Fundamentals of the Dempster-Shafer Theory and its Applications to System Safety and Reliability Modelling

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Dempster-Shafer Applications

Introduction

Objective

- Modelling & expressing uncertainties in safety & reliability analyses
- Evidence measures offer a different kind of flavour to RAMS engineers

What's new?

- Evidence measures belief and plausibility are applied
  instead of → probabilities
  instead of → membership function (fuzzy set theory)

What's not new?

- Methods introduced (FTA, ETA, RCM, FMECA)
- Fundamentals of the Dempster-Shafer Theory

Dempster-Shafer Applications

Introduction

Note

- ESREL 2007 → special DS approach tailored to RCM
- SSARS 2007 → general DS approach to Safety & Reliability Modelling
  → more details

Disclaimer

- Nobody is forced to apply evidence measures
- Not faster, bigger, better, higher → just different

Outline

Introduction

Part 1 – Fundamentals

- History
- Scenario
- Interpretations

Part 2 – Illustration

- The DS calculus in eight steps

Part 3 – Applications to System Safety & Reliability Modelling

- FTA – Fault Tree Analysis
- ETA – Event Tree Analysis
- RCM – Reliability-centred Maintenance
- Further Analyses

Part 4 – Outroduction

- Pros & Cons

History

Introduction

1966 – Arthur P. Dempster

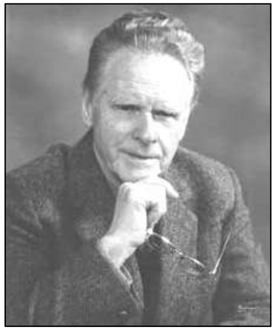
- Developed Theory
- "Upper & lower probabilities"
- Suitable to express uncertain expert judgements

1976 – Glenn Shafer

- Extended, refined, recast
- "Upper probabilities & degrees of belief"
- "DS Theory of Evidence", "DS Evidential Theory" → DST

1988 – George J. Klir & Tina A. Folger

- Introduce → "Degrees of belief & plausibility"
- Evidence measures depart from being probabilities



A. P. Dempster

G. Shafer

The Scenario

Fundamentals

Scenario

- System
- Hypotheses
- Frame of discernment
- Pieces of evidence
- Data sources

System

- Borders
- In- and outputs
- Elements (e.g. components or modules)
- Links between the elements
- Interactions of the elements
- Task of the system

The Scenario

Fundamentals

Scenario

- System
- Hypotheses
- Frame of discernment
- Pieces of evidence
- Data sources

Hypotheses

- Single hypothesis → e.g. represents one state, one answer
- Example → "functioning", "marginal", "faulty"
- Example → "yes", "uncertain", "no"

Properties

- Unique and
- not overlapping and
- mutually exclusive

The Scenario

Fundamentals

Scenario

- System
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- Pieces of evidence
- Data sources

Frame of discernment

- Representation $\rightarrow$ universal set Ω
- Hypotheses $\rightarrow$ elements of frame of discernment
- Ω = {“functioning”, “marginal”, “faulty”}
- Power set 2^{Ω} $\rightarrow$ set of all subsets
- Power set 2^{Ω} $\rightarrow$ single and conjunctions of hypotheses

The Scenario

Fundamentals

Scenario

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- Pieces of evidence
- Data sources

Pieces of Evidence

- Symptoms or events → e.g. failures
- Assignment
  {evidence → hypothesis(es)} corresponds to {cause → consequence(s)}
- Assignment
  {1 p-of-e} assigned to {1 hypothesis} or {1 set of hypotheses}
  {>1 p-of-e} may not be assigned* to {same hypothesis}, {same set}

*) by the same data source

The Scenario

Fundamentals

Scenario

- System
- Hypotheses
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- Pieces of evidence
- Data sources

Data Sources

- Information provider → experts, empirical studies, data
- Task → quantifying strength {p-of-e → hypothesis} assignments → $m(A)$
- Requirements
  → free from bias (esp. experts)
  → representative (esp. studies)
  → no source is more important than another one

The Scenario

Fundamentals

Scenario

- System
- Hypotheses
- Frame of discernment
- Pieces of evidence
- Data sources

Data Sources

- Information provider → experts
- Expert group
  Safety → system eng., software eng., reliability eng., service eng.
  RCM → service eng., maintenance personnel, reliability eng.
- Task → give subjective quantifiable statements
- Basis → data, experience, intuition … ← biased?

The Scenario

Fundamentals

Scenario

- System
- Hypotheses
- Frame of discernment
- Pieces of evidence
- Data sources

Pieces of Evidence

- Expert group → piece of evidence?
  → expert judgement (experience, intuition)
  → experts' subjectivity
- Critical issue?

Objectivity versus Subjectivity

Fundamentals

Objectivity

- Exactly one single hypothesis is objectively true

Subjectivity

- Uncertain which hypothesis fits subjectively best to reality

Dempster-Shafer Theory

- Calculus describes & quantifies the subjective viewpoint as an assessment for an unknown objective fact

Safety & Reliability Engineering

- PSAM/ESREL 2004 $\rightarrow$ hypotheses
  $\rightarrow$ "component i is functioning" and "component i is faulty"
  $\rightarrow$ … same set?!

Assignments & Sets

Fundamentals

Sets

- Ω — universal set
- $A, B, Z \subseteq \Omega$ — sets, containing a single hypothesis or a set of hypotheses

Basic Assignment

- m, $m(A)$ — quantifies if the element belongs exactly to the set A
- $m: 2^{\Omega} \rightarrow [0, 1]$ — mapping (prob. $\Omega \rightarrow [0, 1]$)
- $\Sigma_{A \subseteq \Omega} m(A) = 1$ — all statements of an expert are normalised
- $m(A) > 0$ — focal element, only substantial statements
- $m(\emptyset) = 0$ — simplicity (**not** required)

Differences in Properties to Probabilities

- $m(\Omega) = 1$ — **not** required
- $m(A)$ vs. $m(\neg A)$ — **no** relationship required
- If $A \subset B \subseteq \Omega$, then $m(A) \leq m(B)$ — **not** required

The Basic Assignment

Fundamentals

Interpretation of m

- Task of $m \rightarrow$ assign evidential weight to hypothesis(es) $\rightarrow A \subseteq \Omega$
- Mathematical interpretation of $m \rightarrow$ “evidential weight”
- Probability $\rightarrow$ **no** concept, **no** interpretation (📖 ESREL‘05 Proceedings)

Denotations of m

- “Basic probability assignment” $\leftarrow$ no probability
- “Basic belief assignment” $\leftarrow$ conflicts *belief* measure
- “Basic structure” $\leftarrow$ conflicts Boolean *structure* function
- “Mass assignment function” $\leftarrow$ mass confuses in engg. applications
- “Basic assignment” $\leftarrow$ ☺

