Modelling of Uncertainties in Reliability Centred Maintenance – a Dempster-Shafer Approach

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Reliability Centred Maintenance

Introduction

Objective

- RCM → find a suitable maintenance strategy
- *DS*-RCM → express uncertainties of experts in reasoning
- *DS*-RCM → give weighted recommendations during the RCM process

What's new?

- Evidence measures belief and plausibility are applied instead of
  → either "yes" or "no" decisions
  → probabilities (🕮 ESREL 98)
  → fuzzy membership functions (🕮 ESREL 98)

What's not new?

- RCM process conducted
- RCM diagram applied
- Fundamentals of the Dempster-Shafer Theory (🕮 Proceedings)

Reliability Centred Maintenance

Brief Introduction

Detailed Introduction

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

Five Steps of the RCM Process

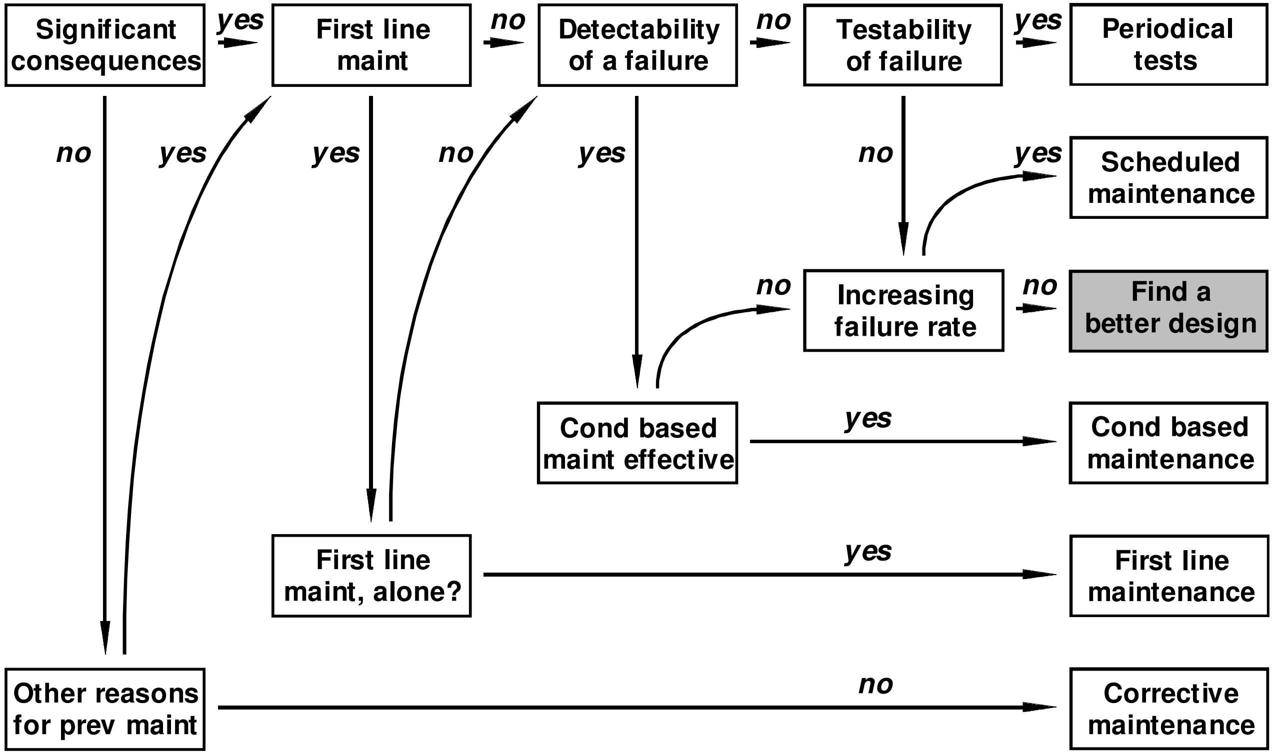
- Step ❶ – Establishing an expert group
- Step ❷ – Functional breakdown of the system
- Step ❸ – Collecting of data
- Step ❹ – Tailoring & applying the RCM decision diagram
- Step ❺ – Documenting results

