Uncertainty Modeling in Health Risk Assessment and Groundwater Resources Management

Elcin Kentel

Dr. Mustafa M. Aral

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Probabilistic-fuzzy health risk modeling

- Health risk analysis of multi-pathway exposure to contaminated water

uncertain parameters

variable parameters

currently treated with statistical approaches

- ❖ randomness

not all uncertainties are due to randomness

fuzzy set theory

- ❖ scarce or incomplete data
- ❖ measurement errors
- ❖ data obtained from expert judgement
- ❖ subjective interpretation of available info.

Human health risk assessment –

simultaneous probabilistic & possibilistic uncertainty propagation

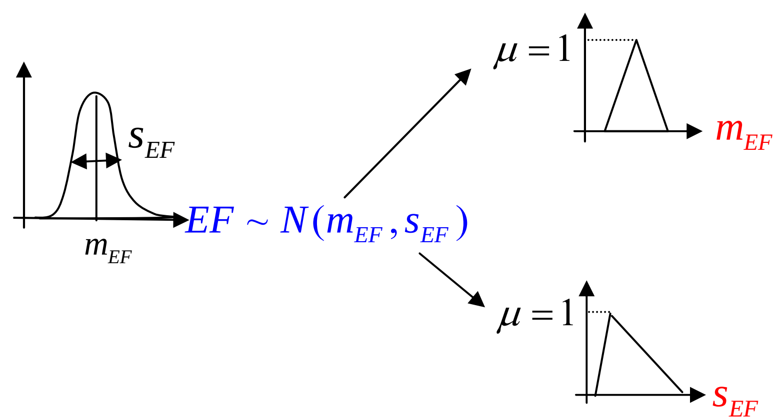
Probabilistic-fuzzy health risk modeling

2D MC vs 2D Fuzzy MC health risk assessment

$$Risk = \sum_{r=ing.,inh.,der.} Risk_r = \sum_{r=ing.,inh.,der.} CDI_r \,.\, CPF_r$$

$$CDI_{r \atop r=ing.,inh.} = C_r \frac{IR_r \,.\, EF \,.\, ED}{BW \,.\, AT} \qquad CDI_{r \atop r=der.} = C_r \frac{SA.F \,.\, PC \,.\, ET \,.\, EF \,.\, ED \,.\, CF}{BW \,.\, AT}$$

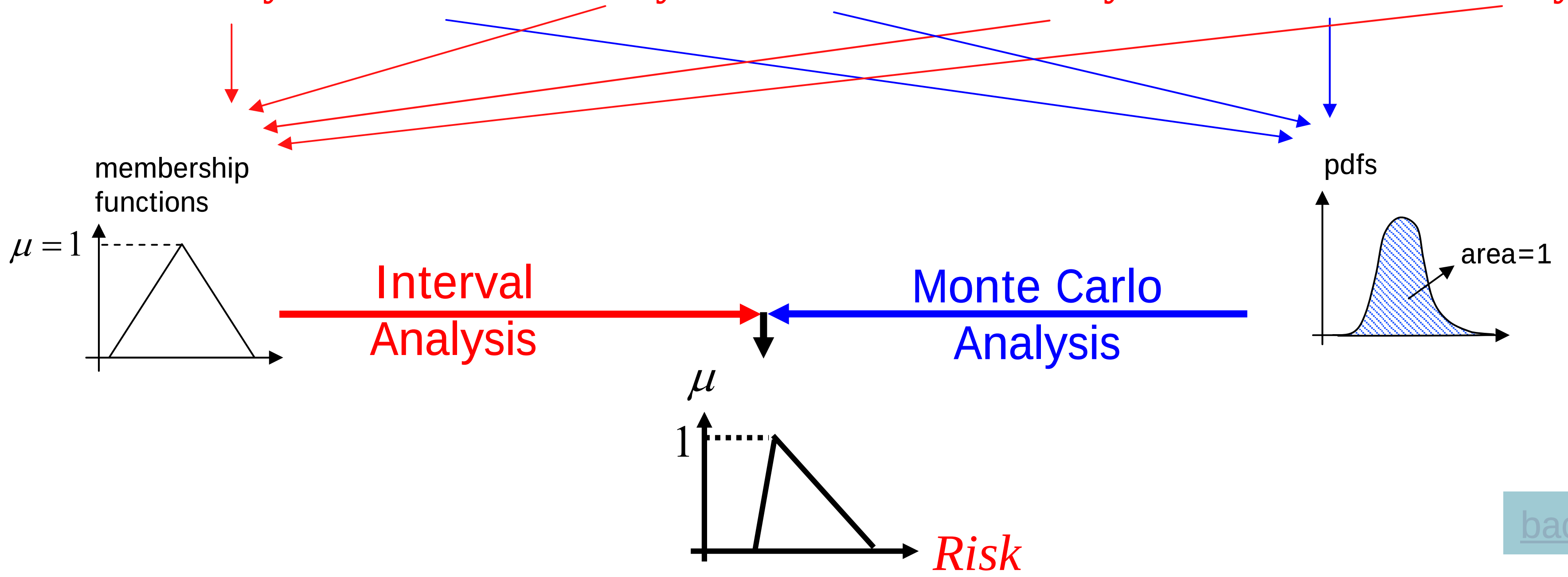
$$\begin{aligned} Risk = C.\Big[\; & \underset{\text{fuzzy}}{\underbrace{f(V_{1_{ing}},\dots,V_{n_{ing}}).CPF_{ing}}} + \\ & \underset{\text{random}}{\underbrace{g(V_{1_{inh}},\dots,V_{m_{inh}}).CPF_{inh}}} + \\ & \underset{\text{fuzzy}}{\underbrace{q(V_{1_{der}},\dots,V_{k_{der}}).CPF_{der}}}\Big] \end{aligned}$$