Evidential Functions

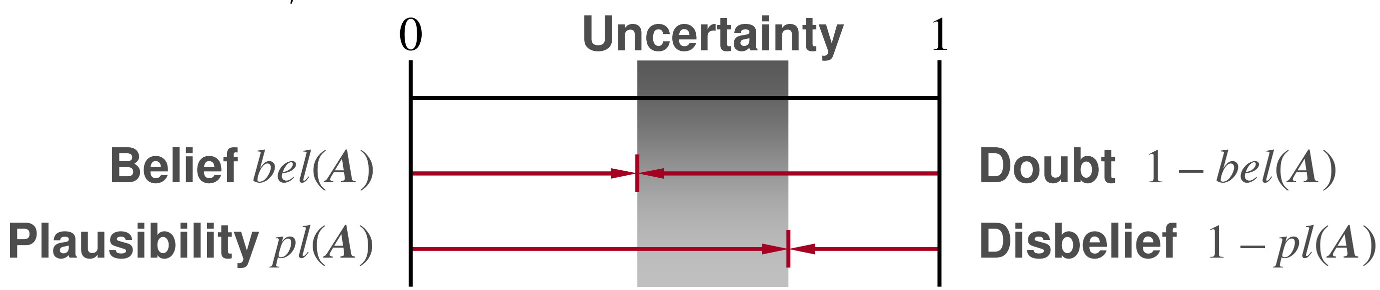
Fundamentals

Belief Measure $bel(A)$

- Belief is the degree of evidence
  that the element in question belongs to the set A
  as well as to the various special subsets of A.
- $bel(\boldsymbol{A}) = \sum_{B \subseteq A; B \neq \phi} m(\boldsymbol{B})$

Plausibility Measure $pl(A)$

- Plausibility is the degree of evidence
  that the element in question belongs to the set A
  or to any of its subsets or to any set that overlaps with A.
- $pl(\boldsymbol{A}) = \sum_{B \cap A \neq \phi} m(\boldsymbol{B})$



Complements

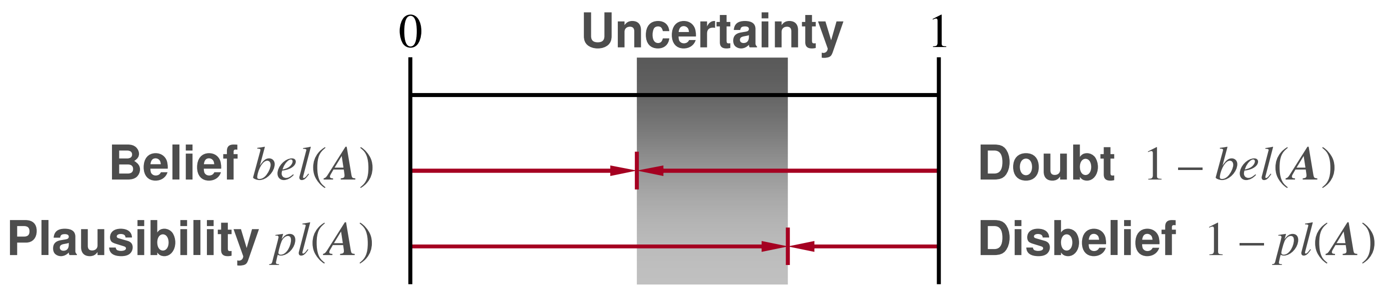
Fundamentals

Direct Complements

- Belief versus doubt
- Plausibility versus disbelief

Contextual Complements

- Certainty → belief versus disbelief
- Uncertainty included → plausibility versus doubt

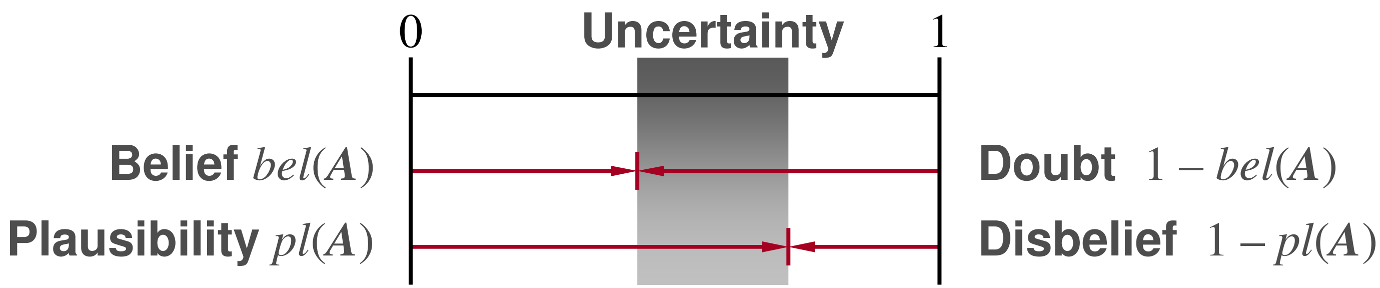


Phenomena

Fundamentals

Difference in Concepts – Existence of Phenomena

- Evidential measures
  No causal relationship between
  belief in existence $bel(\mathbf{A})$
  and belief in non-existence $bel(\neg\mathbf{A}) = 1 - pl(\mathbf{A})$
- Probabilities
  The belief in existence $pr(x_i = 1)$
  implies belief in non-existence $pr(x_i = 0) = 1 - pr(x_i = 1)$



Outline

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Context

Illustration

Typical Situation in a Power Plant

- Operators @control panel → detect serious changes of system properties
- Causes → failures detectable
- Consequence → system fault
  → neither be determined exactly nor interpreted certainly
- Widely discussed (📖 ATHEANA Report, 📖 Eric Hollnagel, etc.)

DST Approach

- Collects pieces of evidence
- Postulates hypotheses
- Proposes conclusions

- Dempster-Shafer approach → supports operators in reasoning
- Objective → to avoid an error forcing context

Procedure

Illustration

Eight Steps

- Step ❶ – Creating the Scenario
- Step ❷ – Quantification of Statements
- Step ❸ – Combining Hypotheses
- Step ❹ – Reducing the Combination Table
- Step ❺ – Calculating Products & Sums of Combined Basic Assignments
- Step ❻ – Combining Basic Assignments
- Step ❼ – Evidence Measures of Combined Hypotheses
- Step ❽ – Interpretation

Creating the Scenario

Illustration – Step ❶

Scenario

- System → power plant
- Data sources → operators → 2 persons
- Pieces of evidence → failures detected → 4 considered
- Hypotheses → system fault states → 3 considered
- Frame of discernment → $\Omega = \{h_1, h_2, h_3\}$

Qualitative Failure-fault(s) Assignments

- 1st operator → h_1, h_2 consequences
- 2nd operator → h_1, h_3 consequences
- Same p-o-e, different hypotheses