The RCM Decision Diagram

Brief Introduction

RCM Decision Diagram – Objective

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

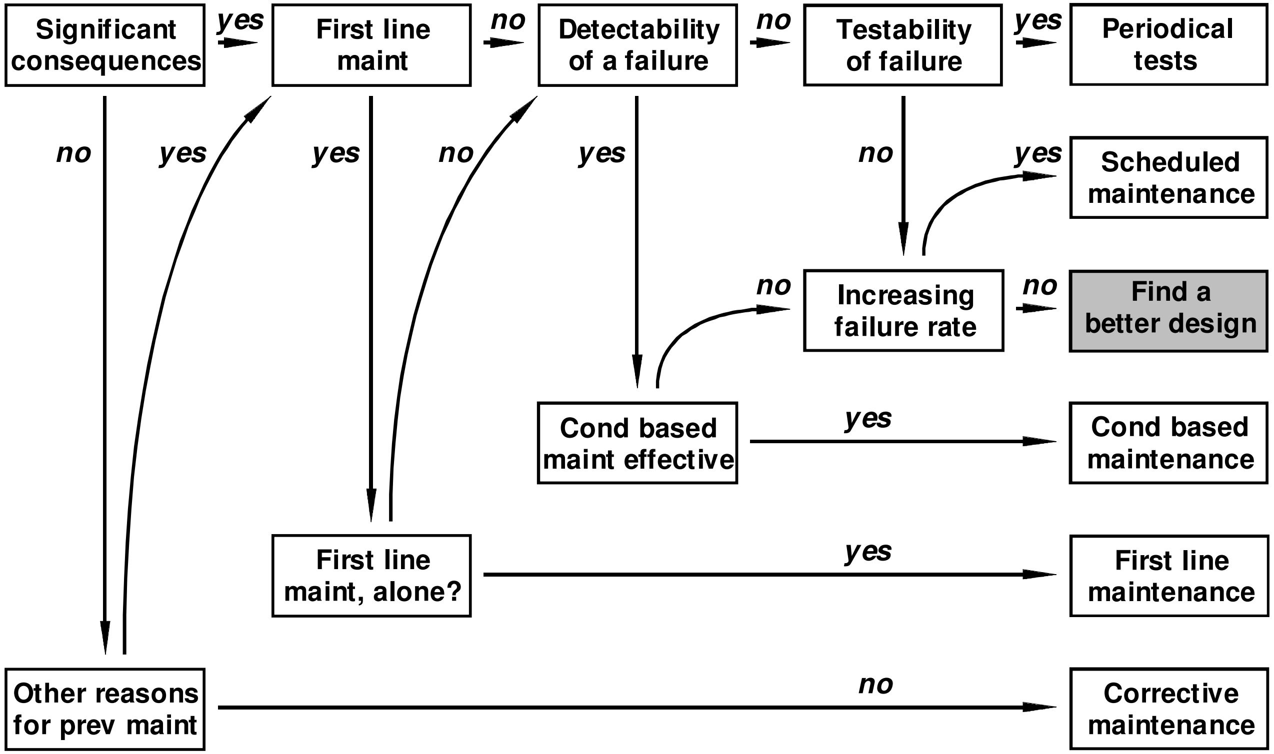


The RCM Decision Diagram

Brief Introduction

Note

- Example → mix of *Det Norske Veritas* & *Marintek* [📖]
- Tailor the diagram to your needs!



Significant consequences

yes

First line maint

no

Detectability of a failure

no

Testability of failure

yes

Periodical tests

no

yes

yes

no

yes

no

yes

Scheduled maintenance

no

Increasing failure rate

no

Find a better design

Cond based maint effective

yes

Cond based maintenance

First line maint, alone?

