

# Intelligente Brücke

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Helmut WENZEL // Bundesanstalt für Straßenwesen, März 2018

## Monitoring von Brücken „von Daten zu Informationen“

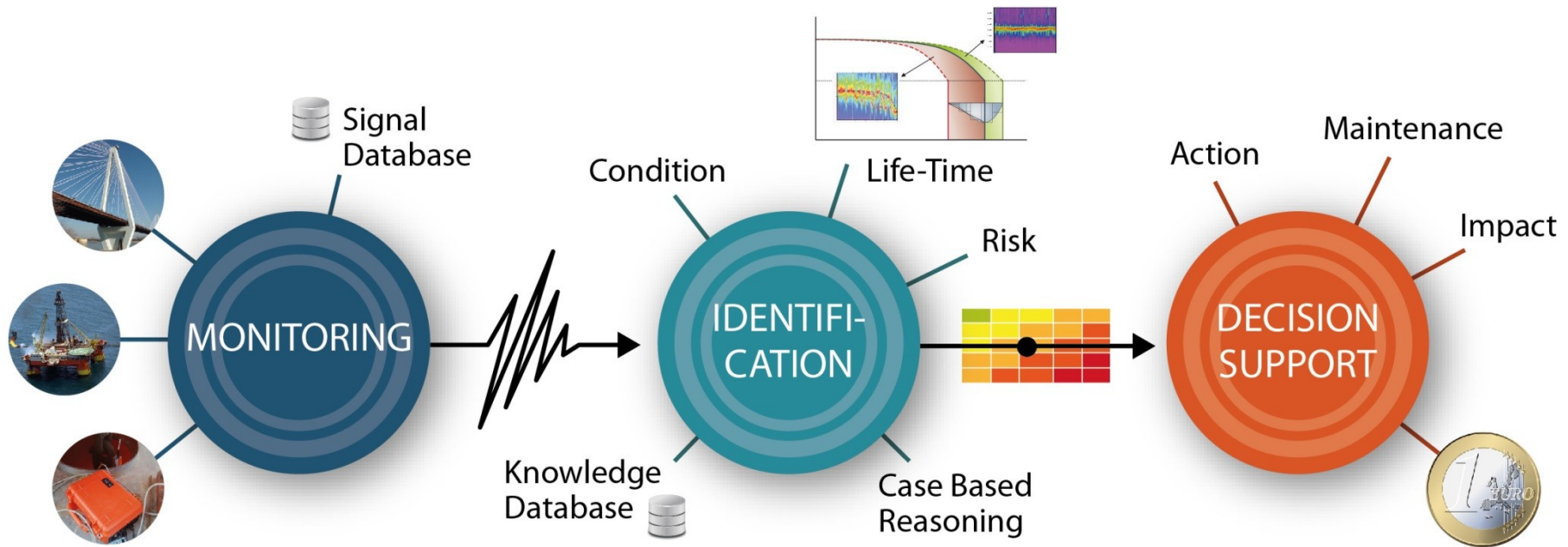


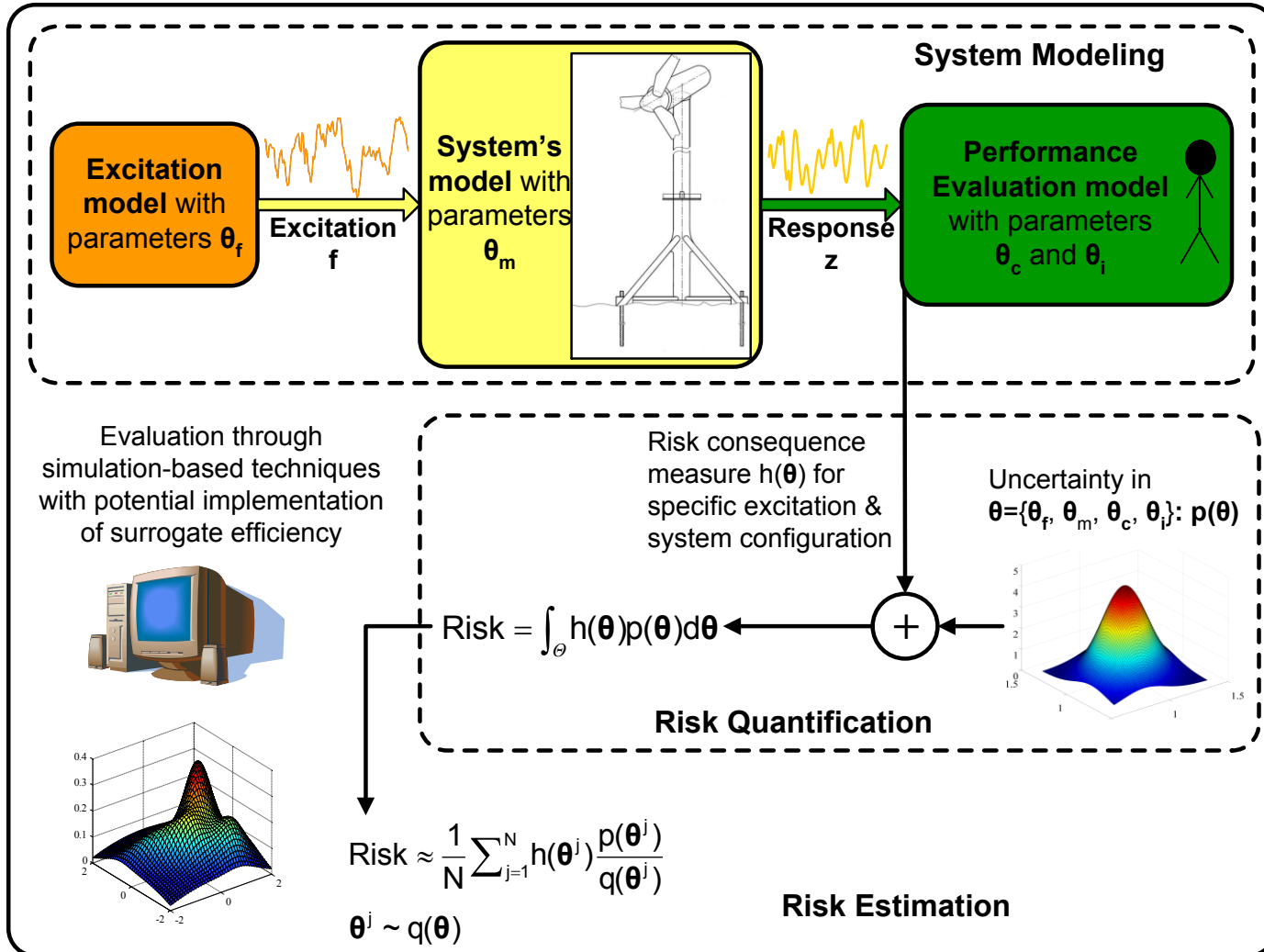
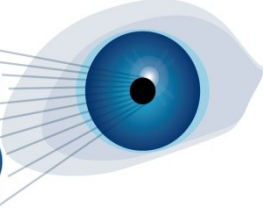
# Statement

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- » Brücken sind jeweils Prototypen
- » Daher kaum Standardlösungen vorhanden
- » Brückenmanagement muss das berücksichtigen
- » Achtung: Zwischen dem Stand der Technik und dem Stand der Wissenschaft und Technik ist zu unterscheiden
- » Monitoring ist kein Spielzeug mehr
- » Richtig angewandt erhöht es die Qualität erheblich
- » Daten und Auswertungen sind nur ein Baustein
- » Algorithmen bringen den Wert
- » Ergebnissen müssen einfach verständlich sein
- » Daten bleiben, Algorithmen wachsen

# Typischer Prozess





# Begrifflichkeiten

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- » Jedes Modell benutzt **Parameter**
- » **Daten** definieren Parameter
- » Relevante Parameter nennen wir **Indikatoren**
- » Indikatoren beschreiben zB. den **Zustand (Index)**
- » Oder das **Verhalten (Performance)**
- » Dies ermöglicht **Prognosen**
- » Und verbessert das **Brückenmanagement**
- » Risiko basierte, optimierte **Entscheidungen** werden möglich
- » Lösungen gibt es bereits auf **Flottenebene** bis herunter zur den **Elementenebene** einer Brücke

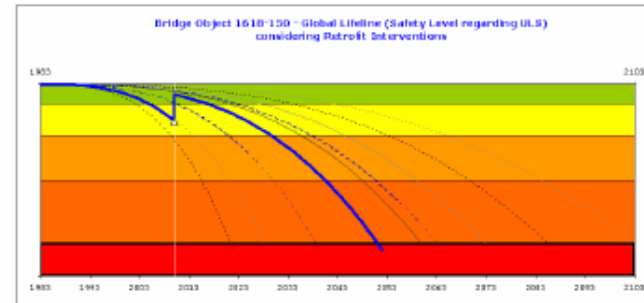
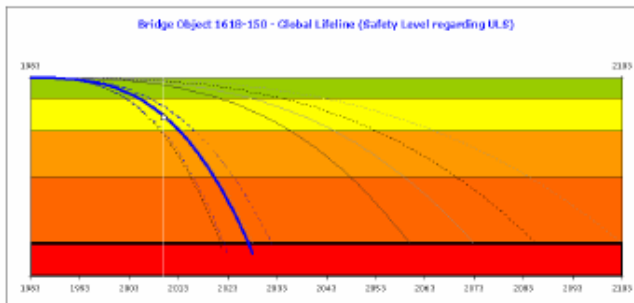
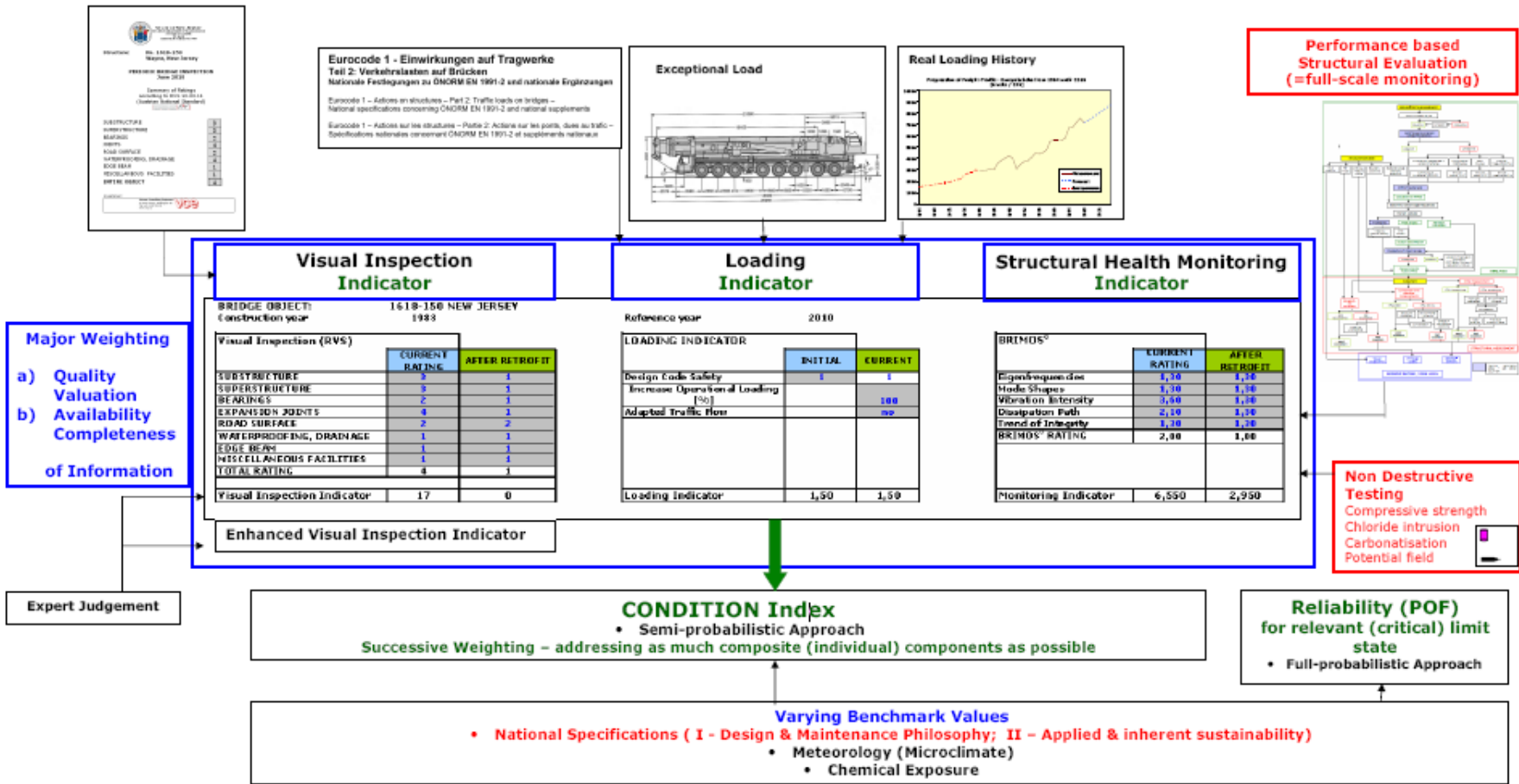
# Umsetzung in den USA im NBI Portal (620000 Brücken)

Modell aus 198 Faktoren mit zugeordneten Unsicherheiten



Wichtig: Qualität der Daten berücksichtigen (data quality index)