Op.	Failure	Fault(s)
1st	ev_1	h_1
	ev_2	h_2
	ev_3	h_1, h_2
	ev_4	h_1, h_2, h_3
2nd	ev_1	h_1
	ev_2	h_3
	ev_3	h_1, h_3
	ev_4	h_1, h_2, h_3

DST Restrictions

- No more than one failure
  lead to the same fault (hypothesis)*

*) each data source

Quantification of Statements

Illustration – Step ❷

Quantification

- Operators quantify statements, basis $\rightarrow$ data, intuition & experience
- $m(\boldsymbol{A}_k) = 0 \rightarrow$ no focal element

Belief

- Example: 1st Operator, set $\{h_1 \cup h_2\}$
- Set and all its subsets
- $\{h_1\}, \{h_2\}, \{h_1 \cup h_2\} \subseteq \{h_1 \cup h_2\}$
- $bel(\boldsymbol{A}_4) = m(\boldsymbol{A}_1) + m(\boldsymbol{A}_2) + m(\boldsymbol{A}_4) = 0.9$

Plausibility

- At least 1 hypothesis in common
- $\{h_1\}, \{h_2\}, \{h_1 \cup h_2\}, \{h_1 \cup h_3\}, \{h_2 \cup h_3\}, \{h_1 \cup h_2 \cup h_3\} \cap \{h_1 \cup h_2\} \neq \varnothing$
- $pl(\boldsymbol{A}_4) = m(\boldsymbol{A}_1) + m(\boldsymbol{A}_2) + m(\boldsymbol{A}_4) + m(\boldsymbol{A}_5) + m(\boldsymbol{A}_6) + m(\boldsymbol{A}_7) = 1$

1st operator	2^{Ω}	2nd operator
$m(\boldsymbol{A}_1) = 0.2$	$\{\boldsymbol{h}_1\}$	$m(\boldsymbol{B}_1) = 0.2$
$m(\boldsymbol{A}_2) = 0.1$	$\{\boldsymbol{h}_2\}$	$m(\boldsymbol{B}_2) = 0$
$m(\boldsymbol{A}_3) = 0$	$\{\boldsymbol{h}_3\}$	$m(\boldsymbol{B}_3) = 0.2$
$m(\boldsymbol{A}_4) = 0.6$	$\{\boldsymbol{h}_1 \cup \boldsymbol{h}_2\}$	$m(\boldsymbol{B}_4) = 0$
$m(\boldsymbol{A}_5) = 0$	$\{\boldsymbol{h}_1 \cup \boldsymbol{h}_3\}$	$m(\boldsymbol{B}_5) = 0.4$
$m(\boldsymbol{A}_6) = 0$	$\{\boldsymbol{h}_2 \cup \boldsymbol{h}_3\}$	$m(\boldsymbol{B}_6) = 0$
$m(\boldsymbol{A}_7) = 0.1$	$\{\boldsymbol{h}_1 \cup \boldsymbol{h}_2 \cup \boldsymbol{h}_3\}$	$m(\boldsymbol{B}_7) = 0.2$

Quantification of Statements

Illustration – Step ❷

Results

- Input by operators $\rightarrow m(\boldsymbol{A}_k)$
- Output by calculus $\rightarrow bel(\boldsymbol{A}_k), pl(\boldsymbol{A}_k)$

$m(A_k)$	$bel(A_k)$	$pl(A_k)$	2^Ω	$m(B_k)$	$bel(B_k)$	$pl(B_k)$
0.2	0.2	0.9	$\{h_1\}$	**0.2**	0.2	0.8
0.1	0.1	0.8	$\{h_2\}$	**0**	0	0.2
0	0	0.1	$\{h_3\}$	**0.2**	0.2	0.8
0.6	0.9	1	$\{h_1 \cup h_2\}$	**0**	0.2	0.8
0	0.2	0.9	$\{h_1 \cup h_3\}$	**0.4**	0.8	1
0	0.1	0.8	$\{h_2 \cup h_3\}$	**0**	0.2	0.8
0.1	1	1	Ω	**0.2**	1	1

Combining Hypotheses

Illustration – Step 3

Combination

- Combining each set of hypotheses of both operators
- Building cut sets ∩ of both

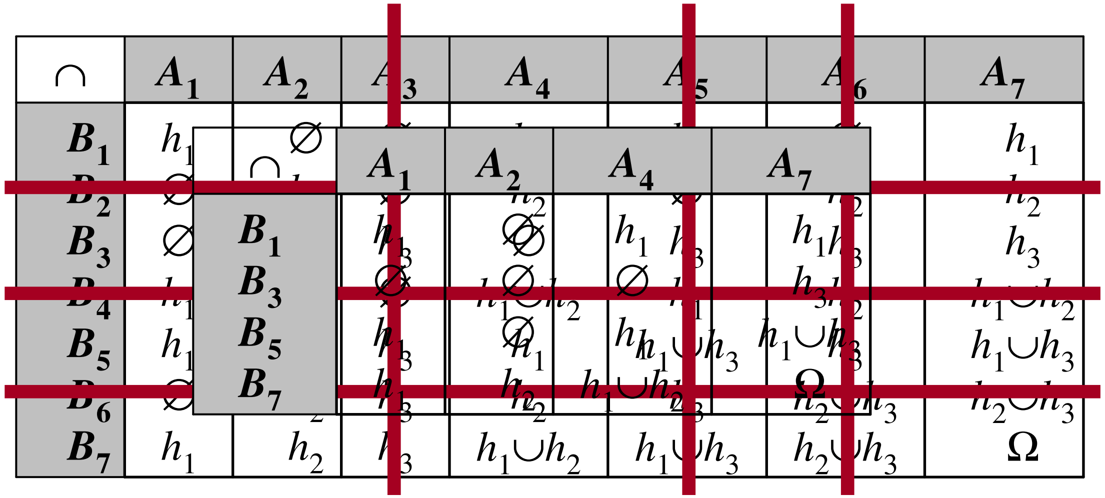
$\cap$	A_1	A_2	A_3	A_4	A_5	A_6	A_7
B_1	h_1	$\varnothing$	$\varnothing$	h_1	h_1	$\varnothing$	h_1
B_2	$\varnothing$	h_2	$\varnothing$	h_2	$\varnothing$	h_2	h_2
B_3	$\varnothing$	$\varnothing$	h_3	$\varnothing$	h_3	h_3	h_3
B_4	h_1	h_2	$\varnothing$	$h_1 \cup h_2$	h_1	h_2	$h_1 \cup h_2$
B_5	h_1	$\varnothing$	h_3	h_1	$h_1 \cup h_3$	h_3	$h_1 \cup h_3$
B_6	$\varnothing$	h_2	h_3	h_2	h_3	$h_2 \cup h_3$	$h_2 \cup h_3$
B_7	h_1	h_2	h_3	$h_1 \cup h_2$	$h_1 \cup h_3$	$h_2 \cup h_3$	Ω