yes

First line maintenance

Other reasons for prev maint

no

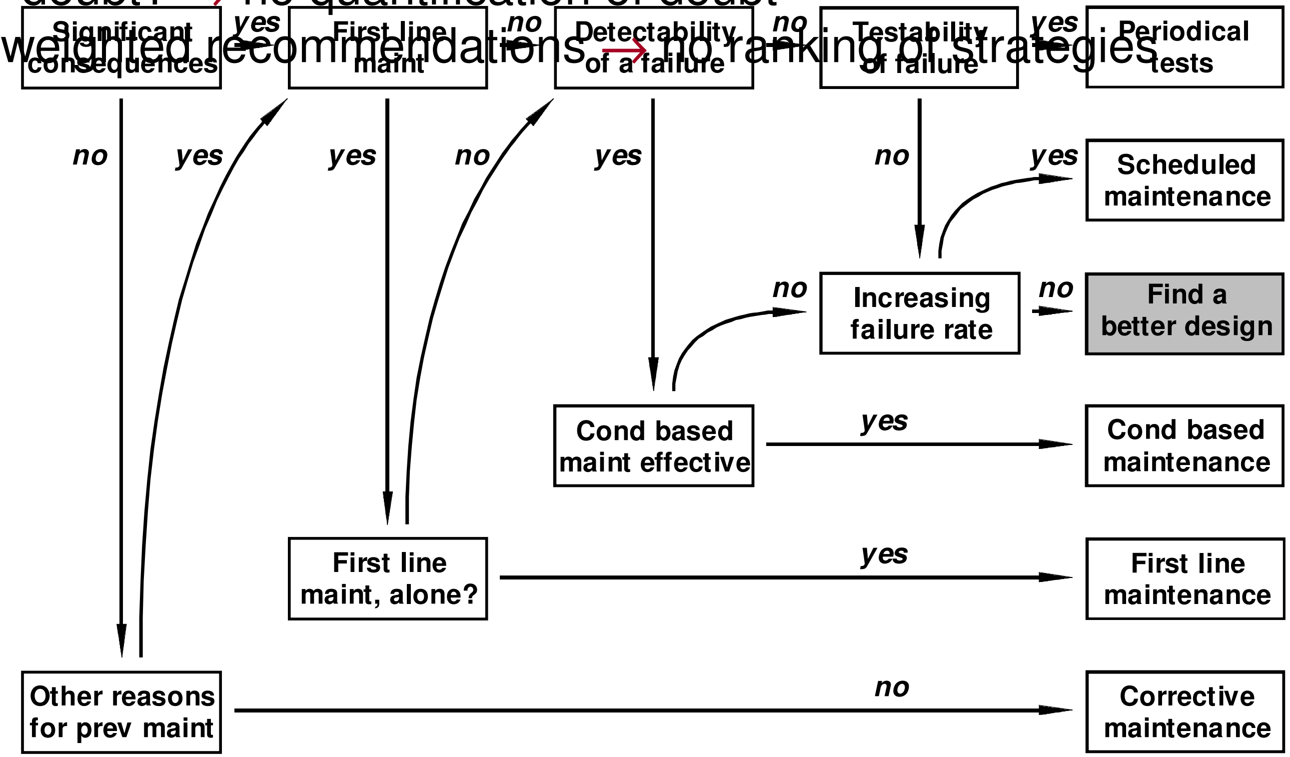
Corrective maintenance

The Qualitative Approach

Brief Introduction

Drawbacks of Qualitative RCM

- Expert group → consensus required
- “Yes” or “no” → no percentage answer
- Any doubt? → no quantification of doubt
- No weighted recommendations → no ranking of strategies



The Probabilistic Approach

Brief Introduction to *p*-RCM

Introducing Probabilities

- Decision variable x_i, $i = 1, \ldots, 8$ (eight questions/decisions)
- "yes" $\rightarrow x_i = 1$, "no" $\rightarrow x_i = 0$
- Expected value p_i

Some Interpretations of p_i

- Probability that an expert answers "yes" to question i
- Degree of an expert's belief that "yes" is the right decision
- Mean value for decision i resulting from questioning many experts
- Expected value of the binomial distributed decision variable x_i

Results r_i

- Decision variable r_i, $i = 1, \ldots, 6$ (six maintenance strategies)
- Apply the *Event Tree* method
- $r_1 = (p_1 + q_1 \cdot p_2)(q_3 + p_3 \cdot q_4)\, q_5 \cdot p_6\,, \ldots, r_6 = q_1 \cdot q_2 \leftarrow$ *DS*-RCM