# Schema: BRIMOS Life Cycle Analysis

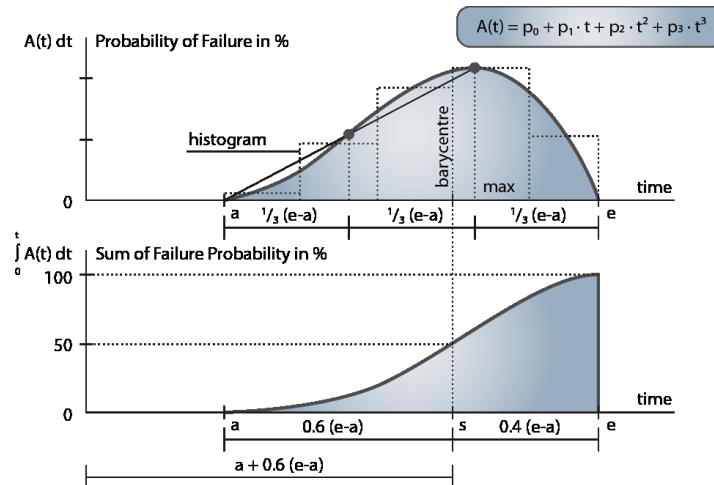
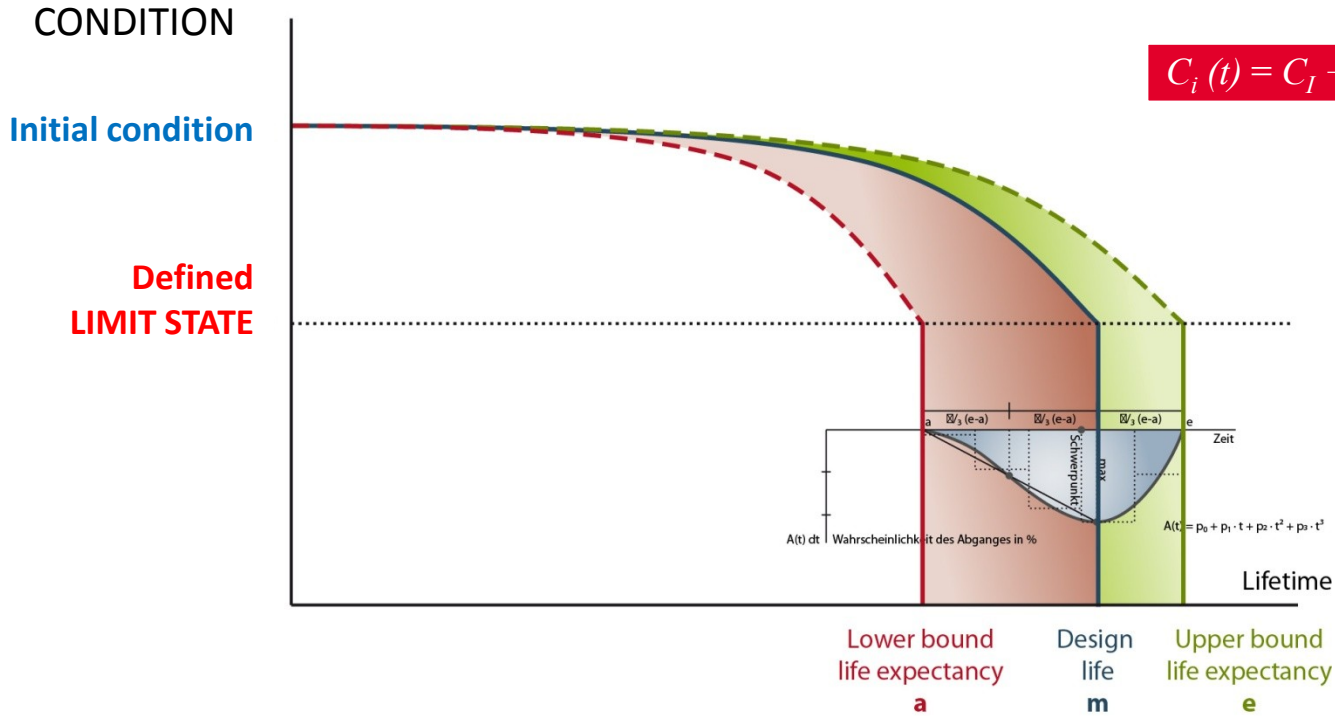


# Ageing model

Structural ageing

CEN/WS 063 / CWA 16633:2013

“Ageing behaviour of Structural Components”





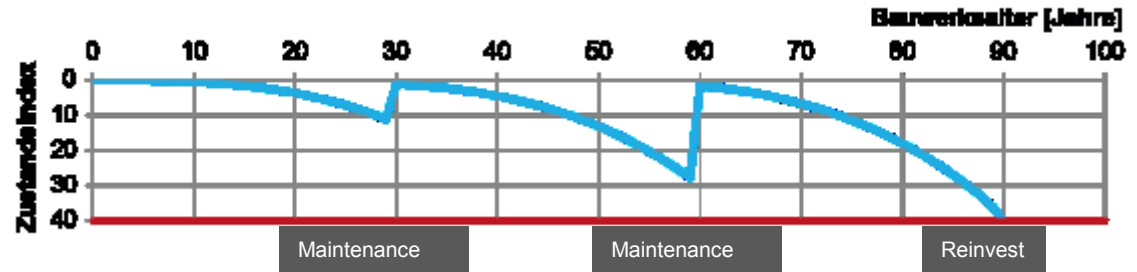
**Motivation:** Supporting the decision process of strategic, integrated Asset Management on a technically & empirically well-founded basis

=> Structure Specific Ageing Models & corresponding Cost Models

**Ageing – target progress**

Service life = 90 years

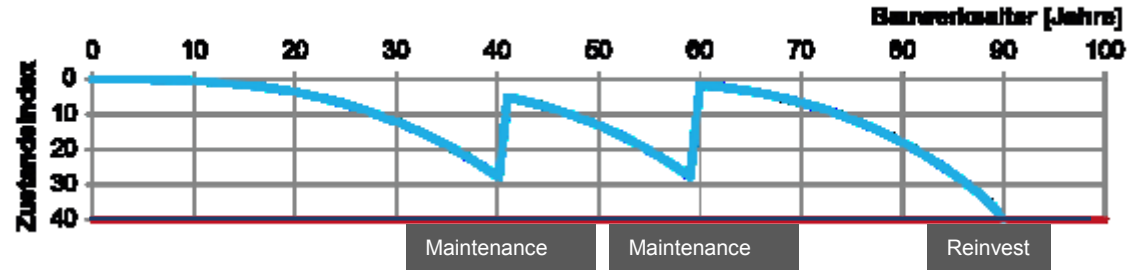
Optimal life-cycle costs



**Ageing – delayed maintenance**

Service life = 90 years

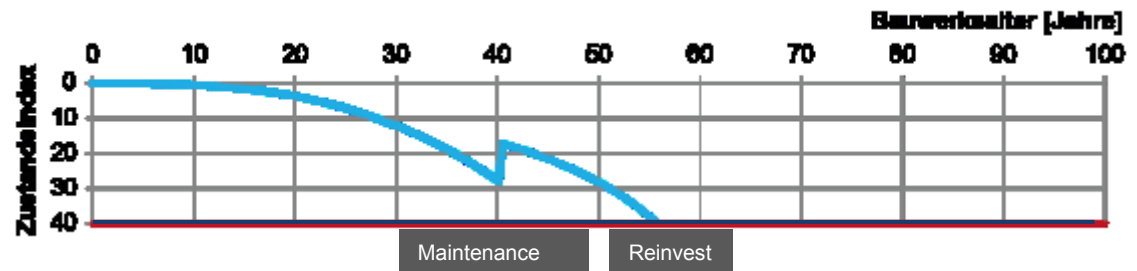
Higher life-cycle costs



**Ageing – delayed maintenance**

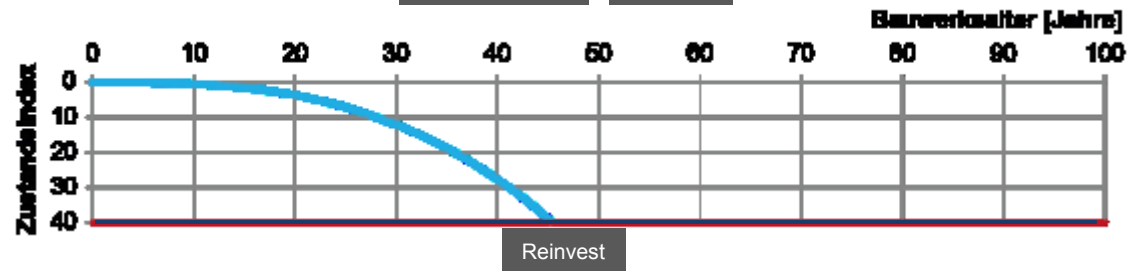
Reduced service life –  
premature reinvestment

Same use of resources as in  
optimal case

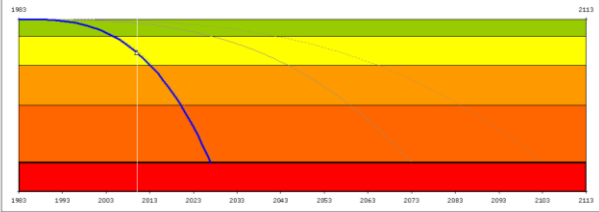


**Ageing – “do-nothing”-  
strategy**

Reduced service life –  
premature reinvestment

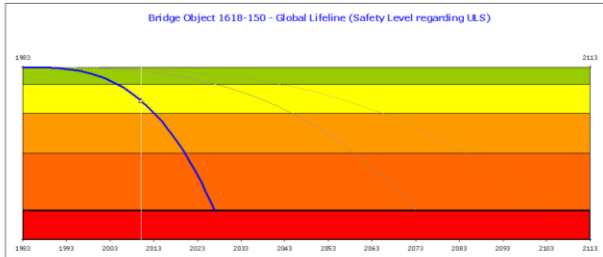


Bridge Object 1618-150 - Global Lifeline (Safety Level regarding LLS)



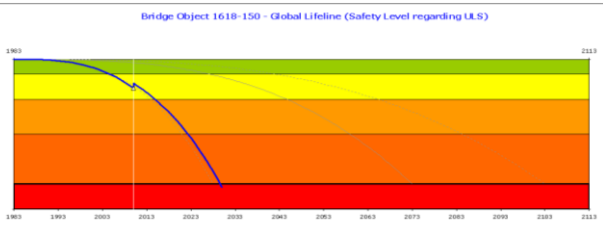
REMAINING LIFE
<b>16</b>

**DO-NOTHING STRATEGY**



REMAINING LIFE
<b>16</b>

**DO-NOTHING STRATEGY**



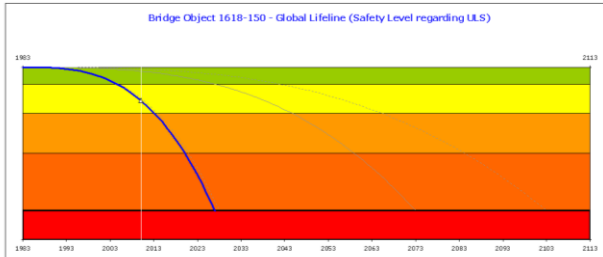
REMAINING LIFE
<b>19</b>

**Substructure:**

Renewal of corrosion protection, Repair of spallings, holes and concrete pockets, removal of contamination of the concrete surface, Deep injection of cracks

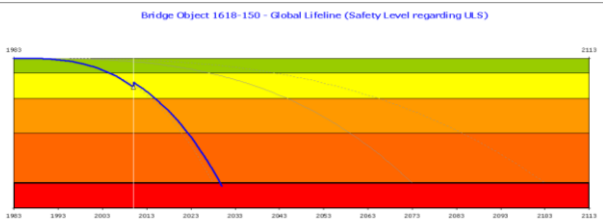
**Dewatering:**

Establishing of an effective drainage concept



REMAINING LIFE
<b>16</b>

## DO-NOTHING STRATEGY



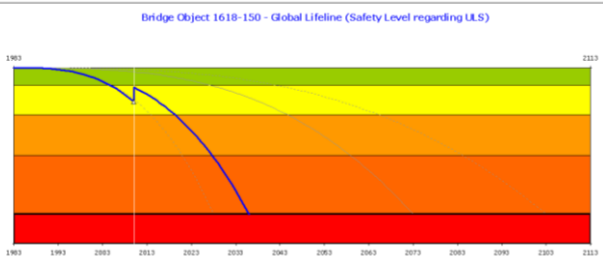
REMAINING LIFE
<b>19</b>

### Substructure:

Renewal of corrosion protection, Repair of spallings, holes and concrete pockets, removal of contamination of the concrete surface, Deep injection of cracks

### Dewatering:

Establishing of an effective drainage concept



REMAINING LIFE
<b>25</b>

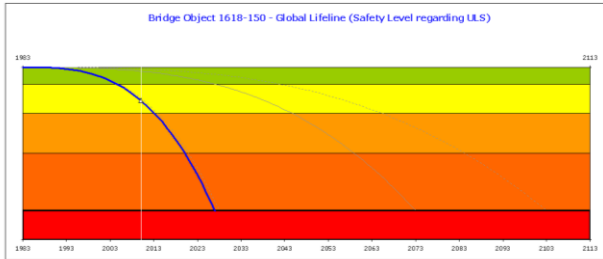


### Expansion Joints:

Proper detailing & design

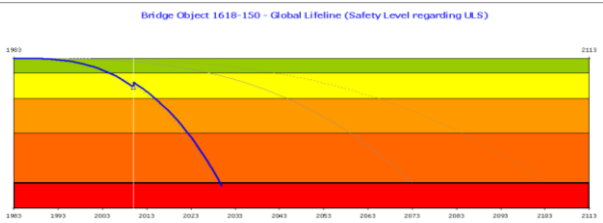
⇒ Full replacement (abutment area)

⇒ Partial replacement (at least seals above the piers)



REMAINING LIFE
<b>16</b>

## DO-NOTHING STRATEGY



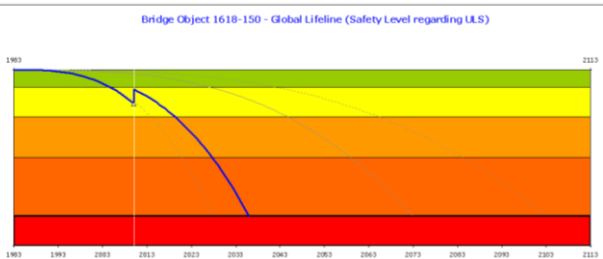
REMAINING LIFE
<b>19</b>

### Substructure:

Renewal of corrosion protection, Repair of spallings, holes and concrete pockets, removal of contamination of the concrete surface, Deep injection of cracks