Reducing the Combination Table

Illustration – Step 4

Combination

- Objective → avoid mathematical effort
- Drop rows & columns → non-focal elements
  $m(\boldsymbol{A}_k) = 0, m(\boldsymbol{B}_k) = 0$



Calculating Products & Sums

Illustration – Step ❺

Calculating Products

- $\{h_1\} \Rightarrow m(\boldsymbol{Z}_1) = m(\boldsymbol{A}_1) \cdot m(\boldsymbol{B}_1) = 0.04$
- $\{h_1\} \Rightarrow m(\boldsymbol{Z}_2) = m(\boldsymbol{A}_1) \cdot m(\boldsymbol{B}_5) = 0.08$
- …
- $\{h_1 \cup h_2 \cup h_3\} \Rightarrow m(\boldsymbol{Z}_{11}) = m(\boldsymbol{A}_7) \cdot m(\boldsymbol{B}_7) = 0.02$

Calculating Sum(s)

- Just $\{h_1\} \Rightarrow \sum_{k=1}^{6} m(\boldsymbol{Z}_k) = 0.54$

$\cap$	A_1	A_2	A_4	A_7
B_1	h_1	$\varnothing$	h_1	h_1
B_3	$\varnothing$	$\varnothing$	$\varnothing$	h_3
B_5	h_1	$\varnothing$	h_1	$h_1 \cup h_3$
B_7	h_1	h_2	$h_1 \cup h_2$	Ω

•	A_1	A_2	A_4	A_7
B_1	0.04	×	0.12	0.02
B_3	×	×	×	0.02
B_5	0.08	×	0.24	0.04
B_7	0.04	0.02	0.12	0.02

Combining Basic Assignments

Illustration – Step ❻

Sum of Product

- Example: hypothesis h_1 again $\rightarrow \sum_{k=1}^{6} m(\mathbf{Z}_k) = 0.54$

Calculating the Focal Sum

- Sum of all basic assignment products $\rightarrow \sum_{k=1}^{11} m(\mathbf{Z}_k) = 0.76$

Basic Assignment of the Comb. Hypothesis

- Example: hypothesis h_1 $\rightarrow m(\{h_1\}) = \frac{\sum_{k=1}^{6} m(\mathbf{Z}_k)}{\sum_{k=1}^{11} m(\mathbf{Z}_k)} \approx 0.7105$

Measures of Combined Hypotheses

Illustration – Step ❼

Evidence Measures

- Input by Step ❻ $\rightarrow m(\mathbf{Z}_k)$
- Output by calculus of Step ❷ $\rightarrow bel(\mathbf{Z}_k), pl(\mathbf{Z}_k)$
- Ranking according to $pl(\mathbf{Z}_k)$ & certainty

2^Ω	m	bel	pl
Ω	**0.0263**	1	1
$\{h_1 \cup h_2\}$	**0.1579**	0.8947	0.9737
$\{h_1 \cup h_3\}$	**0.0526**	0.7895	0.9737
$\{h_1\}$	**0.7105**	0.7105	0.9471
$\{h_2\}$	**0.0263**	0.0263	0.2105
$\{h_3\}$	**0.0263**	0.0263	0.1053

Interpretation

Illustration – Step 8

Interpretation

- Which fault may be responsible for the serious changes of system properties?
- Probabilistic approach $\rightarrow$ blames h_1 alone
- Dempster-Shafer approach $\rightarrow$ points h_1 and gives a hint to h_2
- Different mappings $\Omega \rightarrow [0, 1]$ versus $2^\Omega \rightarrow [0, 1]$

2^Ω	m	bel	pl
Ω	**0.0263**	1	1
$\{h_1 \cup h_2\}$	**0.1579**	0.8947	0.9737
$\{h_1 \cup h_3\}$	**0.0526**	0.7895	0.9737
$\{h_1\}$	**0.7105**	0.7105	0.9471
$\{h_2\}$	**0.0263**	0.0263	0.2105
$\{h_3\}$	**0.0263**	0.0263	0.1053

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- Pros & Cons

Fault Tree Analysis

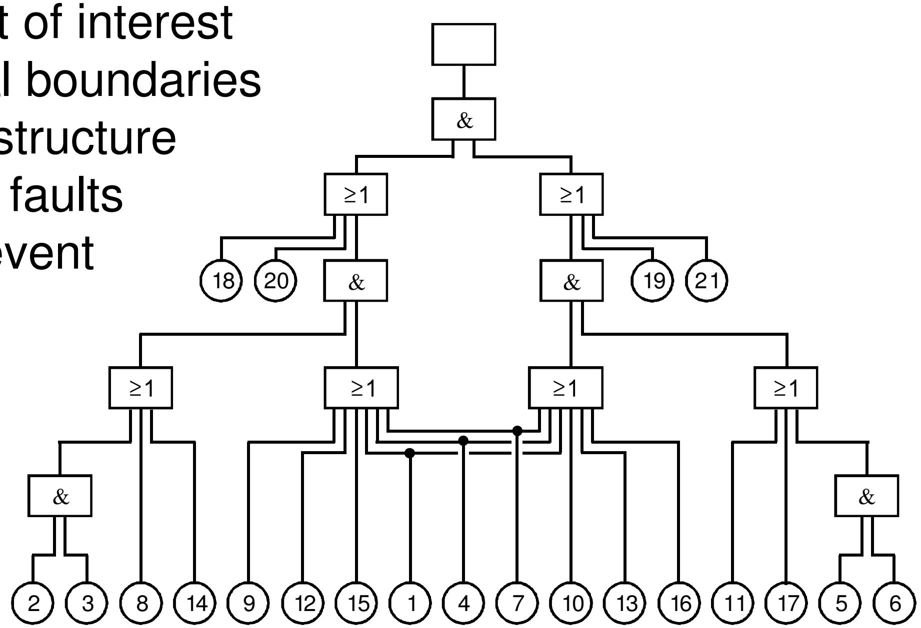
Brief Introduction

Detailed Introduction

- IEC 61025
- Proceedings 📖 → references

Four Steps of the FTA

- Step ❶ – Define the top event of interest
- Step ❷ – Define the analytical boundaries
- Step ❸ – Define the tree-top structure
- Step ❹ – Develop the path of faults for each branch to the basic event