Tailoring a Dempster-Shafer RCM

Modelling

Scenario

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

Frame of Discernment

- Only one single question/decision is considered
- Representation → universal set Ω

The Scenario

Modelling

Scenario

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

Hypotheses

- Single hypothesis → one answer to a question
  → “yes”, “no”, or “uncertain”
- Hypotheses → unique and not overlapping and mutually exclusive
- Universal set Ω represents → $\Omega = \{$“yes”, “no”, “uncertain”$\}$
- Subsets of Ω → single or conjunctions of hypotheses
- Set of all subsets → power set 2^{Ω}

The Scenario

Modelling

Scenario

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

Data Sources

- Expert group
  → e.g. service eng., maintenance personnel, system eng., reliability eng.
- Task → give subjective quantifiable statements
- Basis → data, intuition & experience

The Scenario

Modelling

Scenario

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

Pieces of Evidence

- Piece of evidence → expert judgement
- Assignment: piece evidence → hypothesis
- Assignment strength → quantified by m

The Scenario

Modelling

Scenario

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

Pieces of Evidence

- Piece of evidence → expert judgement (data, intuition & experience)
- Assignment
  (evidence → hypothesis) corresponds to (cause → consequence)
- Assignment
  (1 p-of-e) assigned to (1 hypothesis or 1 set of hypotheses)
  (different p-of-e) may not be assigned to (same hypothesis nor set)
- Quantification
  strength of implication → $m(\boldsymbol{A})$

Fundament

The Dempster-Sh

This is no probability mapping

Sets

- Ω universal set
- set, contains a single hypothe theses

Ba ent

Again & again, these are NO probabilities

- $m,$ quantifies if the eleme
- $m:$ $1]$ mapping
- $=1$ all statements of an expert are normalised
- 0 focal element
- $= 0$ simplicity (**not** required)

Differences in Properties to Probabilities

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

Evidential Functions

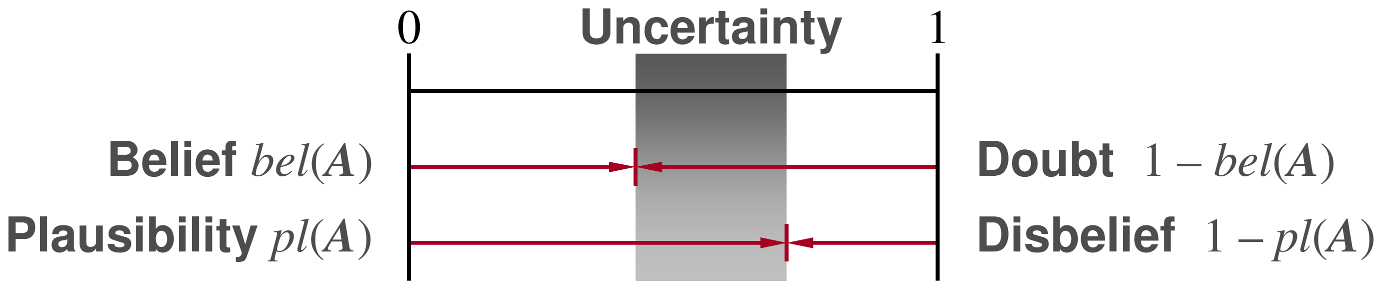
Dempster-Shafer Calculus

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.
- $pl(\boldsymbol{A}) = \sum_{B \cap A \neq \phi} m(\boldsymbol{B})$