### Dewatering:

Establishing of an effective drainage concept



REMAINING LIFE
<b>25</b>

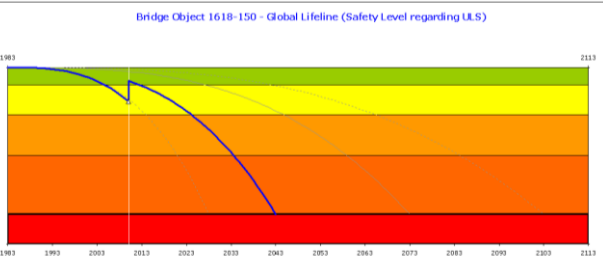


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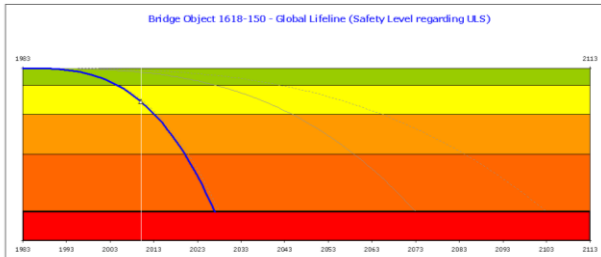


REMAINING LIFE
<b>32</b>



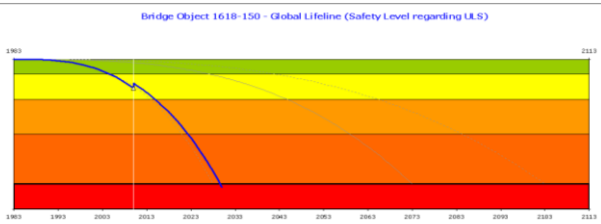
### Superstructure:

Renewal of corrosion protection, Repair of the concrete surface, fatigue cracks, Repair of corroded stringers, Replacement of wind bracings



REMAINING LIFE
<b>16</b>

## DO-NOTHING STRATEGY



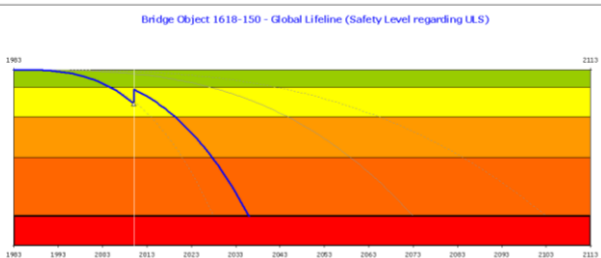
REMAINING LIFE
<b>19</b>

### Substructure:

Renewal of corrosion protection, Repair of spallings, holes and concrete pockets, removal of contamination of the concrete surface, Deep injection of cracks

### Dewatering:

Establishing of an effective drainage concept



REMAINING LIFE
<b>25</b>

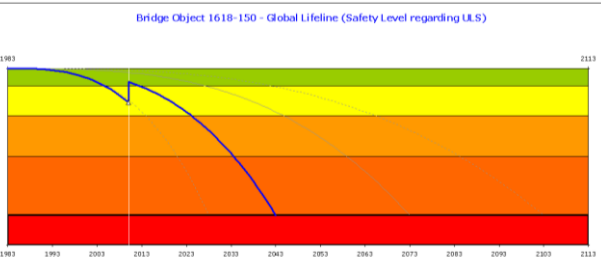
+

### Expansion Joints:

Proper detailing & design

⇒ Full replacement (abutment area)

⇒ Partial replacement (at least seals above the piers)

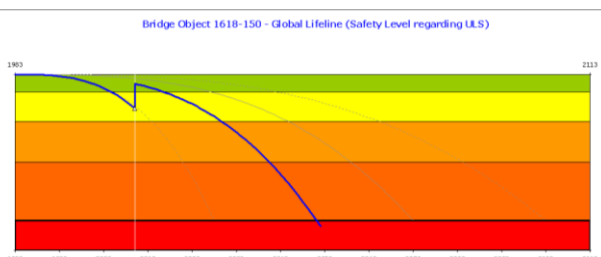


REMAINING LIFE
<b>32</b>

+

### Superstructure:

Renewal of corrosion protection, Repair of the concrete surface, fatigue cracks, Repair of corroded stringers, Replacement of wind bracings



REMAINING LIFE
<b>41</b>

+

### Bearings:

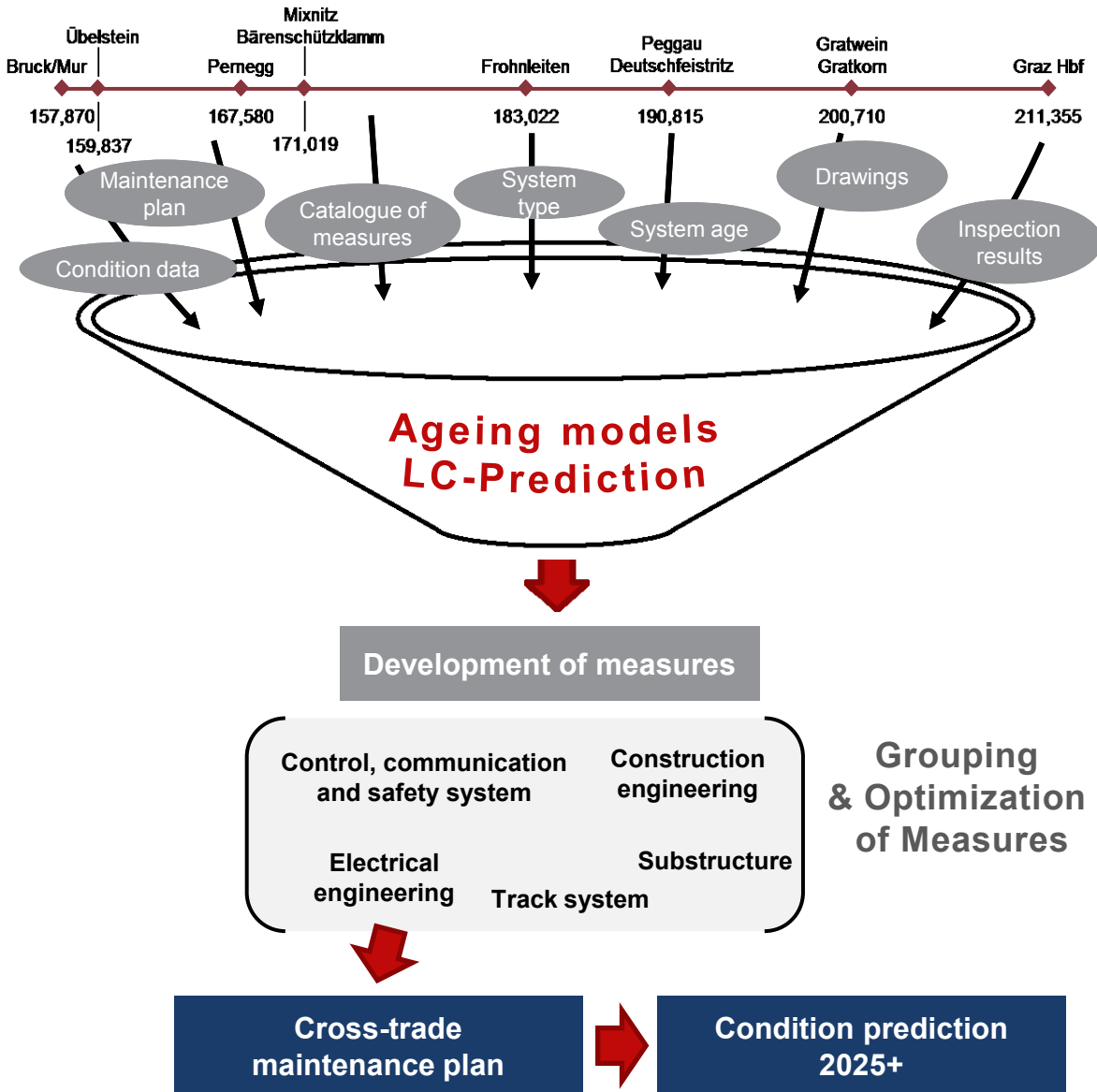
proper replacement of the bearings

### Book-Publication:

**“IRIS-Industrial Safety & Life Cycle Engineering”**

Publisher: VCE Vienna Consulting Engineers ZT GmbH,  
Vienna - Austria, 08/2013; ISBN: 978-3-200-03179-1

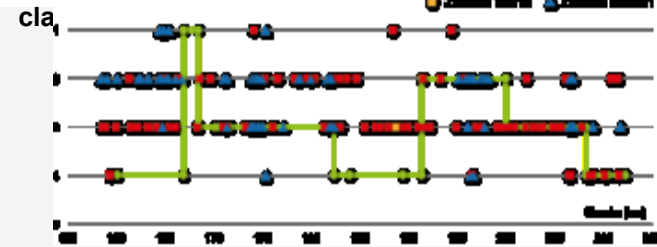
# LCM model VCE/ÖBB



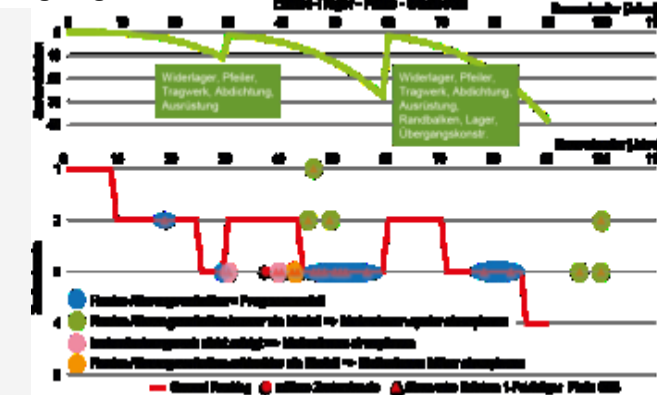
## Input data



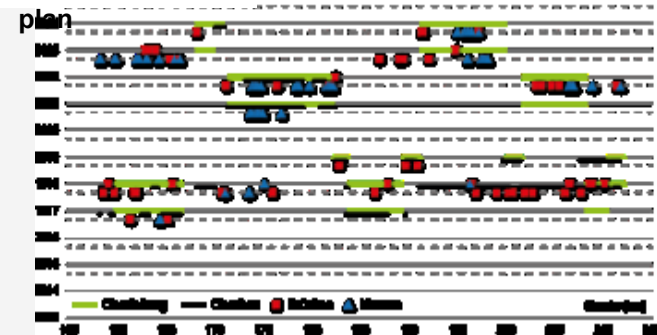
## Co

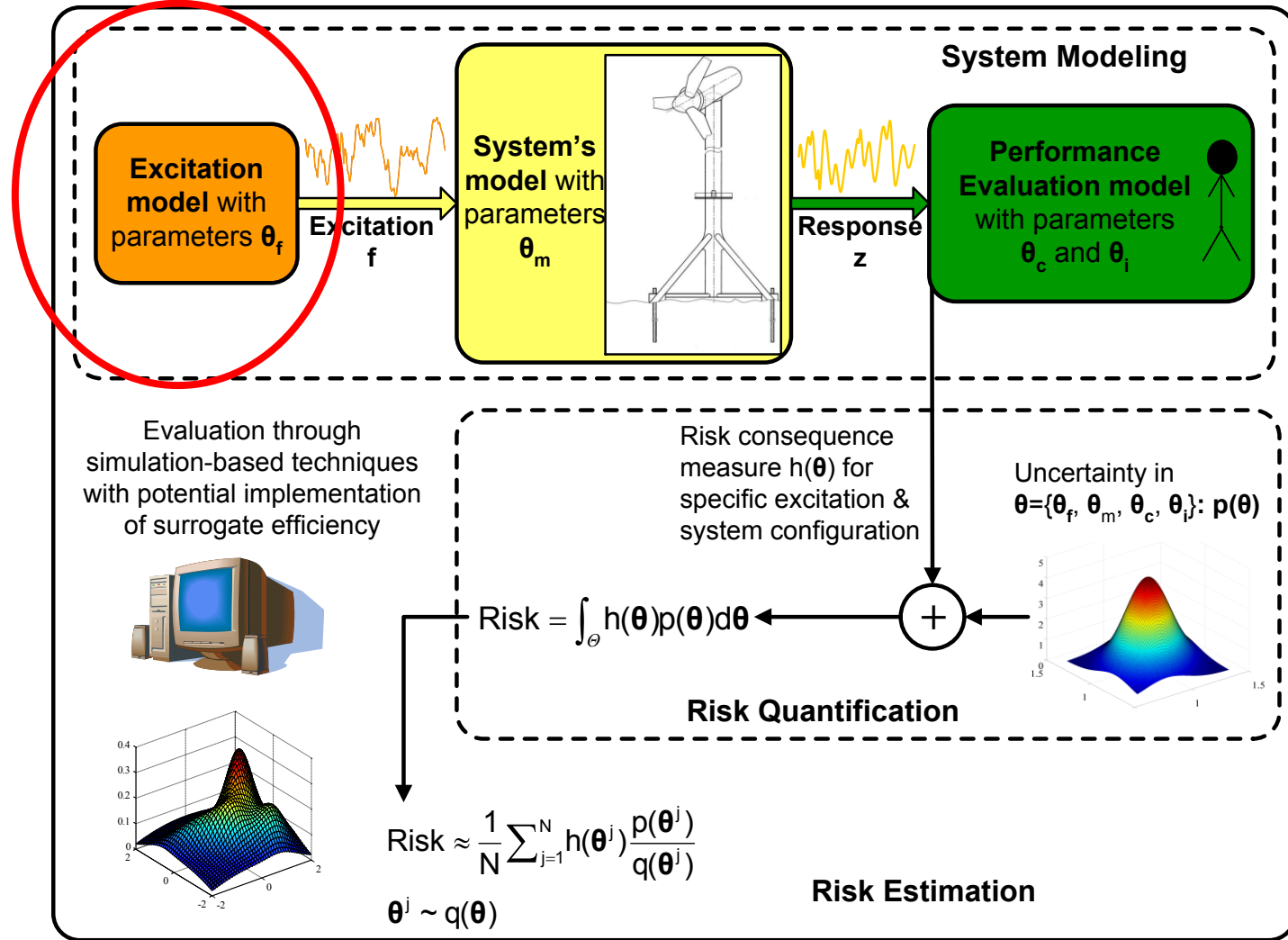
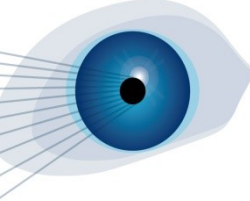