Dempster-Shafer FTA Approach

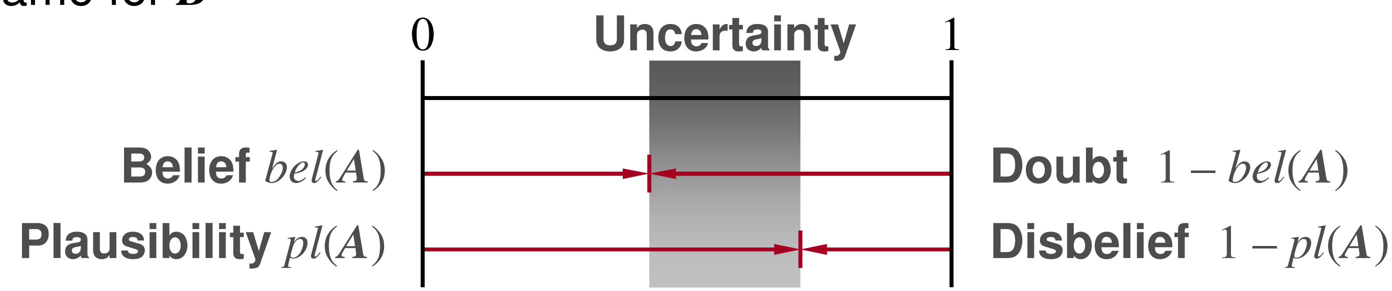
Fault Tree Analysis

Scenario

- $\Omega = \{h_1, h_2, h_3\} \rightarrow$ {"state occurs", "uncertain", "state does not occur"}
- Gates $\rightarrow$ **And** or **Or**
- Inputs $\rightarrow$ e.g. two states, $m(\boldsymbol{A})$ and $m(\boldsymbol{B})$
- Output $\rightarrow$ state $m(\boldsymbol{Z})$

The Guth Approach to *DS*-FTA 🕮

- $m(\boldsymbol{A}_1) \equiv bel(\boldsymbol{A})$
- $m(\boldsymbol{A}_2) \equiv pl(\boldsymbol{A}) - bel(\boldsymbol{A})$
- $m(\boldsymbol{A}_3) \equiv 1 - pl(\boldsymbol{A})$
- $m(\boldsymbol{A}_1) + m(\boldsymbol{A}_2) + m(\boldsymbol{A}_3) = 1$
- Same for $\boldsymbol{B}$



Dempster-Shafer FTA Approach

Fault Tree Analysis

AND and OR Combination

- Similar to min/max operations

AND Gate According to Step ❺

- $m(\boldsymbol{Z}_1) = m(\boldsymbol{A}_1)\ m(\boldsymbol{B}_1)$
- $m(\boldsymbol{Z}_2) = m(\boldsymbol{A}_1)\ m(\boldsymbol{B}_2) + m(\boldsymbol{A}_2)\ m(\boldsymbol{B}_1) + m(\boldsymbol{A}_2)\ m(\boldsymbol{B}_2)$
- $m(\boldsymbol{Z}_3) = \ldots = m(\boldsymbol{A}_1)\ m(\boldsymbol{B}_3) + m(\boldsymbol{A}_2)\ m(\boldsymbol{B}_3) + m(\boldsymbol{A}_3)$

OR Gate According to Step ❺

- $m(\boldsymbol{Z}_1) = \ldots = m(\boldsymbol{A}_1) + m(\boldsymbol{A}_2)\ m(\boldsymbol{B}_1) + m(\boldsymbol{A}_3)\ m(\boldsymbol{B}_1)$
- $m(\boldsymbol{Z}_2) = m(\boldsymbol{A}_2)\ m(\boldsymbol{B}_2) + m(\boldsymbol{A}_2)\ m(\boldsymbol{B}_3) + m(\boldsymbol{A}_3)\ m(\boldsymbol{B}_2)$
- $m(\boldsymbol{Z}_3) = m(\boldsymbol{A}_3)\ m(\boldsymbol{B}_3)$

And	$\boldsymbol{A}_1$	$\boldsymbol{A}_2$	$\boldsymbol{A}_3$
$\boldsymbol{B}_1$	h_1	h_2	h_3
$\boldsymbol{B}_2$	h_2	h_2	h_3
$\boldsymbol{B}_3$	h_3	h_3	h_3

Or	$\boldsymbol{A}_1$	$\boldsymbol{A}_2$	$\boldsymbol{A}_3$
$\boldsymbol{B}_1$	h_1	h_1	h_1
$\boldsymbol{B}_2$	h_1	h_2	h_2
$\boldsymbol{B}_3$	h_1	h_2	h_3

Dempster-Shafer FTA Approach

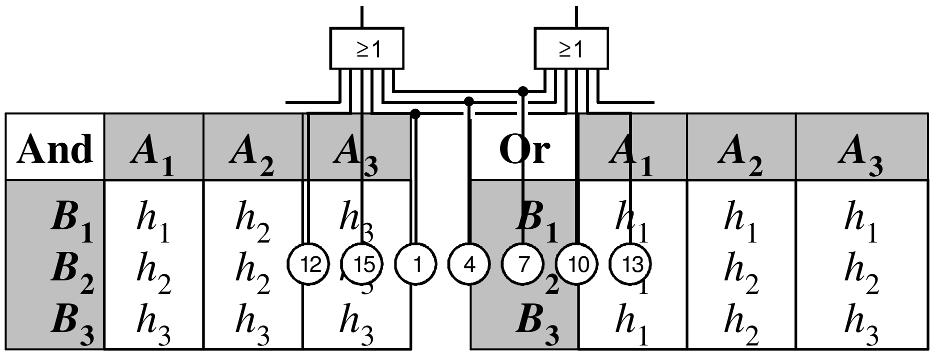
Fault Tree Analysis

Develop the path

- Output of the lower gate $\rightarrow m(\boldsymbol{Z}_1), m(\boldsymbol{Z}_2), m(\boldsymbol{Z}_3)$
- Input of the next upper gate $\rightarrow m(\boldsymbol{A}_1), m(\boldsymbol{A}_2), m(\boldsymbol{A}_3)$

Criticism 📖

- Interval arithmetic is more concise and efficient in operation than DST
  → However, fault tree structure may cause trouble with the sub-distributivity property of subtraction operations as known from the fuzzy FTA
- Multistate modelling, upper/lower probs, Bayesian networks …



Event Tree Analysis

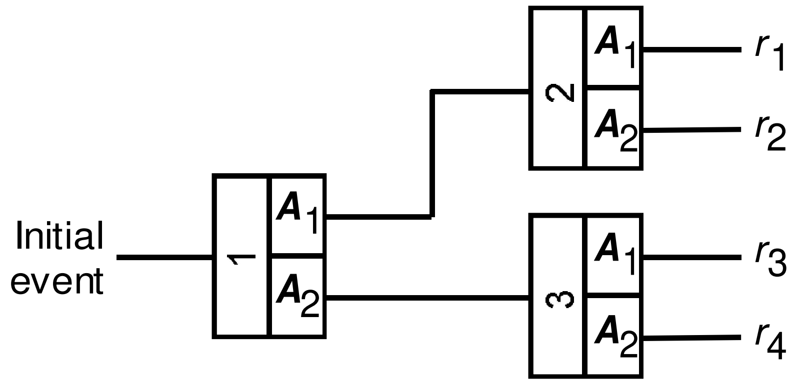
Brief Introduction

Detailed Introduction

- IEC 62502
- Proceedings 📖 → references

Five Steps of the ETA

- Step ❶ – List all possible initiating events
- Step ❷ – Identify functional responses
- Step ❸ – Define failure sequences
- Step ❹ – Assign probabilities to each step
- Step ❺ – Calculate the total probability of occurrence for each sequence



