart

Warngau, June 8th, 1975

ACTORS

Driver
3594 S

Driver
3591

Train
3594 S

Train
3591

Train
3592

Operator
Warngau 2

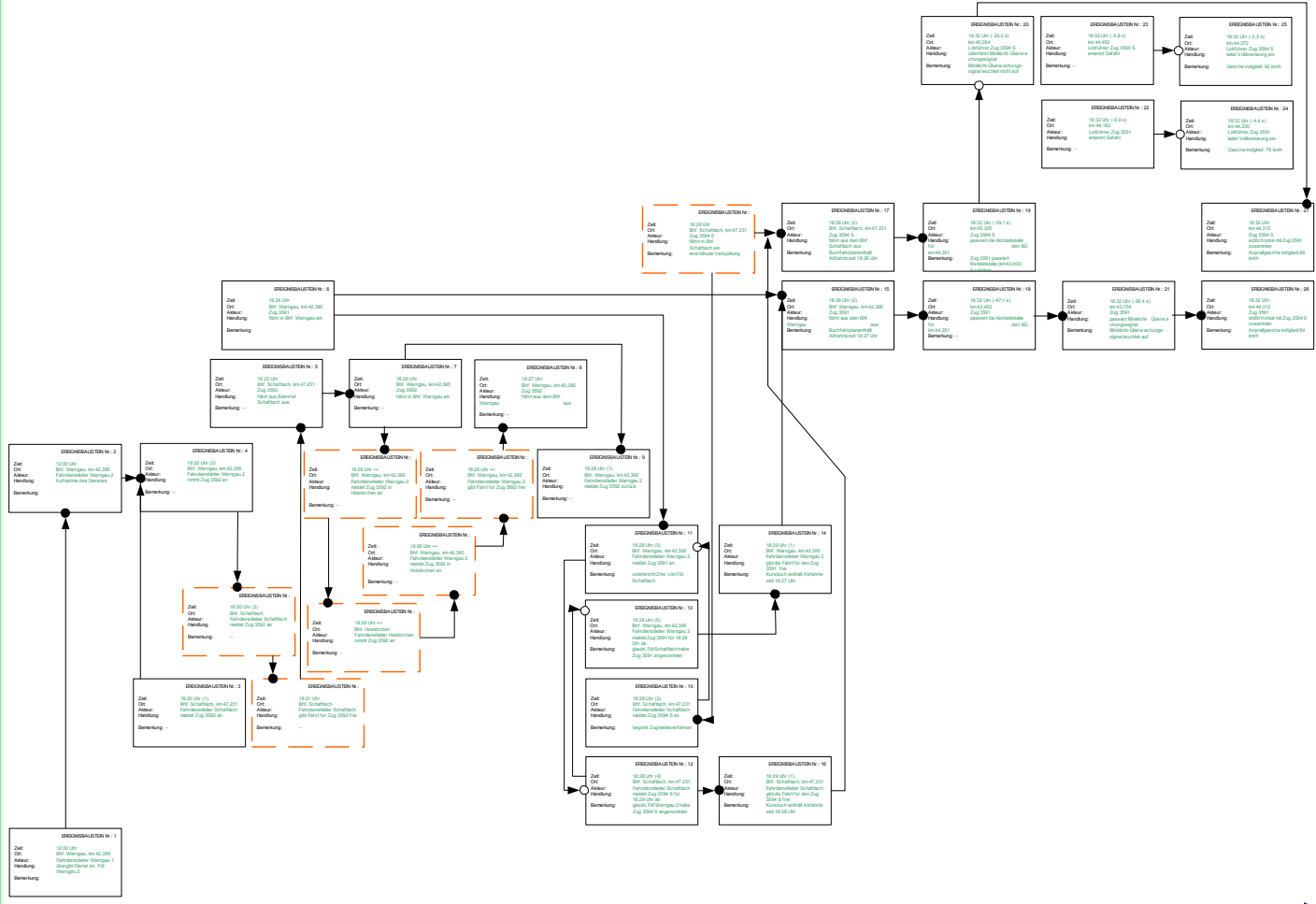
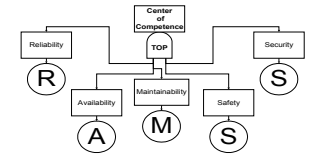
Operator
Schaftlach