## Ageing models



## Maintenance plan







# Lokaler Transport (kein Gigaliner)

Aswan Bridge / Jan. 2013

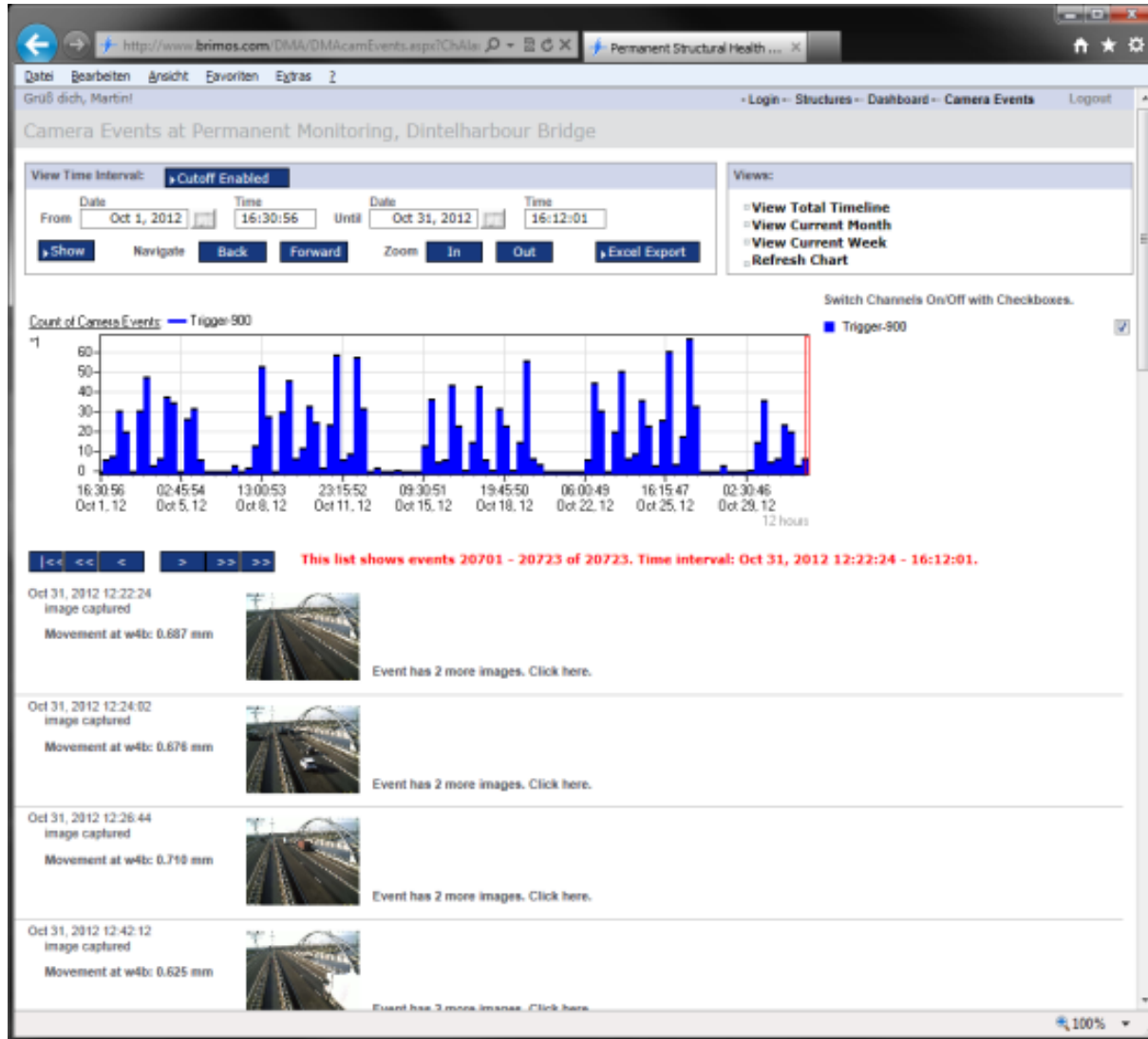


# Vergleich von Lastkollektiven mit der Norm

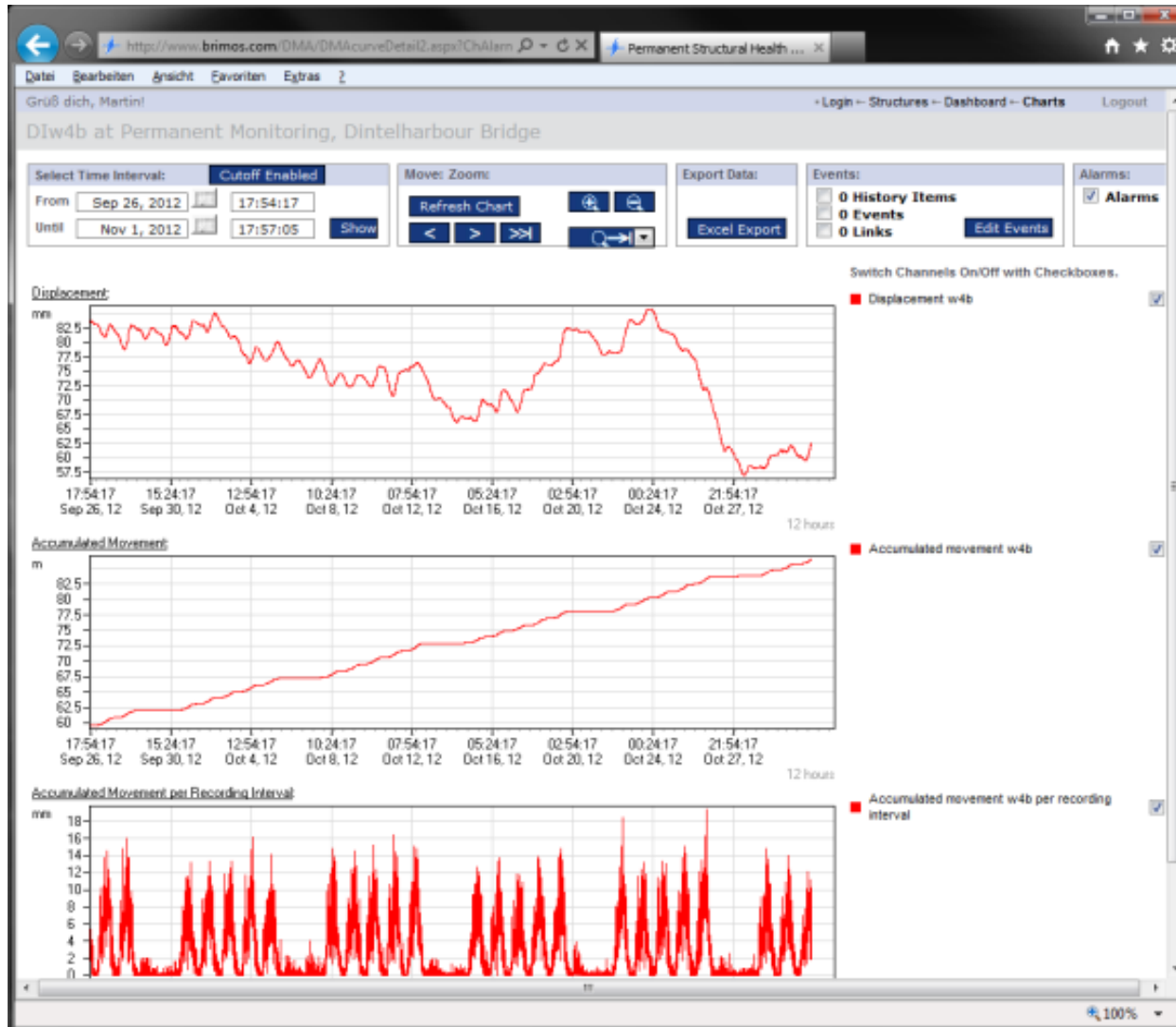
## Dintelhavenbrücke (Holland)



# Dintelhaven Monitoring: Load Collectives

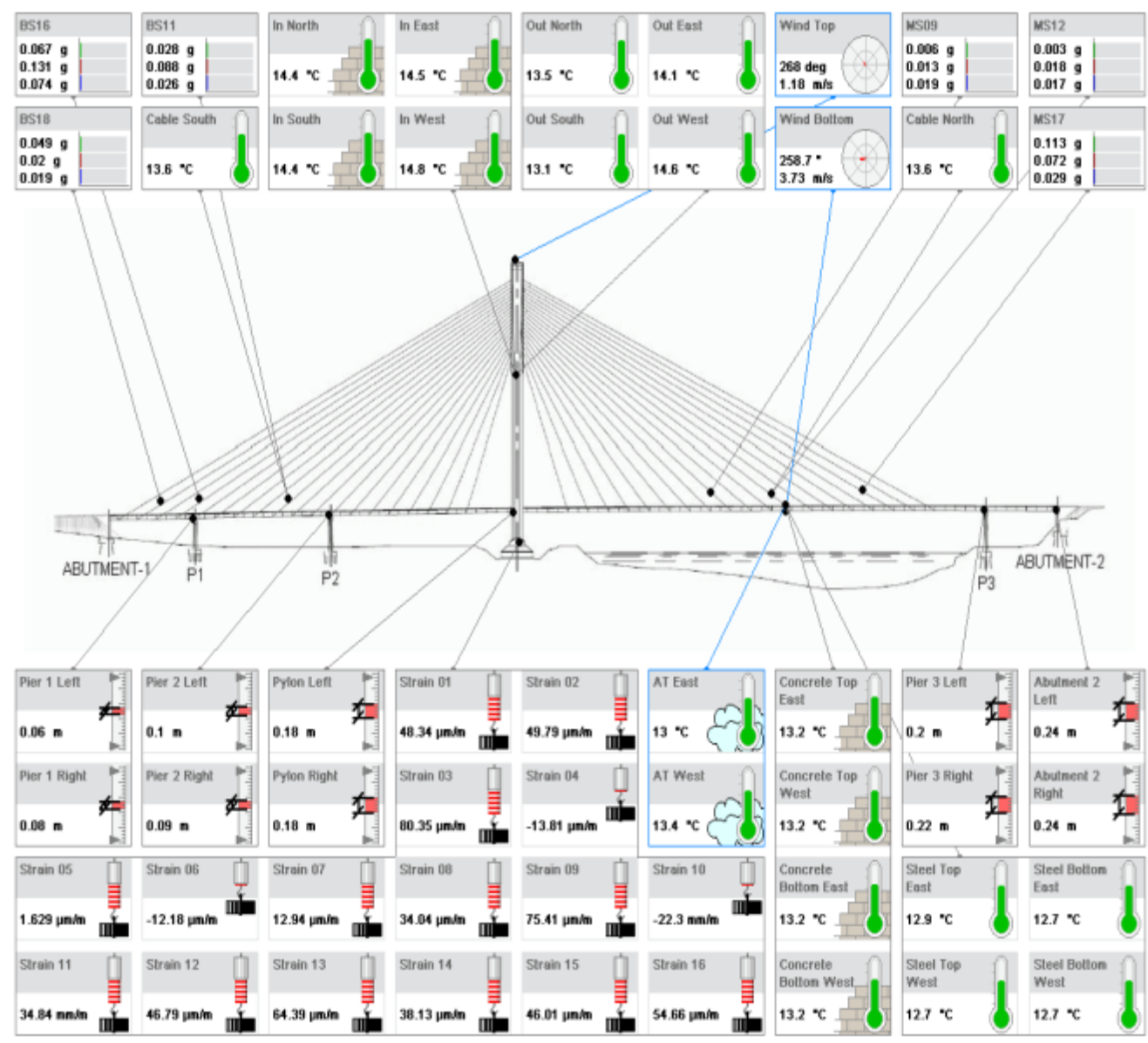


# Incheon (KR) Monitoring: Displacement Collectives



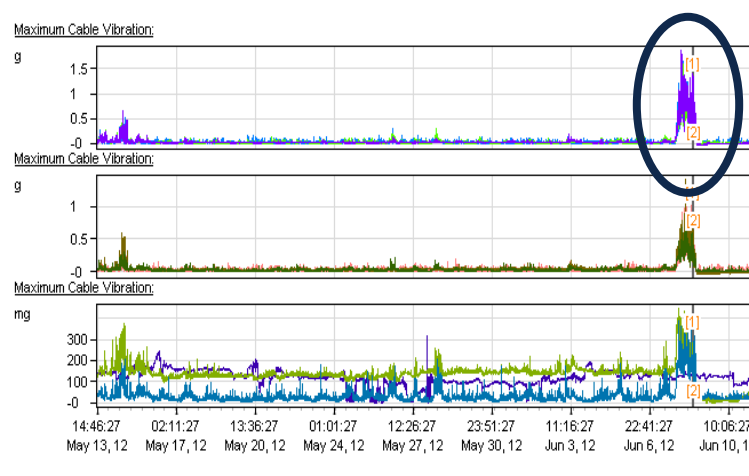
# Lasten an Schrägseilen, Waterford, Irland





Select Time Interval: From May 13, 2012 14:46:27 Until Jun 13, 2012 14:42:50 Show

Move: Refresh Chart Zoom: Excel Export



7-Zip Dateimanager

File Edit View Favorites Extras ?