Dempster-Shafer ETA Approach

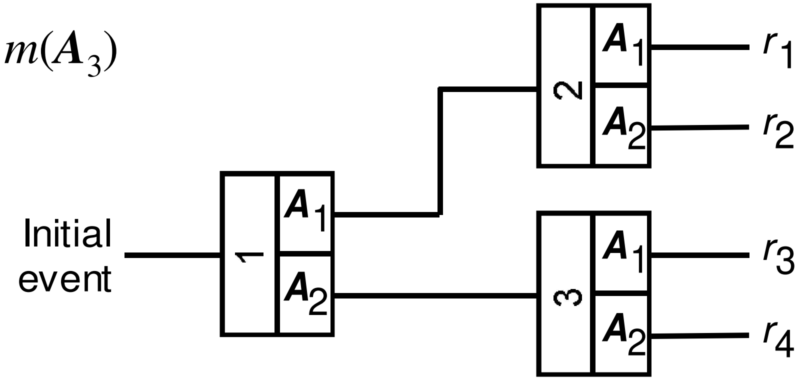
Event Tree Analysis

Scenario

- $\Omega = \{h_1, h_2, h_3\} \rightarrow$ {"failure", "no failure", "uncertain"}
- Inputs $\rightarrow$ data source gives 3 values $m(\boldsymbol{A}_1), m(\boldsymbol{A}_2), m(\boldsymbol{A}_3)$
- Output 1 $\rightarrow$ evidence measures for "failure"
- Output 2 $\rightarrow$ evidence measures for "no failure"

Evidence Measures

- $bel(\boldsymbol{Z}_1) = m(\boldsymbol{A}_1)$
- $pl(\boldsymbol{Z}_1) = m(\boldsymbol{A}_1) + m(\boldsymbol{A}_3)$
- $bel(\boldsymbol{Z}_2) = m(\boldsymbol{A}_2)$
- $pl(\boldsymbol{Z}_2) = m(\boldsymbol{A}_2) + m(\boldsymbol{A}_3)$

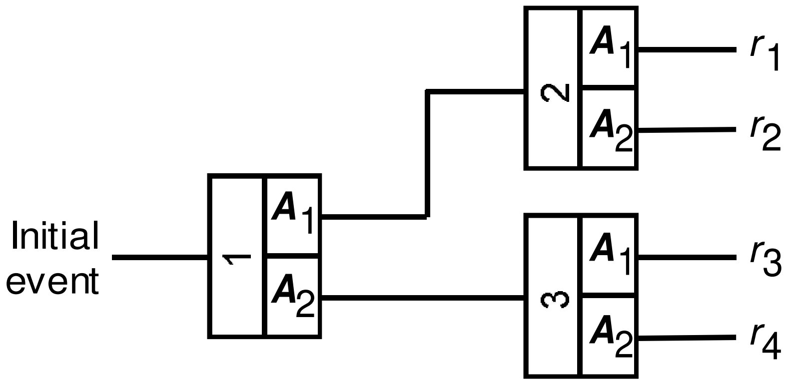


Dempster-Shafer ETA Approach

Event Tree Analysis

Procedure

- Calculating evidence measures of every bifurcation of the ET
- Then applying interval arithmetic
- More details → RCM



Reliability Centred Maintenance

Brief Introduction

Detailed Introduction

- IEC 60300-3-11
- Proceedings 🕮 → references

Seven Steps of the RCM Process

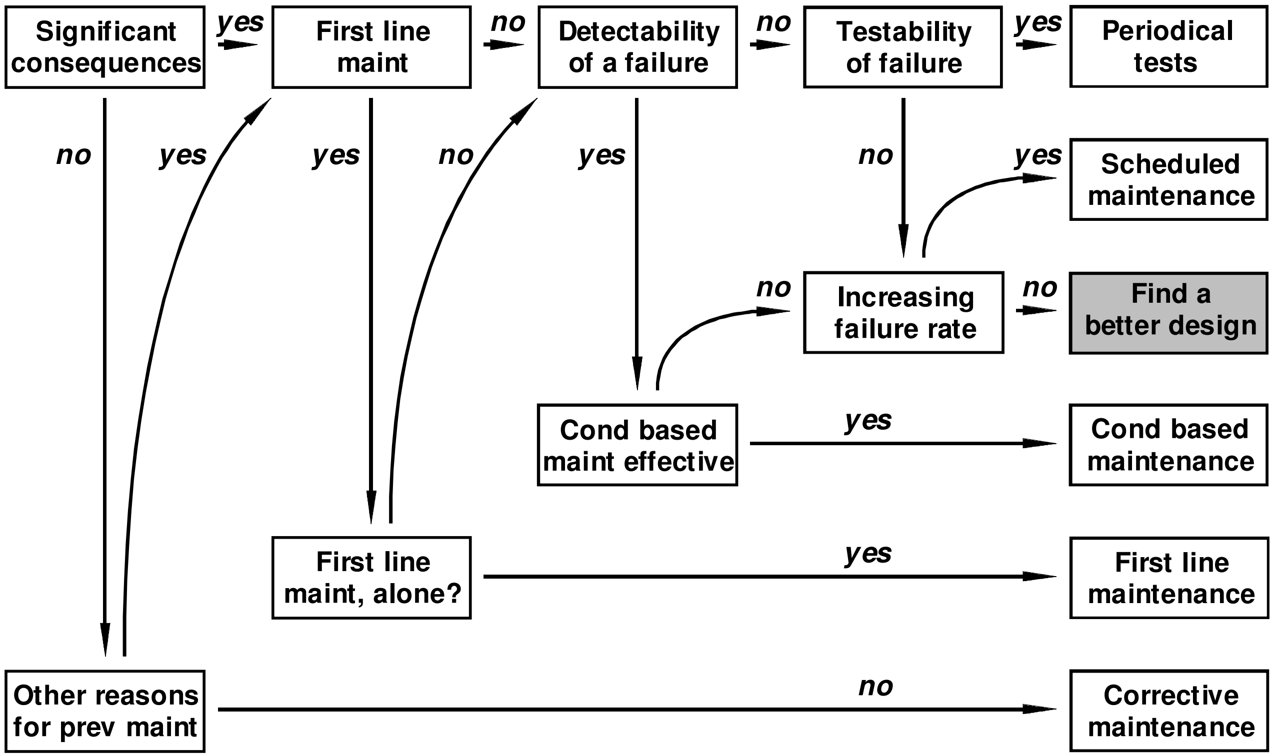
- Step ❶ – Establishing an expert group
- Step ❷ – Functional breakdown of the system
- Step ❸ – Conducting FMECA
- Step ❹ – Collecting of data
- Step ❺ – Tailoring the RCM decision diagram
- Step ❻ – Applying the RCM decision diagram
- Step ❼ – Documenting results