Operator
Warngau 1

June 8th,
1975

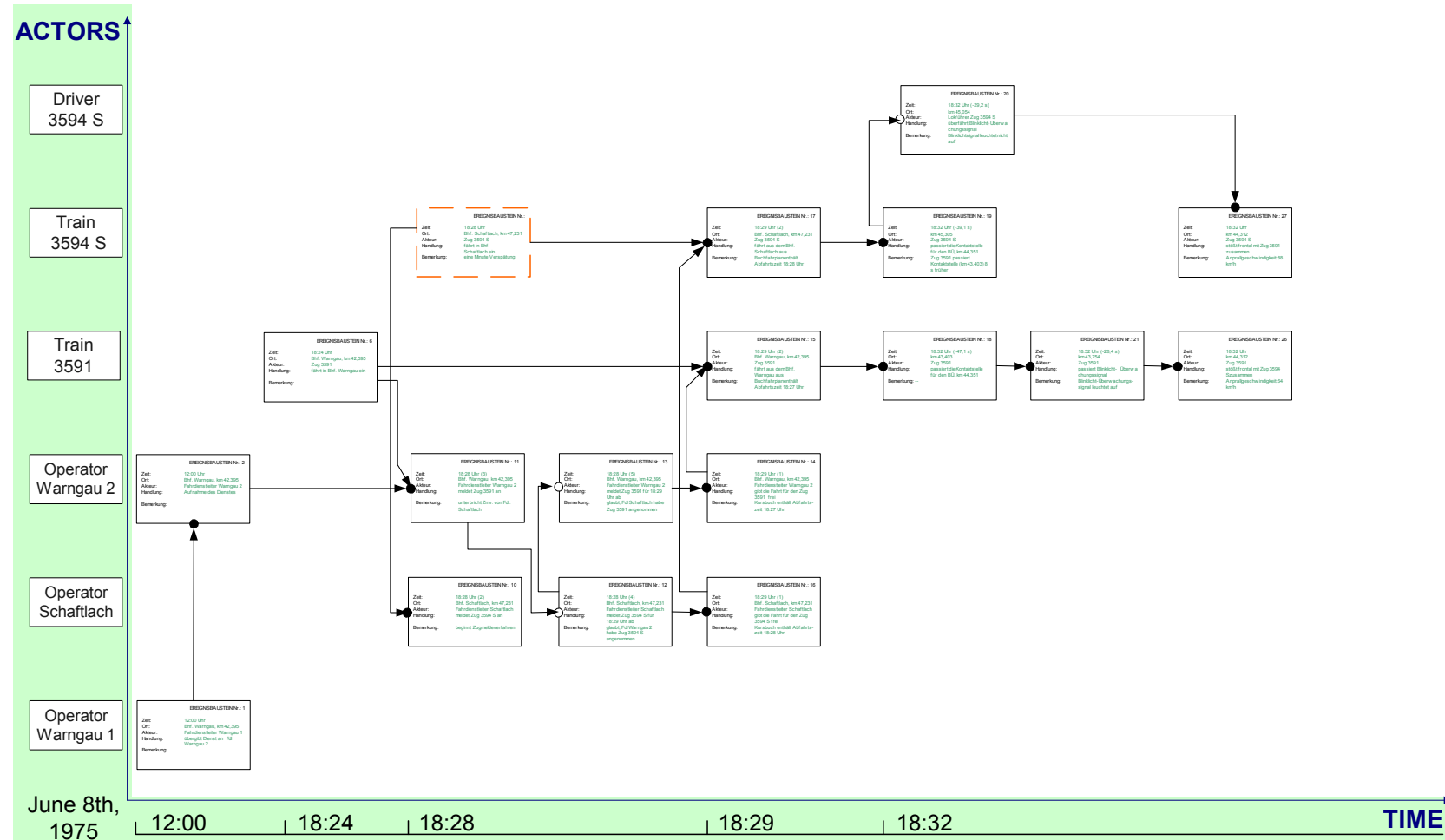
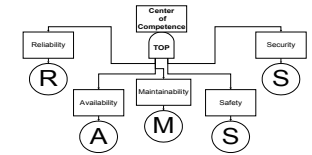
12:00 18:20 18:28 18:29 18:32