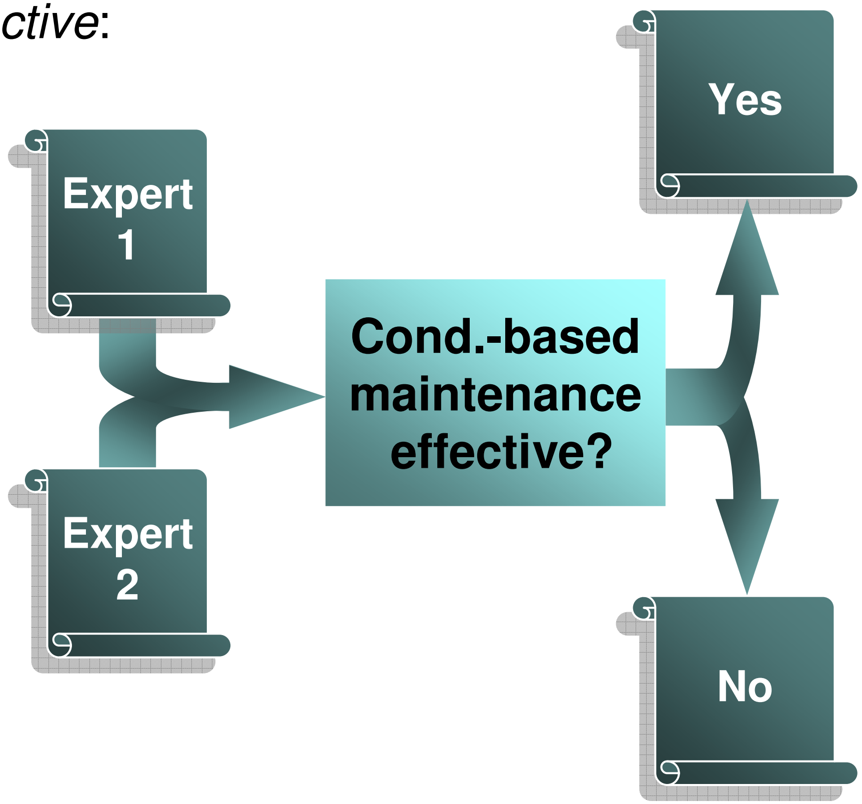


Expert Assessment

RCM Application

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

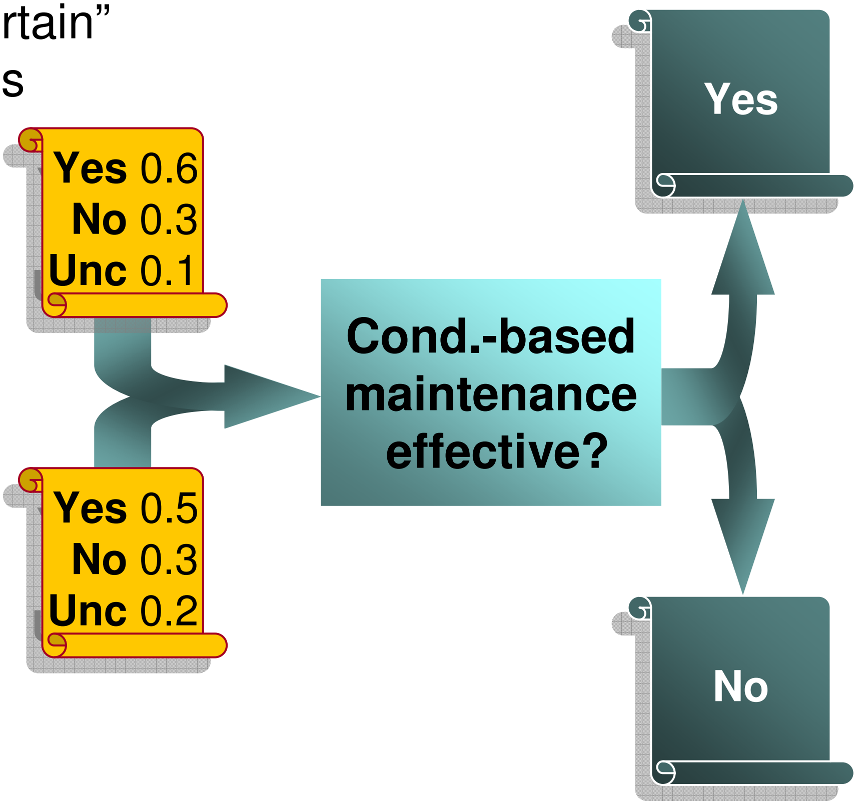


Input & Output

RCM Application

Input

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