Brief Introduction

Reliability-centred Maintenance

RCM Decision Diagram – Objective

- Find a suitable strategy → component, module, system
- Framework of eight questions, six strategies

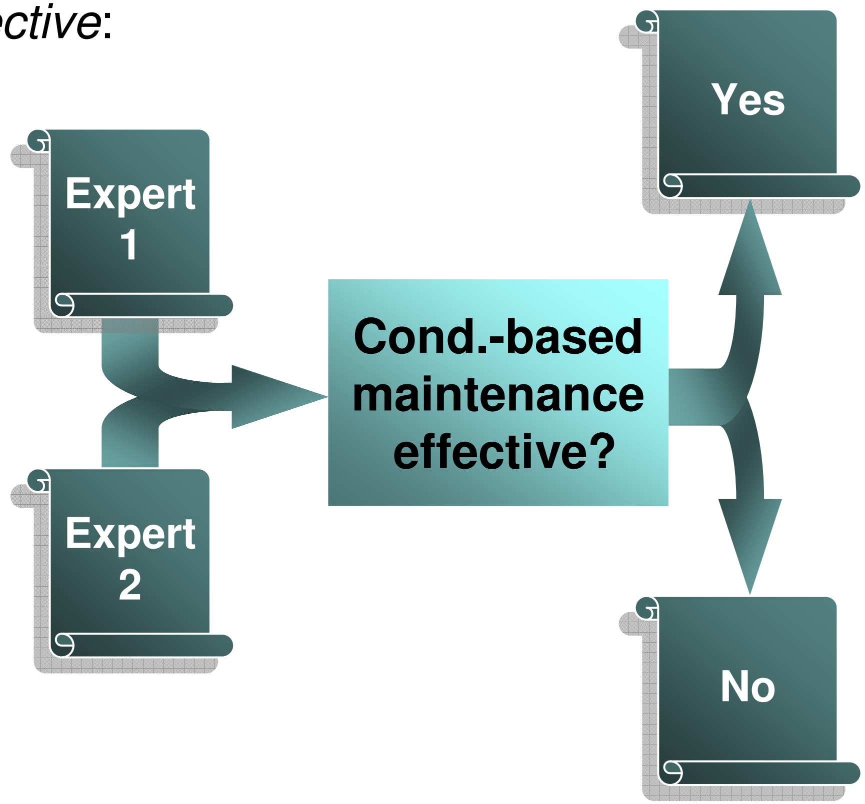


Expert Assessment

Reliability-centred Maintenance

_DS_-RCM Example

- *Condition-based maintenance effective*: Do methods exist for effective condition monitoring so that an item failure can be avoided?
- Two answers
- Two experts (example) → two statements

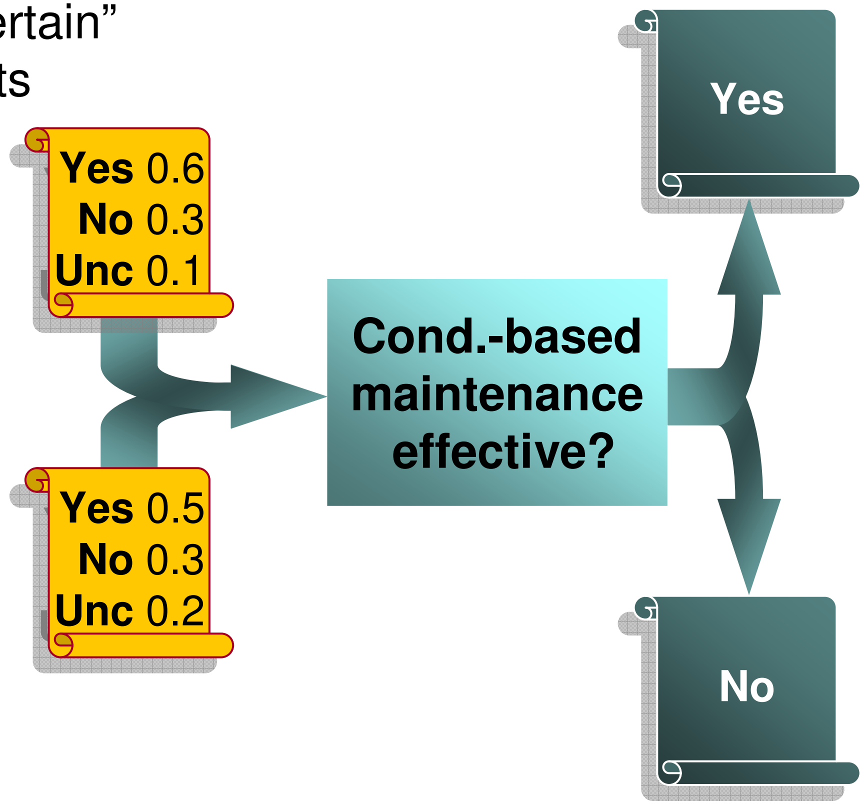


Input & Output

Reliability-centred Maintenance

Input

- Statements → “yes”, “no”, or “uncertain”
- Quantification → basic assignments



Input & Output

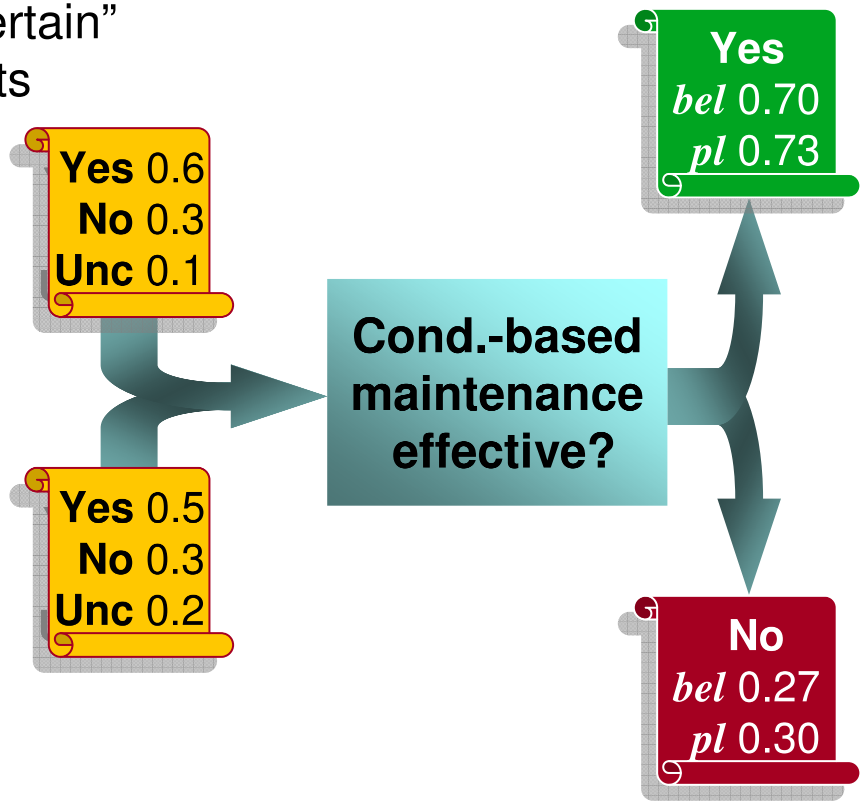
Reliability-centred Maintenance

Input

- Statements → “yes”, “no”, or “uncertain”
- Quantification → basic assignments

Output

- Values of evidential functions
- Certainty
  → 70% in “yes”
  → 27% in “no”
- Uncertainty
  → 3%