Hinzufügen Entpacken Überprüfen Kopieren Verschieben Löschen Eigenschaften

C:\Users\Furtner\AppData\Local\Temp\brimosdata\_20120613\_144423.zip\

Name	Größe	Gepackte Größe	Geändert am	Erstellt am	Letzter Zugriff	Att
brimosdata_20120613_144423.WATERFORD-CV.csv	1 624 850	482 990	2012-06-13 14:44			
brimosdata_20120613_144423.WATERFORD-STAT.csv	2 901 977	806 984	2012-06-13 14:44			
brimosdata_20120613_144423.WATERFORD-STRAIN.csv	1 415 673	475 274	2012-06-13 14:44			

brimosdata\_20120613\_144423.WATERFORD-CV.csv - Microsoft Excel

File Start Einfügen Seitenlayout Formeln Daten Überprüfen Ansicht

Calibri 11

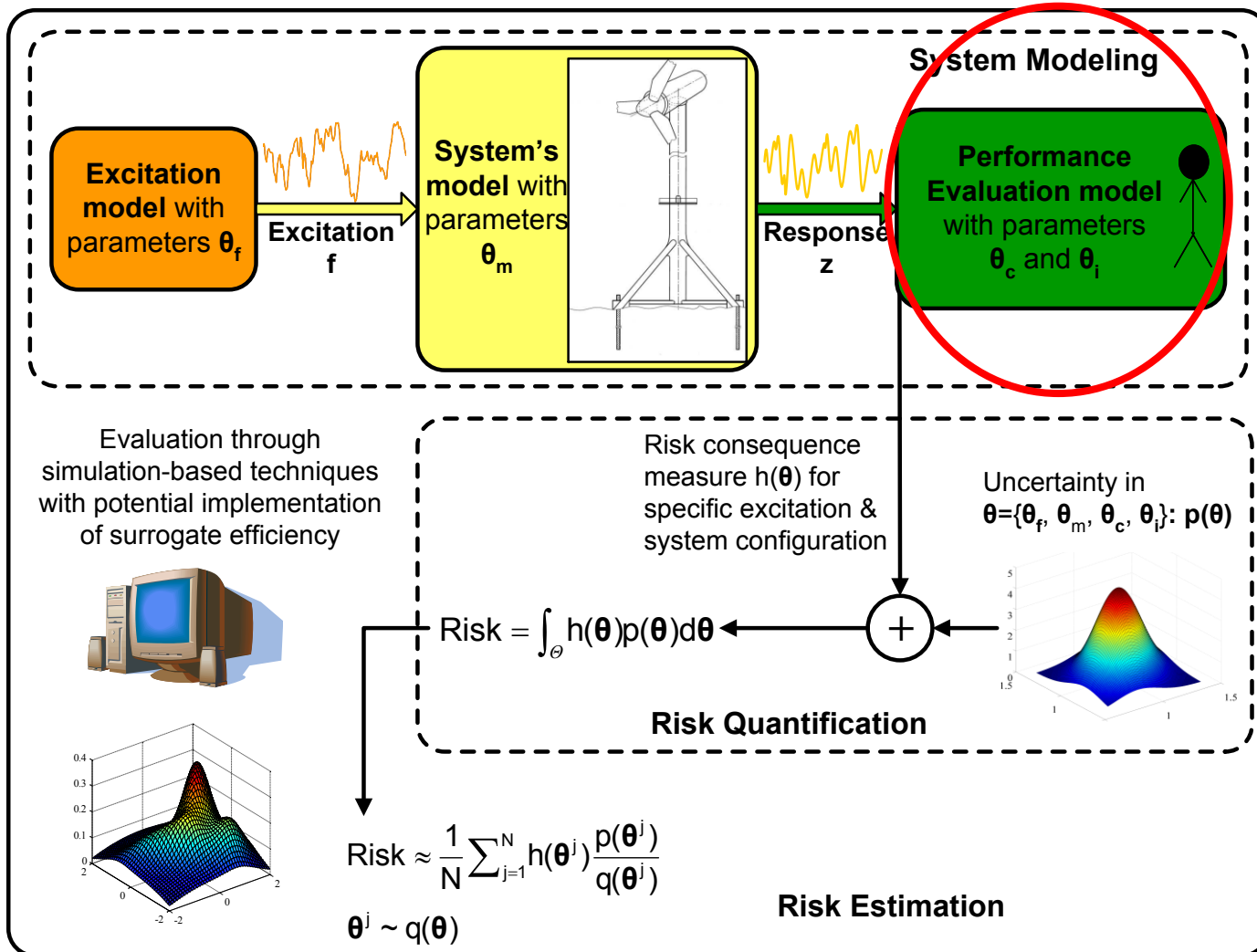
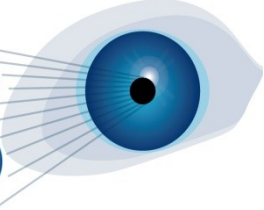
Standard % 000

Bedingte Formatierung Als Tabelle formatieren Zellenformatvorlagen

Einfügen Löschen Format Zellen Sortieren und Filtern

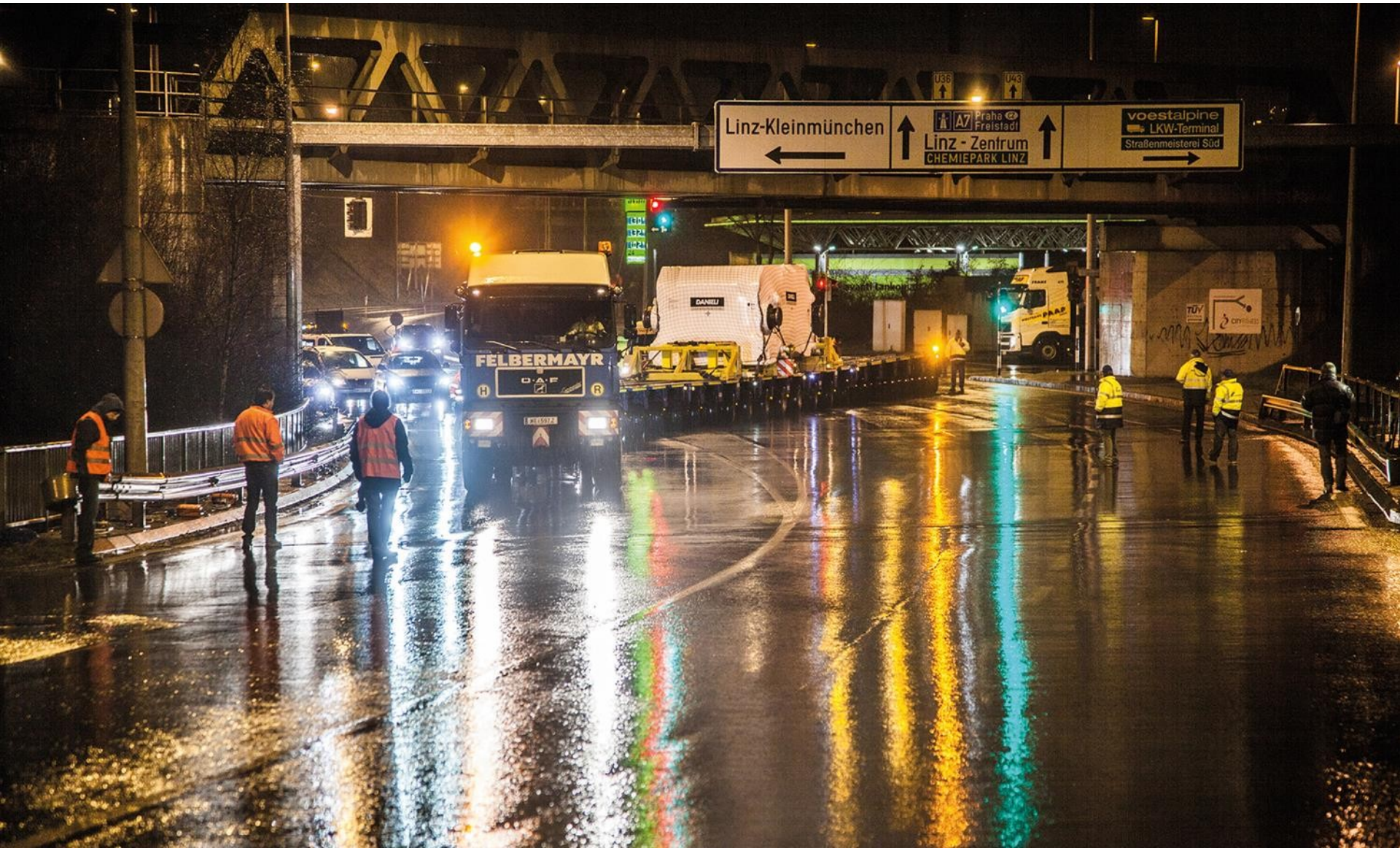
1 Objekt(e) ma

A1	# section: header									
	A	B	C	D	E	F	G	H	I	J
1	# section: header									
2	# filetype: CSV-File									
3	# creator: db2image V2.0beta35a 18.Mai.2012									
4	# object: WATERFORD									
5	# project: DMA									
6	#									
7	#									
8	# section: measurements									
9	# channelgroup: WATERFORD-CV									
10	# units: s									
11	# columns: timeIndex	g	g	g	g	g	g	g	g	g
12	# data:									
13	13.05.2012 14:46	0,044115	0,125661	0,042098	0,005927	0,120198	0,040066	0,041735	-0,000968	0,013298
14	13.05.2012 14:51	0,061635	0,171083	0,031067	0,004629	0,103165	0,022546	0,063399	0,013794	0,010865
15	13.05.2012 14:57	0,024486	0,112683	0,021171	0,041454	0,108032	0,037146	0,044123	0,000168	0,018327
16	13.05.2012 15:02	0,082399	0,126797	0,065296	0,011605	0,105923	0,025953	0,053028	0,011686	0,031792
17	13.05.2012 15:12	0,081588	0,11609	0,046316	0,0653	0,146154	0,092788	0,039186	0,002439	0,013623
18	13.05.2012 15:18	0,027082	0,143181	0,071623	0,0215	0,117116	0,084191	0,055426	0,017363	0,026601
19	13.05.2012 15:23	0,044277	0,136043	0,130996	0,071789	0,108032	0,028062	0,053866	0,008441	0,013461
20	13.05.2012 15:29	0,065204	0,147561	0,038691	0,134731	0,226454	0,13383	0,071158	0,029854	0,013461
21	13.05.2012 15:34	0,014753	0,09565	0,04226	0,065138	0,219802	0,179902	0,06163	0,011037	0,052394
22	13.05.2012 15:40	0,110951	0,20807	0,123047	0,070491	0,119063	0,060831	0,067659	0,011361	0,018976
23	13.05.2012 15:45	0,076722	0,145452	0,091089	0,007711	0,102678	0,041364	0,075533	0,016877	0,013947
24	13.05.2012 15:51	0,121008	0,177734	0,283485	0,026367	0,123929	0,072024	0,065008	0,011037	0,022707
25	13.05.2012 15:56	0,083535	0,142208	0,104716	0,092229	0,206014	0,124259	0,07174	0,013308	0,027898





# Schwertransporte (bis 500t) Verhalten online prüfen



# Schwertransporte (bis 500t) Verhalten online prüfen

Vergleich der durchgeführten Sondertransporte hinsichtlich Gewicht, dessen Verteilung und Lage am Tieflader

1.Überfahrtsserie



	1. Überfahrtsserie 16.12.2013	
	Überfahrt 1	Überfahrt 2
Tonnage	305	305
Achszahl Tieflader	20	20
Gewichtverteilung	Achse 7-15	Achse 7-15

2.Überfahrtsserie



	2. Überfahrtsserie 21.01.2014	
	Überfahrt 1	Überfahrt 2
Tonnage	280	285
Achszahl Tieflader	20	20
Gewichtverteilung	Achse 9-11	Achse 9-12

3.Überfahrtsserie

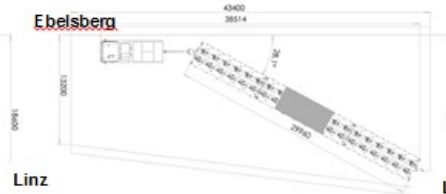
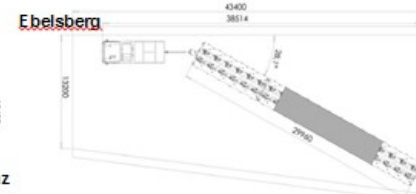
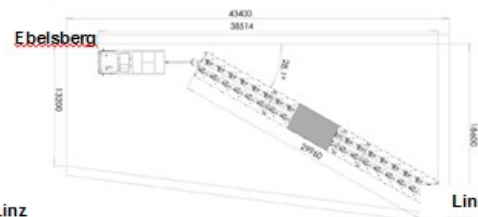
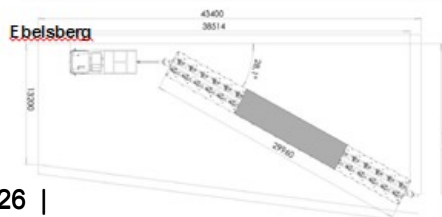
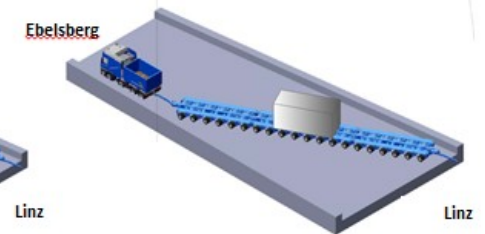
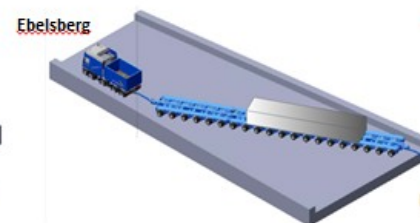
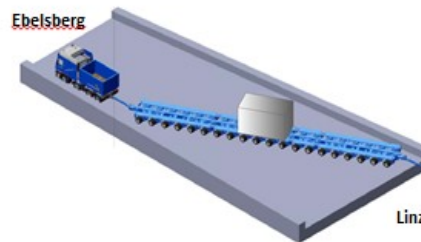
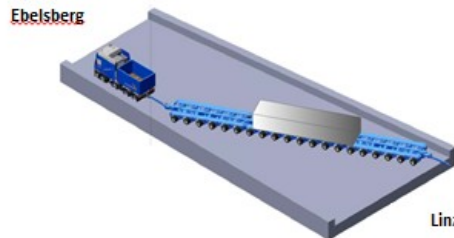