Input & Output

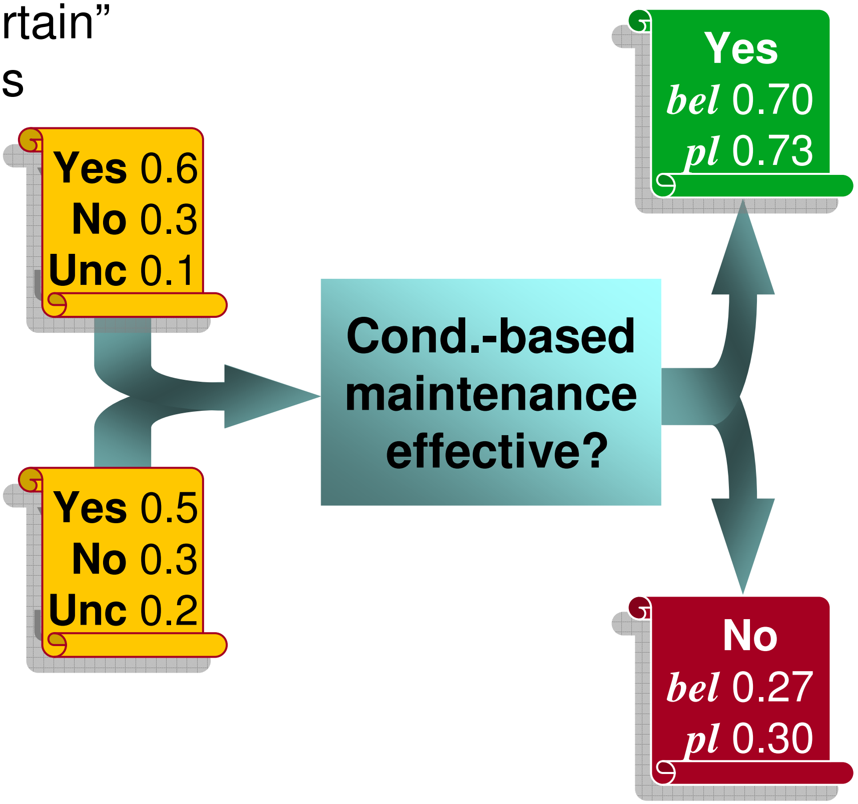
RCM Application

Input

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

Output

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



Yes 0.6
No 0.3
Unc 0.1

Yes 0.5
No 0.3
Unc 0.2

Cond.-based maintenance effective?