TIME



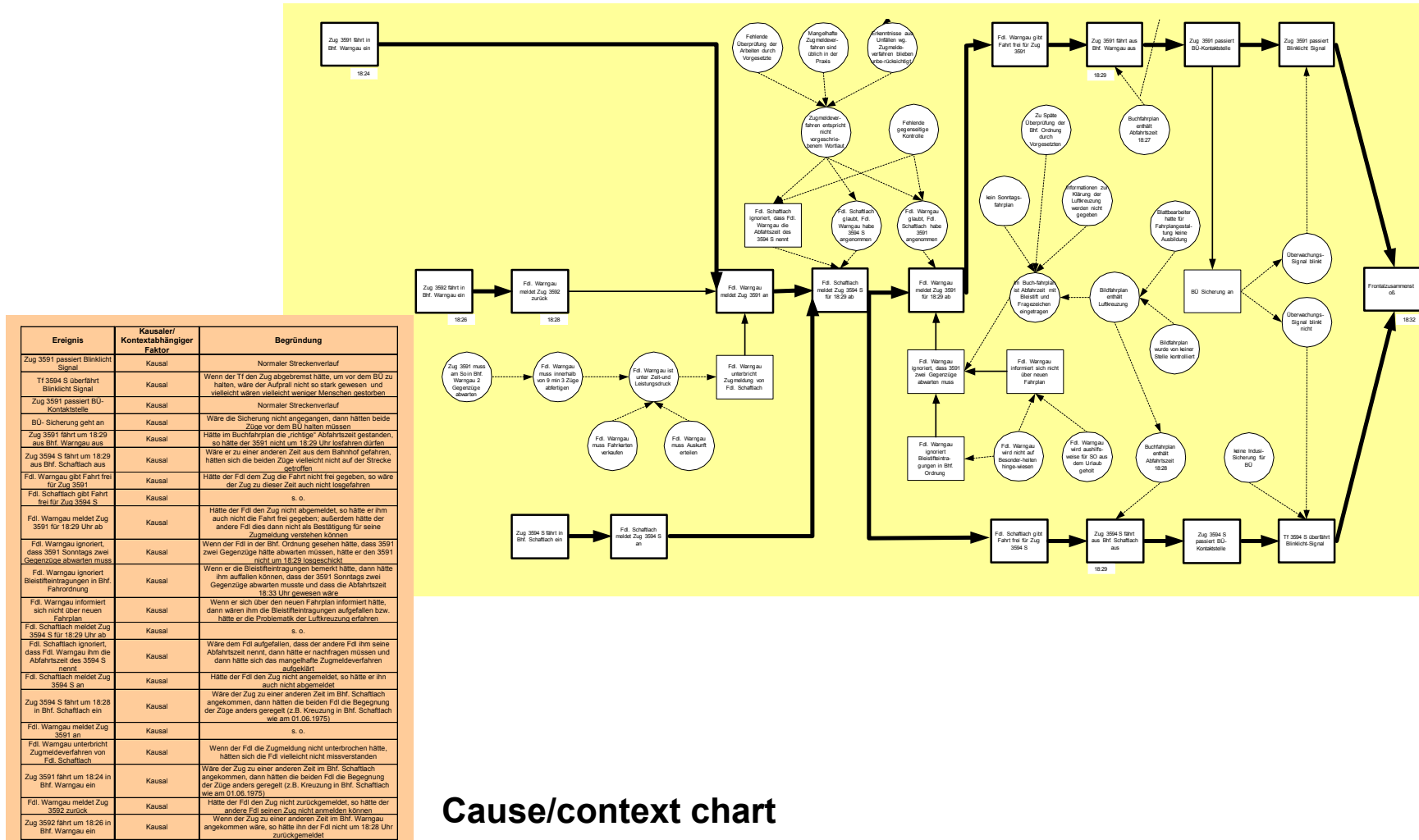
Final MES Chart

Warngau, June 8th, 1975



ECF Chart

Warngau, June 8th, 1975

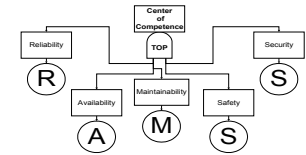


Cause/context chart

Strengths and Weaknesses

	Strengths	Weaknesses
SOL	■ Single timeline ■ Checklist for organisational factors based on experience ■ Commercial tool	■ No borderline between past events and contributing factors ■ Weak causal structure ■ Method not fully published
MES	■ Single timeline ■ Strict guidelines ■ Includes causal relations	■ Unclear whether organisational causes are covered ■ Non-events and states are not considered
ECF	■ Single timeline ■ Guidelines for EBBs ■ Causal reasoning	■ Causal reasoning not included in chart ■ Causal reasoning for events only

Conclusions and Way Forward



- Application of SOL, MES or ECF is helpful to understand what happened by illustrating events using a Time-Actor diagram.
- MES's causal reasoning process and ECF's linking of events help finding gaps in the initial description of what happened.
- SOL provides least formal means to illustrate causality.
- Only SOL categorizes “causal” factors and what's more it assists in finding them.
- ECF provides a more precise overview of “causal” factors compared to SOL and shows attempts to consider causal-linking of events.
- MES's causal reasoning process with its necessary and sufficient criteria makes it similar to WBA.
- MES with its reconstruction and illustration of what happened may be a very good entrance to causal analysis, which should be continued with adding WBA's states and non-events.