	3. Überfahrtsserie 17.02.2014	
	Überfahrt 1	Überfahrt 2
Tonnage	295	295
Achszahl Tieflader	20	20
Gewichtverteilung	Achse 8-17	Achse 8-17

4.Überfahrtsserie



	4. Überfahrtsserie 20.03.2014	
	Überfahrt 1	Überfahrt 2
Tonnage	295	280
Achszahl Tieflader	20	20
Gewichtverteilung	Achse 8-13	Achse 8-13

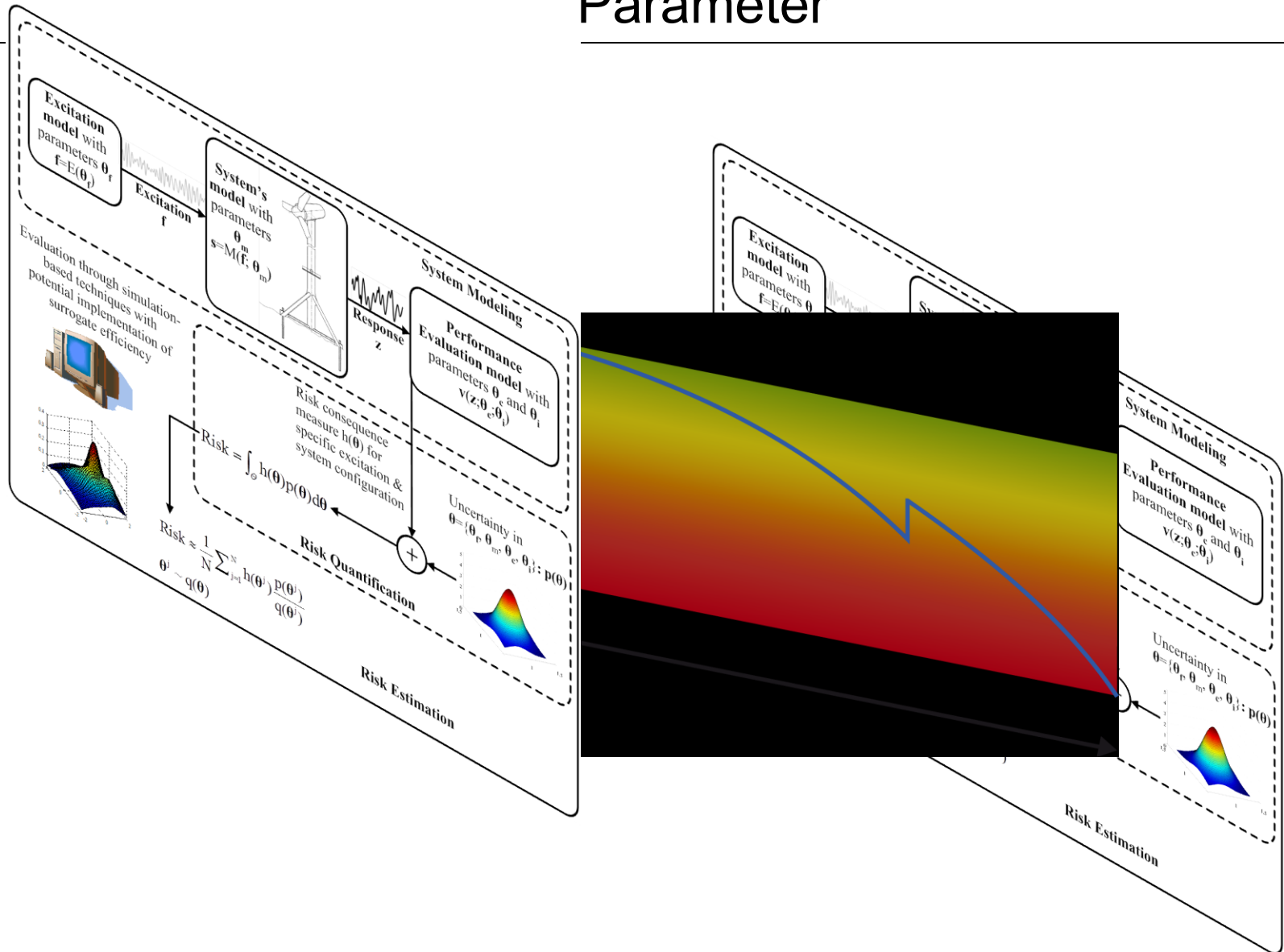


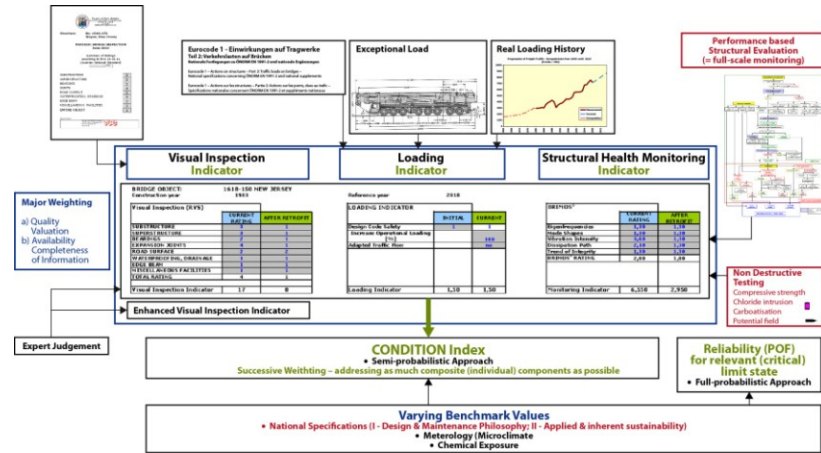
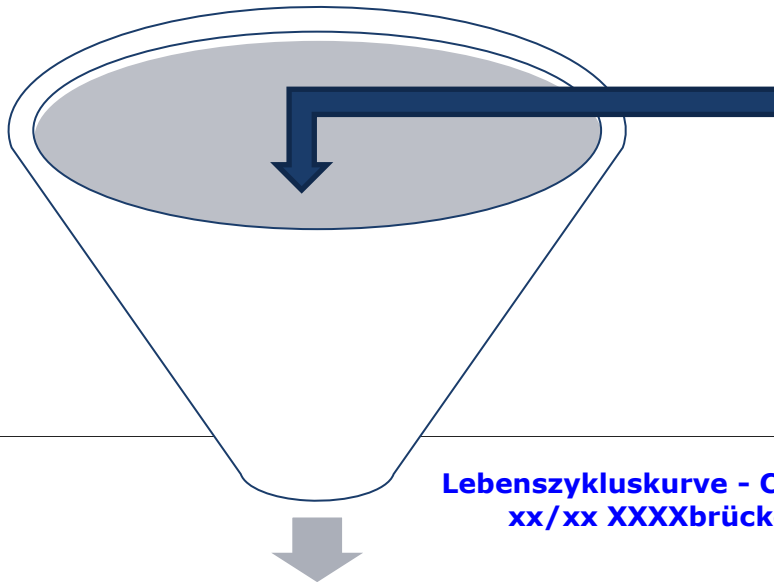
# Schwertransporte (bis 500t) Verhalten online prüfen