Yes
bel 0.70
pl 0.73

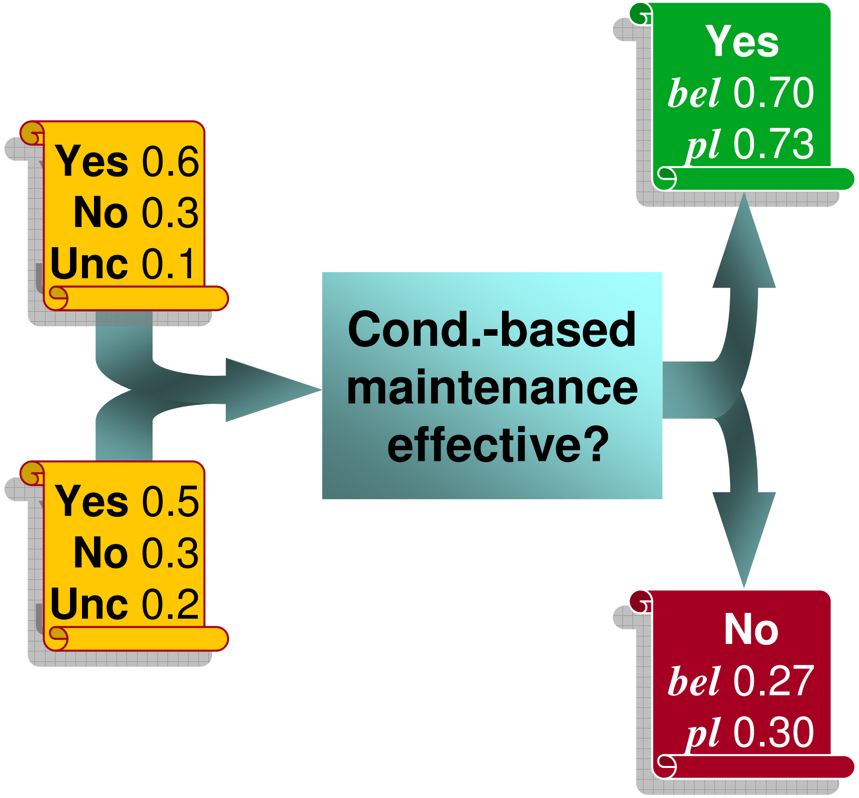
No
bel 0.27
pl 0.30

Complements

RCM Application

Complements

- Belief in "yes" **versus**
  doubt in "yes" ≡ plausibility of "no"
- Plausibility of "yes" **versus**
  disbelief in "yes" ≡ belief in "no"



Weighted Recommendations

RCM Application

Input

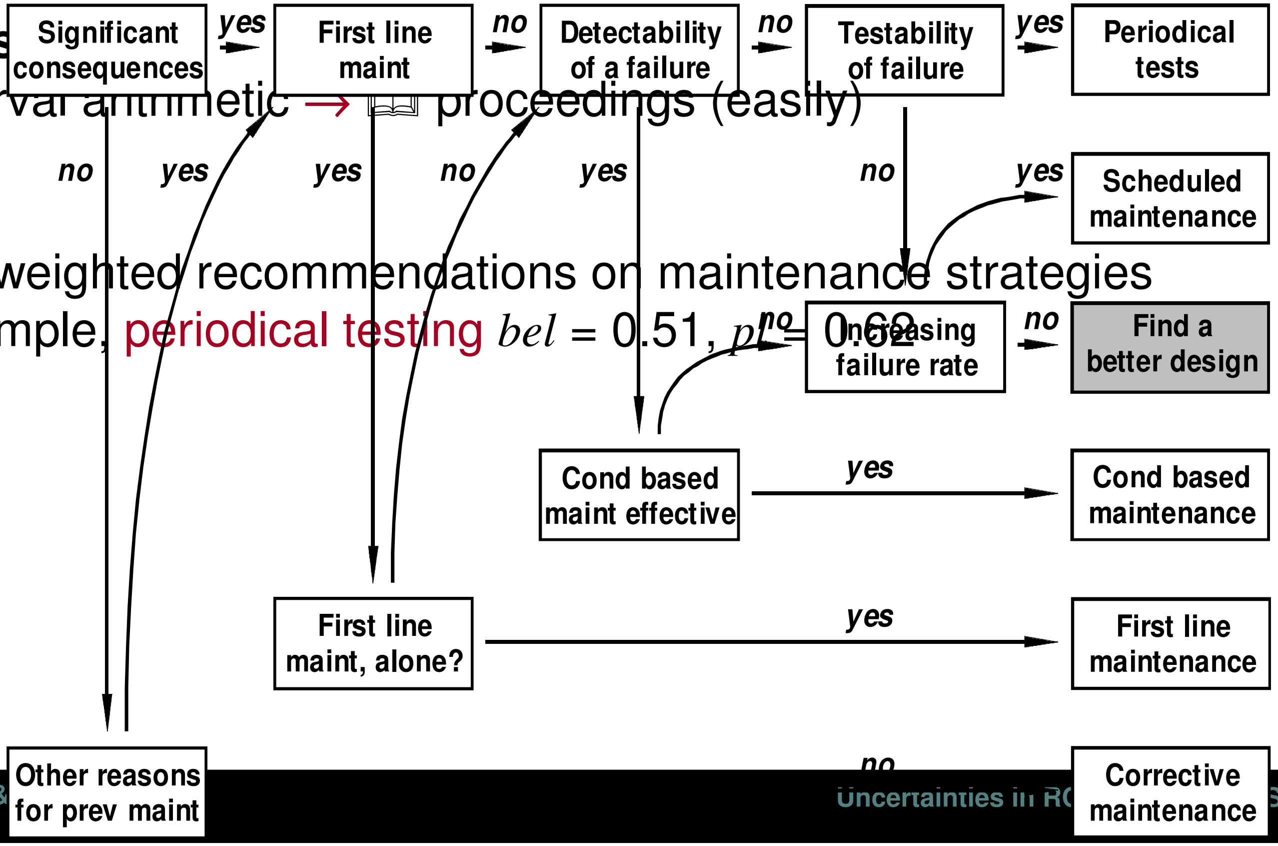
- Eight results of every “yes” or “no” decision
  → values of evidential functions bel and pl