Weighted Recommendations

Reliability-centred Maintenance

Input

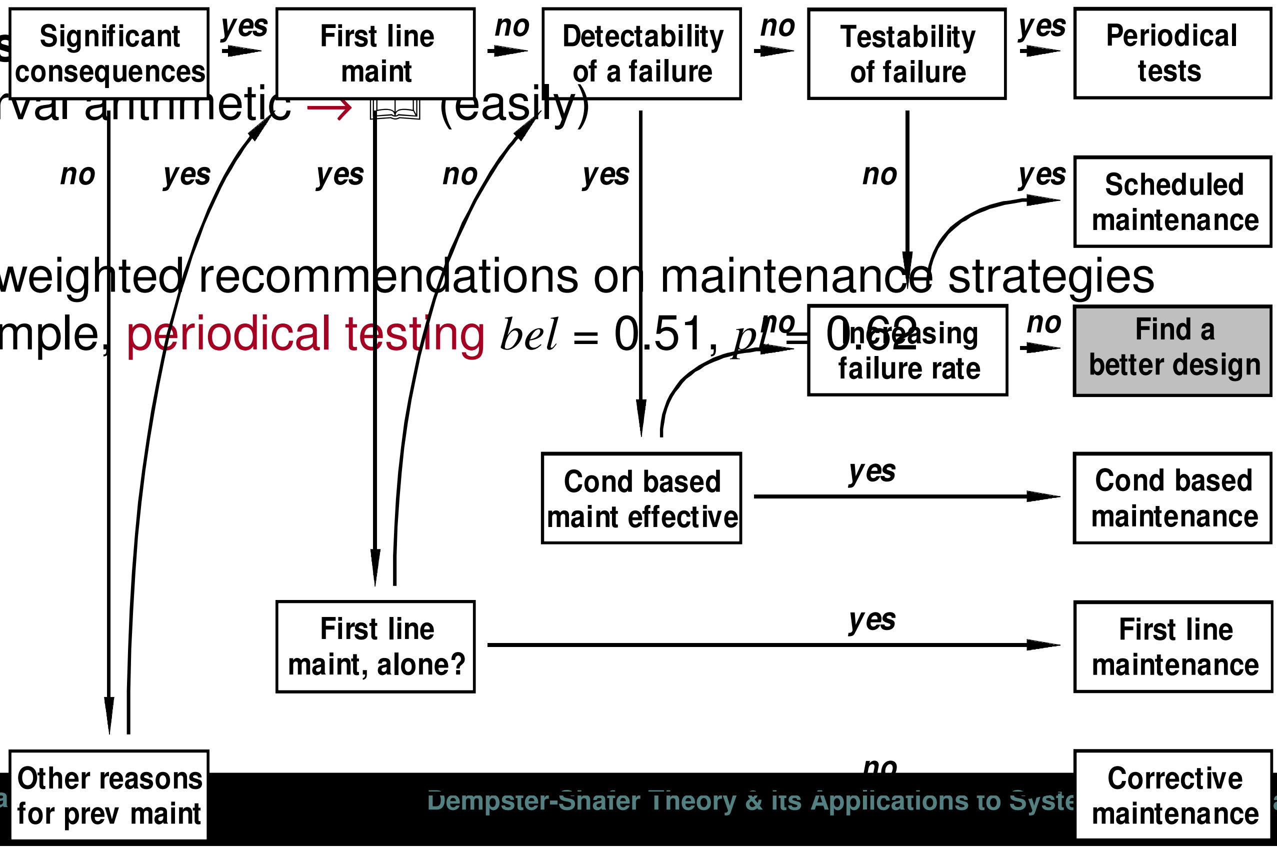
- Eight results of every "yes" or "no" decision
  → values of evidential functions bel and pl

Calculus

- Interval arithmetic → 📖 (easily)

Output

- Six weighted recommendations on maintenance strategies
- Example, periodical testing $bel = 0.51$, $pl = 0.62$



Further Analyses

Some Hints

Failure Mode, Effects and Criticality Analysis

- IEC 60812
- Dempster-Shafer approach → Section 4.1 Proceedings 🕮

Preliminary/Potential Hazard Analysis

- … same holds for PHA

Outline

Part 4

Part 1 – Fundamentals
- History
- Scenario
- Interpretations

Part 2 – Illustration
- The DS calculus in eight steps

Part 3 – Applications to System Safety & Reliability Modelling
- FTA – Fault Tree Analysis
- ETA – Event Tree Analysis
- RCM – Reliability-centred Maintenance
- Further Analyses

Part 4 – Outroduction
- Pros & Cons

Some Comments

Outroduction

Disclaimer

- Nobody is forced to apply DST instead of Probability Theory
- No uncertainties → no DS modelling recommended (?)
- Prefer modelling uncertainties by probabilities? → apply probabilities
- Prefer … interval arithmetic? → apply interval arithmetic
- Prefer … fuzzy sets? → apply fuzzy sets
- Applying DST is an option, not an obligation

Disadvantages of the DST

Outroduction

Disadvantages (also valid for Probabilities)

- *Lack of introspection or assessment strategies*
  unreasonable requirement for precision $\rightarrow m$
  difficult to determine with necessary precision
- *Instability*
  estimated m may be influenced by the conditions of its estimation
- *Ambiguity*
  ambiguous or imprecise judgement could not be expressed
  by the evidence measures

Disadvantages

- Frame of discernment $\Omega \rightarrow$ given k hypotheses $\rightarrow$ up to 2^k elements
  larger number of values $\rightarrow$ than after the Probability Theory
- DST does not offer a procedure for implementation of a diagnostic system

Advantages of the DST

Outroduction

Advantages

- Calculus describes & quantifies the subjective viewpoint as an assessment for an unknown objective fact
- Applying DST is an option, not an obligation
- "If the only tool you have is a hammer, you tend to see every problem as a nail." 🕮 Abraham Maslow

Fundamentals of the Dempster-Shafer Theory and its Applications to System Safety and Reliability Modelling

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