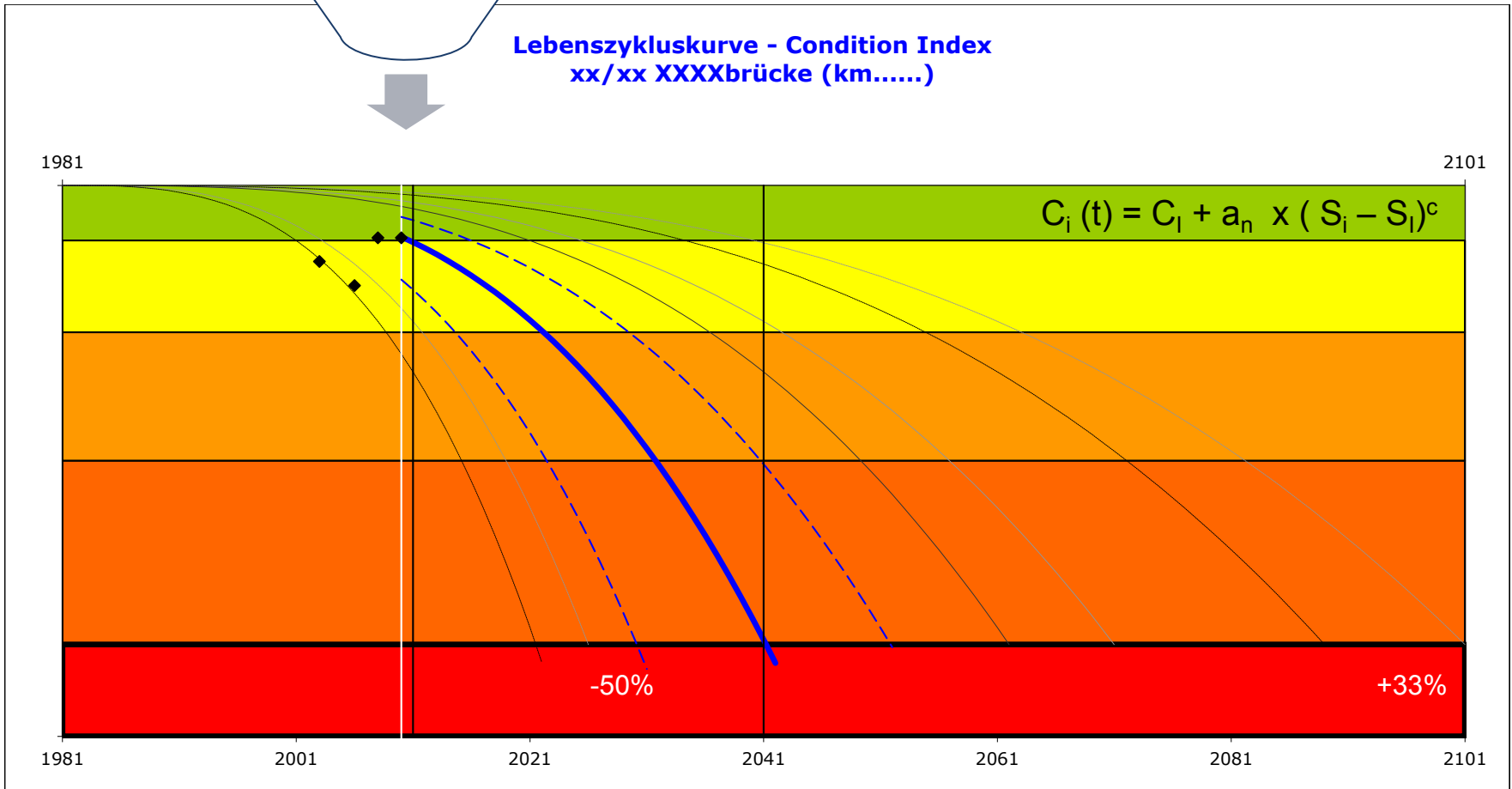
# The IRIS Risk Paradigm

## Parameter



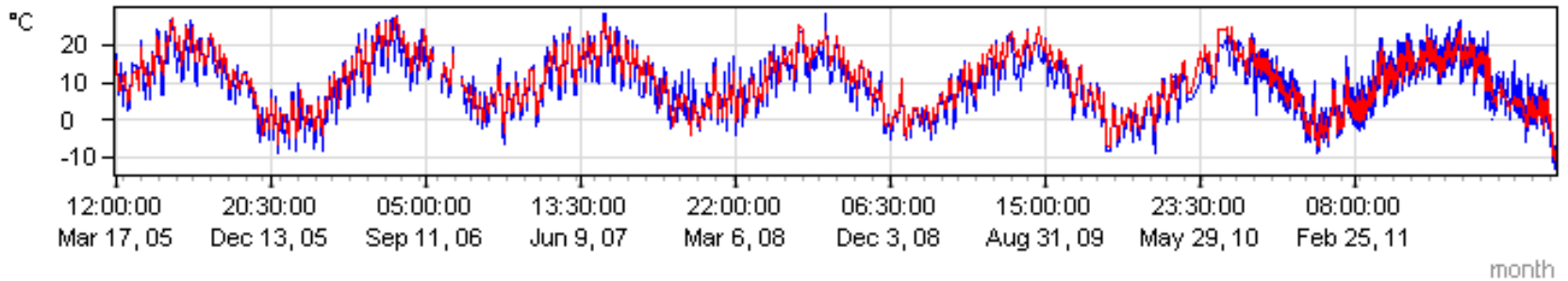


### Lebenszykluskurve - Condition Index xx/xx XXXXbrücke (km.....)

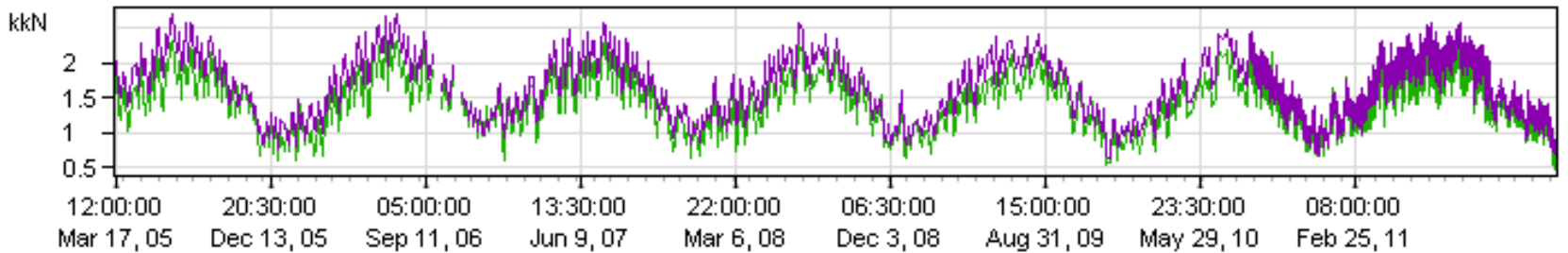


# 3 LERNEFFEKT DURCH BEOBACHTUNG MEHRERER JAHRE

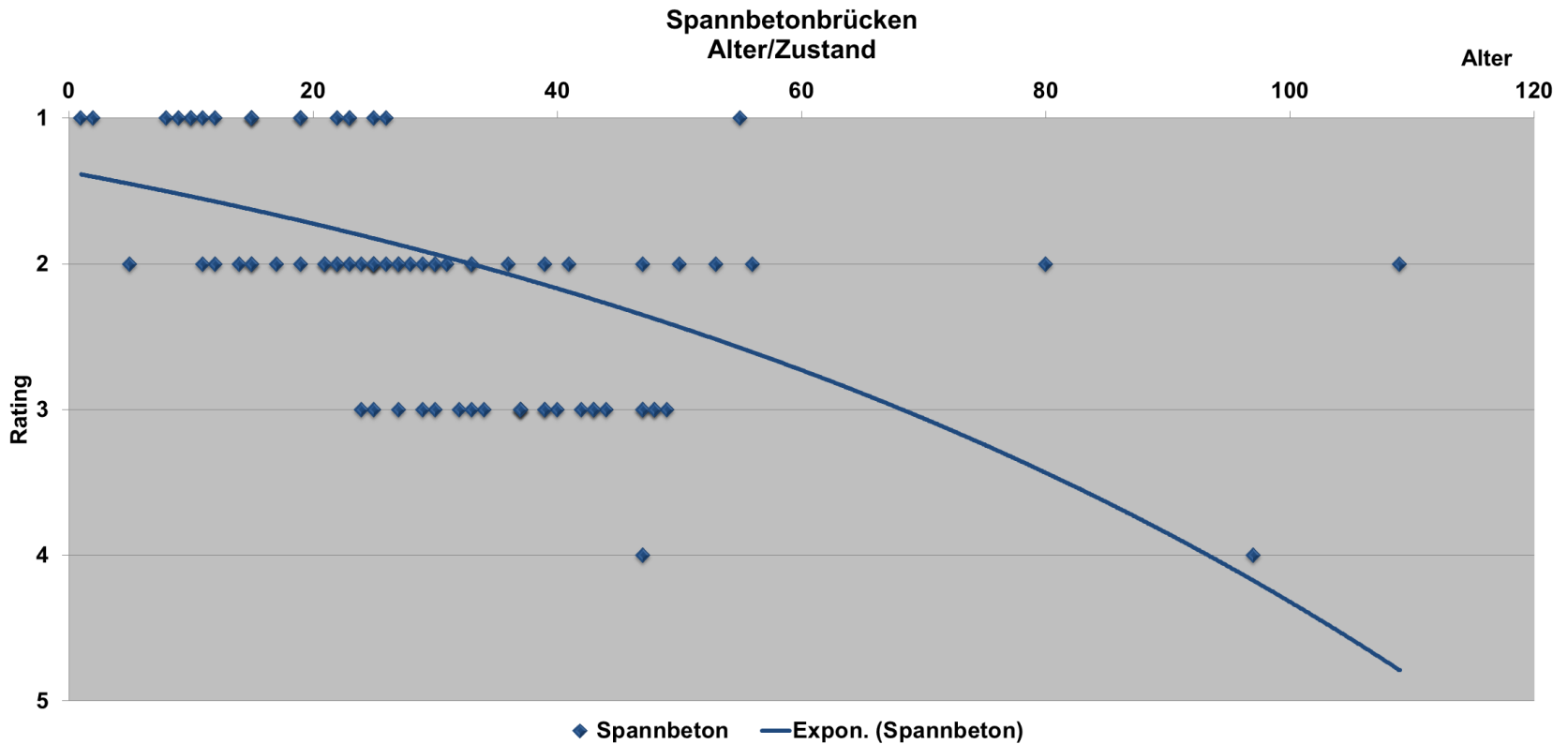
Temperatur:



Kraftmessung:

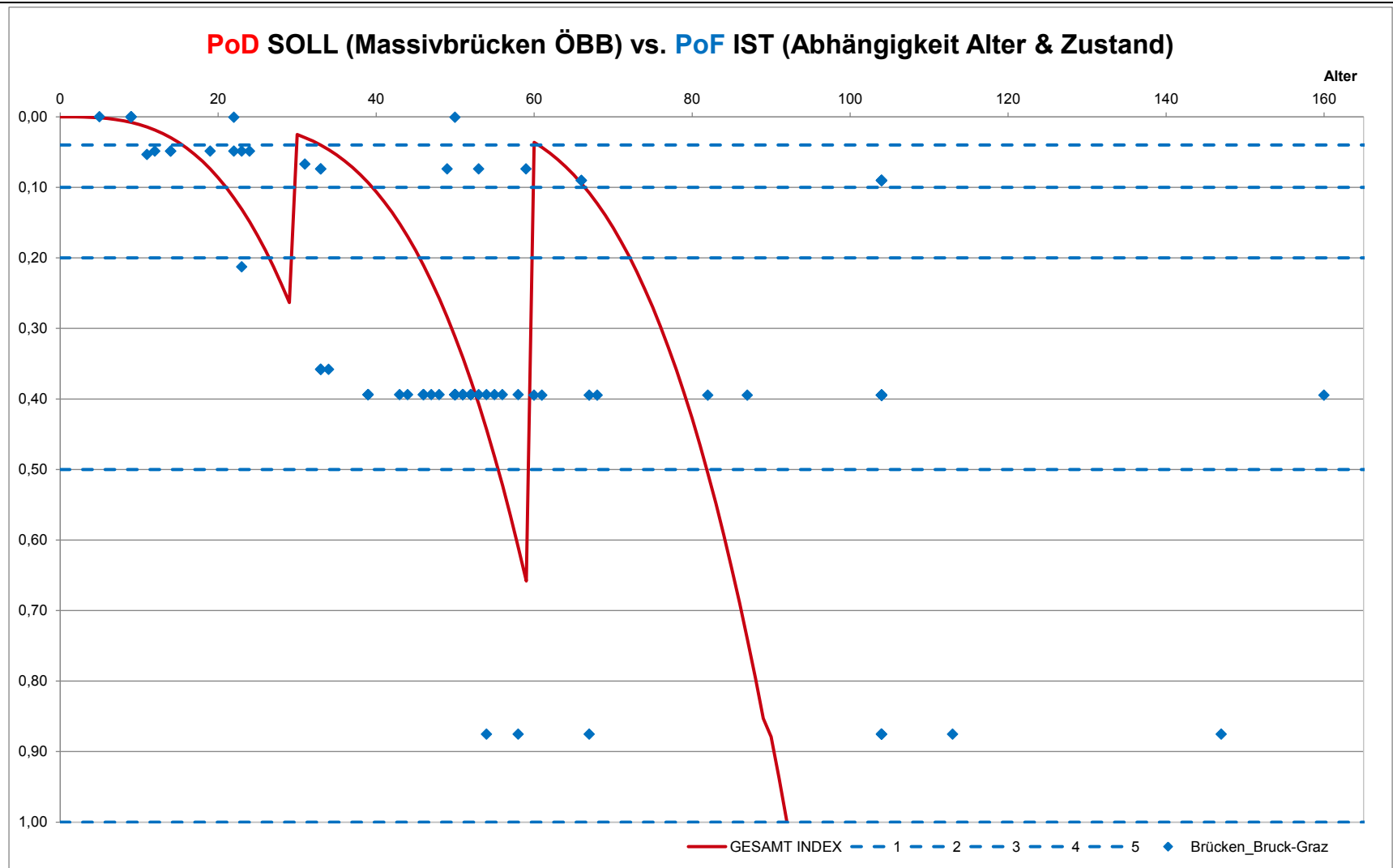


# 2 ÖBB NETZ – BRÜCKEN - SPANNBETON



# 2

## Richtige Darstellung (Interventionen)

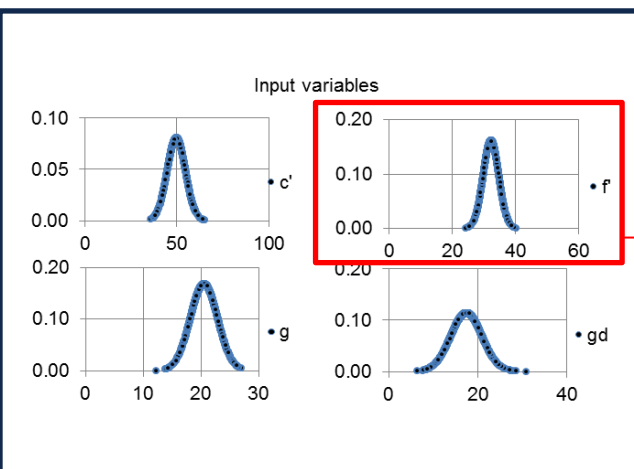




# 4 Monte Carlo applied to slope-stability analysis

- » Propagation of the uncertainties.
- » Input are random within the range **avg ± st.dev**
- » Many simulations
- » It works only if the physics behind is known

Input parameters					Fix	$\mu$	$\sigma$	$\sigma$ (%)
$\gamma$	=	20.3	KN/m <sup>3</sup>	wet sand	<input type="checkbox"/>	20.5	2.3	11.2
$\gamma_d$	=	17.3	KN/m <sup>3</sup>	dry sand	<input type="checkbox"/>	17.5	3.5	20.0
$\gamma_w$	=	10.0	KN/m <sup>3</sup>	water	<input checked="" type="checkbox"/>	10	0	0.0
$c'$	=	59.2	KN/m <sup>3</sup>	cohesion	<input type="checkbox"/>	50	5	10.0
$\phi'$	=	31.6	deg	angle of internal friction	<input type="checkbox"/>	32.5	2.5	7.7
$a_g$	=	0.0	m/s <sup>2</sup>	horiz. seismic acceler.	<input checked="" type="checkbox"/>	0.0	0.8	#DIV/0!
$a_{vg}$	=	0.0	m/s <sup>2</sup>	vertic. seismic acceler.	<input checked="" type="checkbox"/>	0.0	0.6	#DIV/0!
$g$	=	9.806	m/s <sup>2</sup>	gravity	<input checked="" type="checkbox"/>			



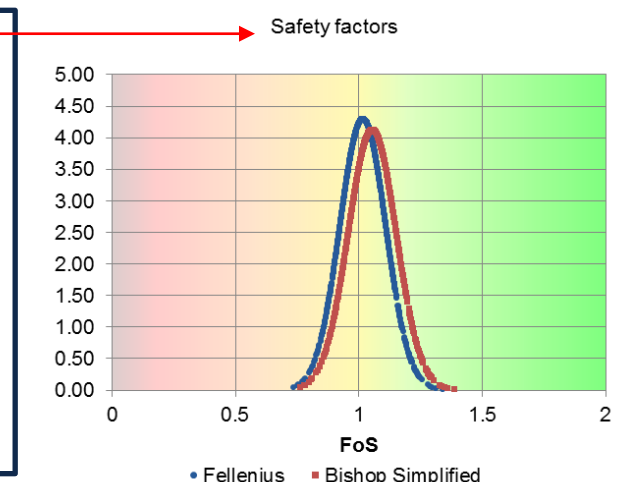
Safety factor

$$FS = \frac{\sum_{i=1}^n T_{fi}}{\sum_{i=1}^n T_i} = \frac{M_S}{M_R}$$

$$M_S = r \cdot \sum_{i=1}^n T_{fi} = r \cdot \sum_{i=1}^n [c' \cdot \Delta l_i + N_i' \cdot \tan \phi_i']$$

$$M_R = r \cdot \sum_{i=1}^n T_i = r \cdot \sum_{i=1}^n W_i \cdot \sin \alpha_i$$