Calculus

- Interval arithmetic → 📖 proceedings (easily)

Output

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



Conclusion

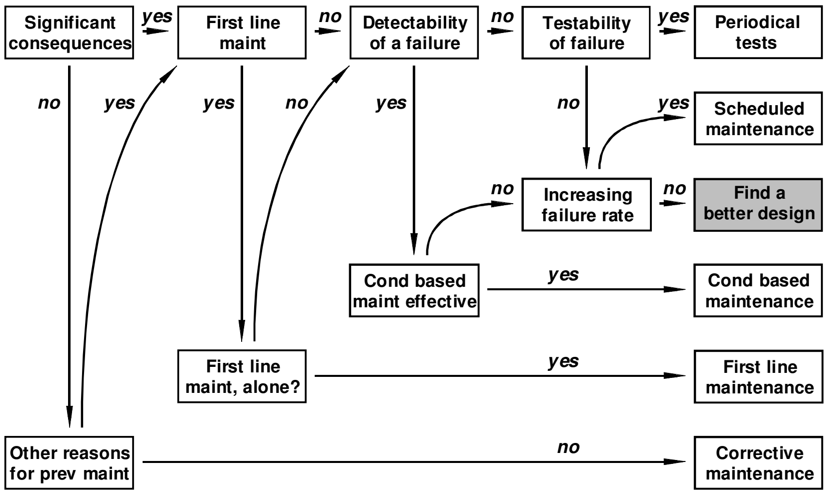
Outroduction

Comments on the Methods

- Probabilistic, fuzzy-, and Dempster-Shafer RCM → hardly comparable
- *Prob* → one-dimensional value
- *Fuzzy* → graph, peak, results depend on defuzzification method
- *DS* → interval, no peak

Comments on the Results

- Results are close to each other
- Results based on
  → different interpretations
- Interpretations based on
  → different theoretical concepts

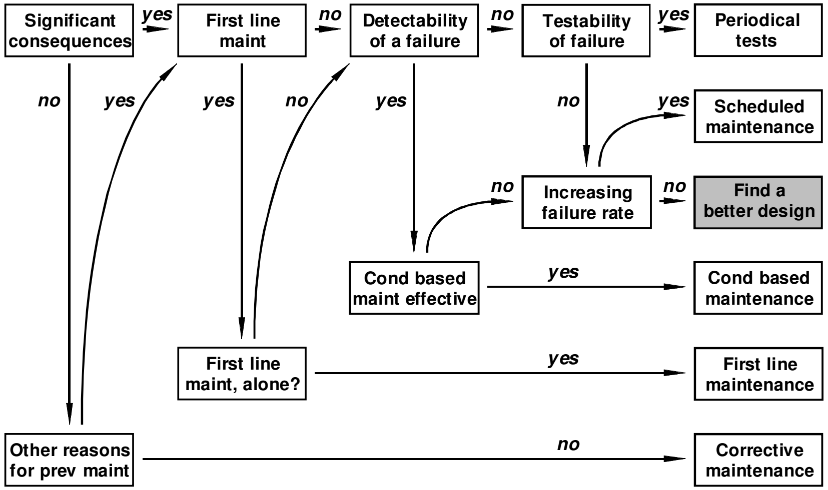


Conclusion

Outroduction

Even more Comments

- DS calculus → easy to apply → less than one page 🕮
- Experts feel more comfortable → degrees instead “yes” or “no”
- Not forced to single strategy → second best?
- etc. → 🕮
- *DS*-RCM offers a different kind of flavour to the maintenance analyst



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