Deterministic set of equations descr. the phenomenon



# Effect of landslides on the dam

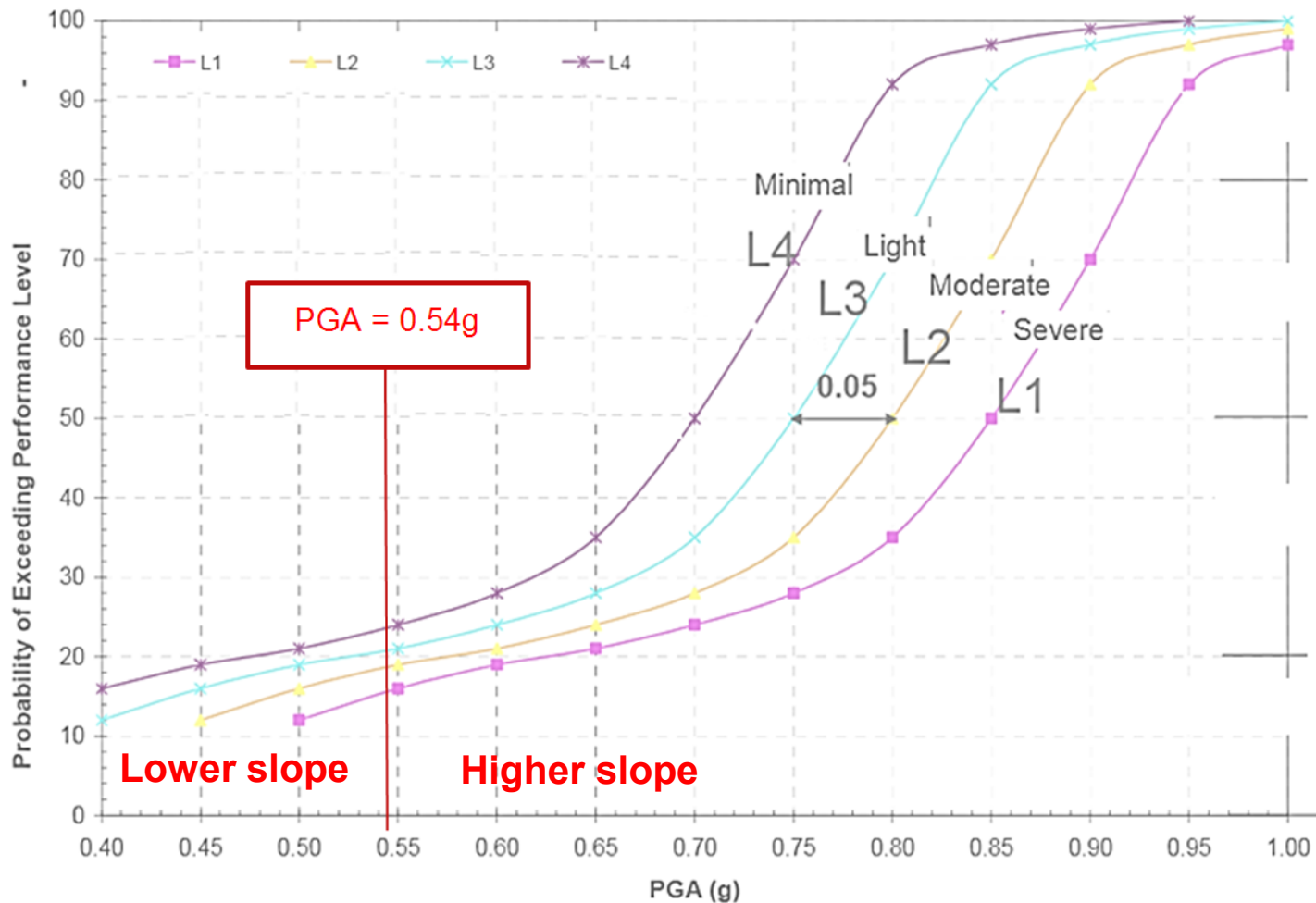
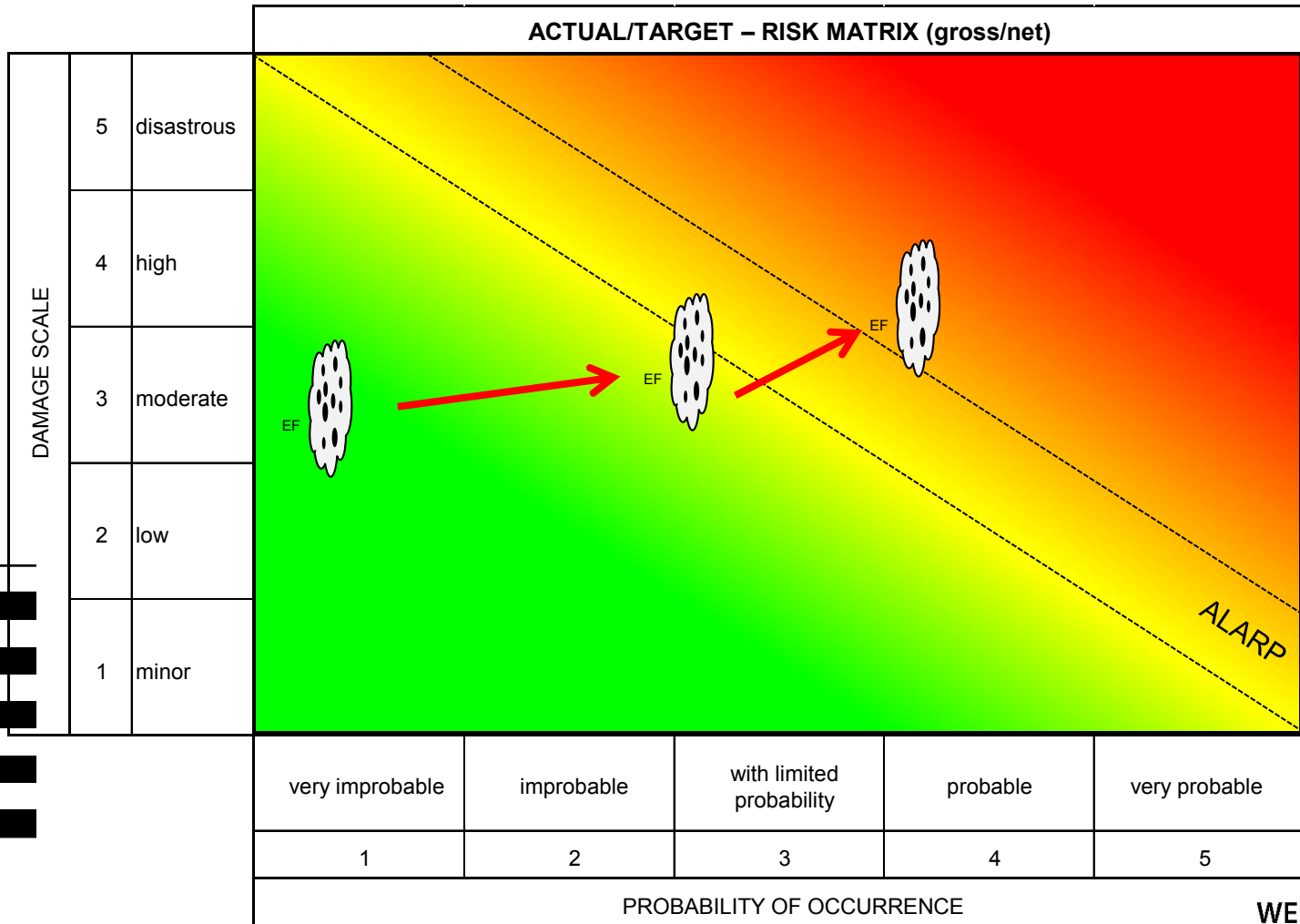


Figure 108: Fragility functions developed on the effects of real earthquakes on 29 embankment dams located in the US.

# 6 RISK CHANGES WITH CLIMATE CHANGE

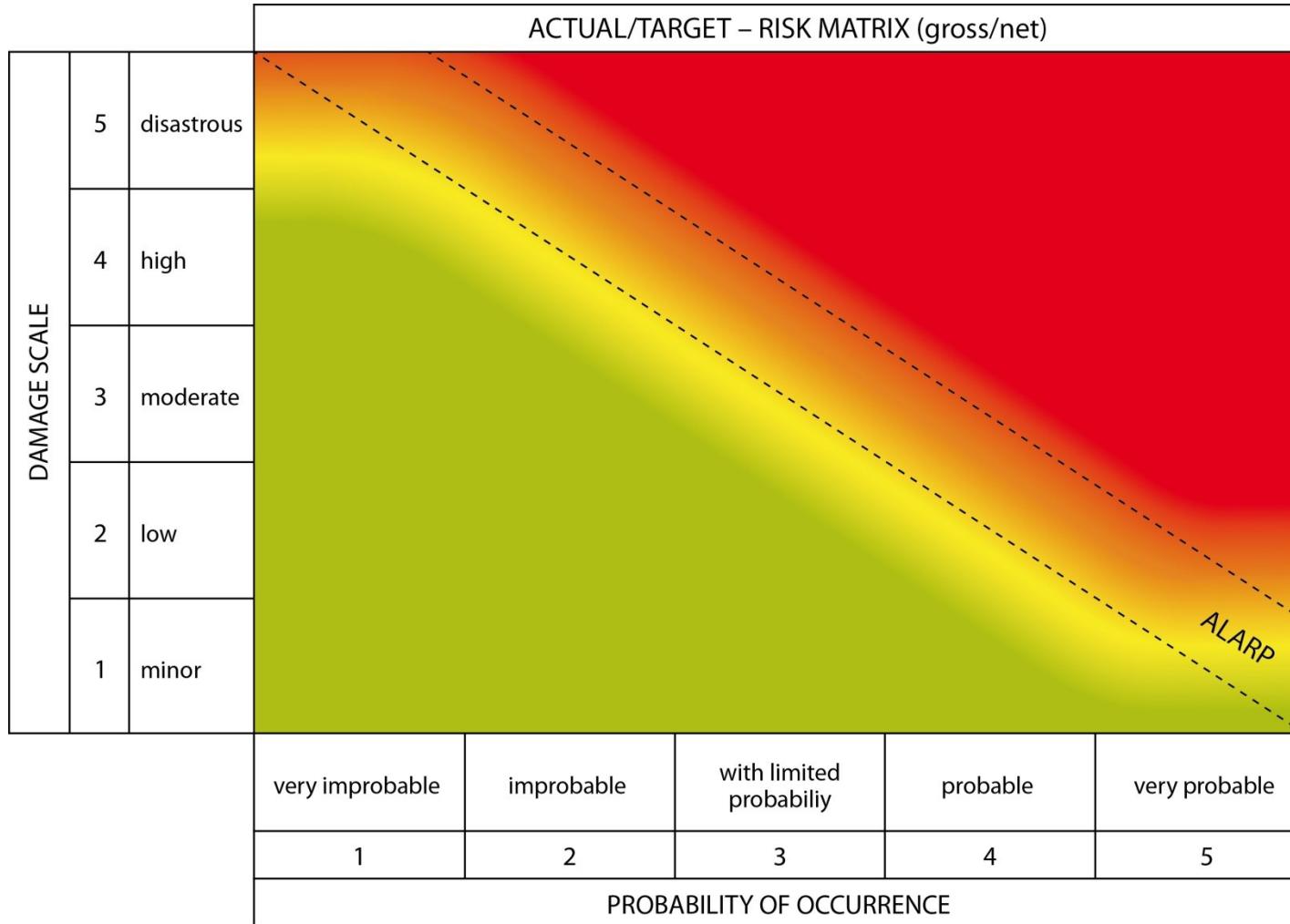
2050

2100



Symbol	Description
D	Debris flow
RQ	Rongq Gully
HC	Hypothetical case
A	Accumulation body

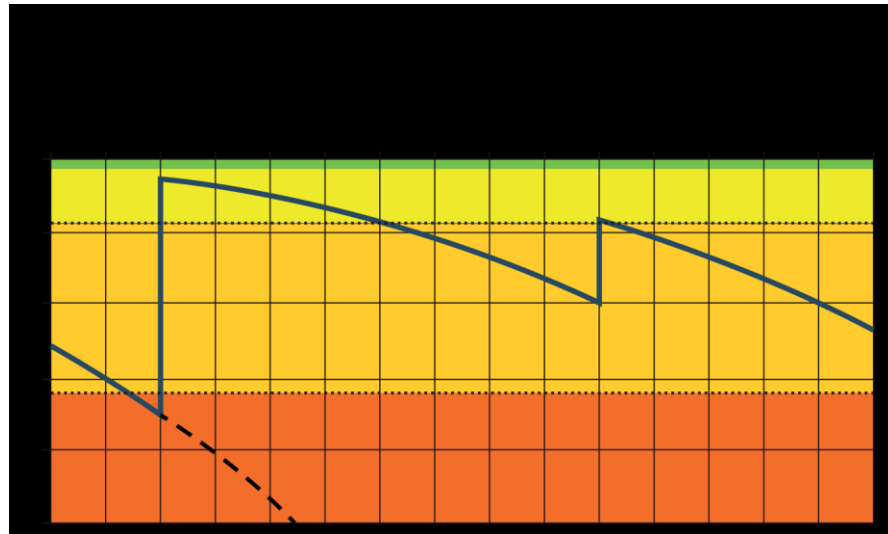
# 6 Representation of Risk (refined)



# 9

## Trigger Mechanisms => Maintenance Measures

SUPERSTRUCTURE		
PARAMTER	median	
$t_n =$	0	
$h_n (2054) =$	20	
$b_0 =$	0	
$t =$	45	
$c =$	3	
$a_n =$	2.19E-04	
weighting factor	1.3	
	Do Nothing $c = 3$	Rating
$t$		
0	0.0000	1
1	0.0002	1
2	0.0018	1
3	0.0059	1
4	0.0140	1
5	0.0274	1
6	0.0474	1
7	0.0753	1
8	0.1124	1
9	0.1600	2
10	0.2195	2
11	0.2921	2
12	0.3793	2
13	0.4822	2
14	0.6022	2
15	0.7407	2
16	0.8990	2
17	1.0783	2
18	1.2800	2
19	1.5054	2
20	1.7558	2
21	2.0326	2
22	2.3370	2
23	2.6704	2
24	3.0341	2
25	3.4294	2
26	3.8576	3
27	4.3200	3
28	4.8180	3
29	5.3529	3
30	5.9259	3
31	6.5385	3
32	7.1919	3
33	7.8874	3
34	8.6264	3
35	9.4102	3
36	10.2400	3
37	11.1173	3
38	12.0432	3
39	13.0193	3
40	14.0466	4
41	15.1267	4
42	16.2607	4
43	17.4501	4
44	18.6961	4
45	20	4



**Routine Maintenance**

**Heavy Maintenance**

**Strengthening**

1 – Excellent Condition
2 – Good Condition
3 – Satisfactory Condition
4 – Poor Condition
5 – Critical Condition

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# Zusammenfassung

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- » Daten immer aufheben (sie sind ein Schatz)
- » Nutzen wir Messungen um unsere Bauwerke besser zu verstehen (Monitoring)
- » Forschen und arbeiten wir an verbesserten Algorithmen für die Entscheidungsfindung

**Danke !**

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