Probabilistic-fuzzy health risk modeling

$$Risk = CW.\Big[\overbrace{f(V_{1_{ing}},\dots,V_{n_{ing}}).CPF_{ing}}^{\text{ingestion}} + \overbrace{g(V_{1_{inh}},\dots,V_{m_{inh}}).CPF_{inh}}^{\text{inhalation}} + \overbrace{q(V_{1_{der}},\dots,V_{k_{der}}).CPF_{der}}^{\text{dermal contact}}\Big]$$

fuzzy **random** **fuzzy** **random** **fuzzy** **random** **fuzzy**



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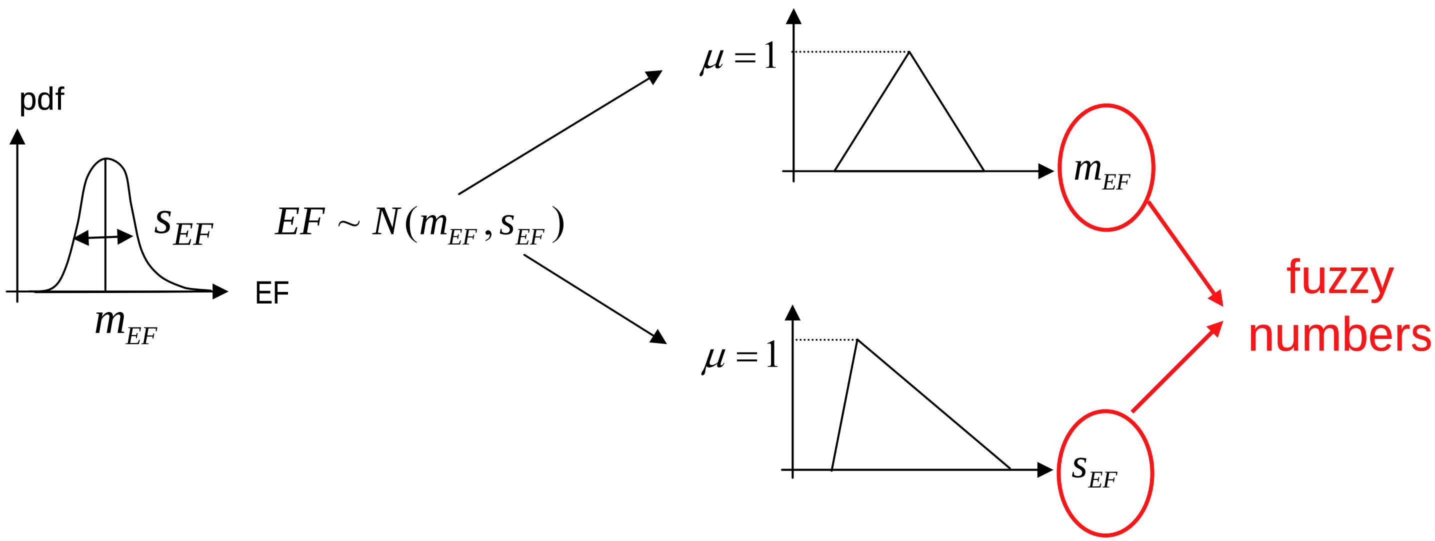
2D Fuzzy Monte Carlo

$$CDI = \frac{C.IR.EF.ED}{BW.AT}$$

$$Risk = CDI.CPF$$



variability
in EF

uncertainty
in parameters

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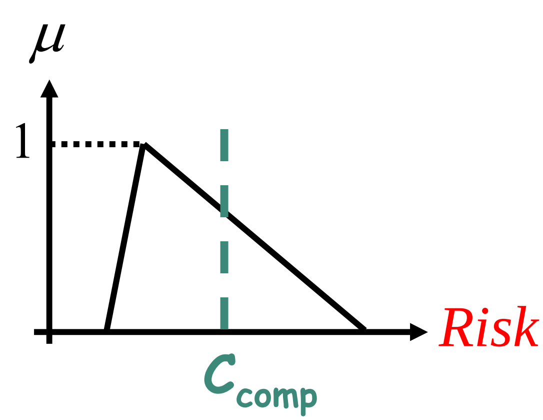
Human health risk assessment – simultaneous probabilistic & possibilistic uncertainty propagation

Probabilistic-fuzzy health risk modeling

2D MC versus 2D Fuzzy MC health risk assessment



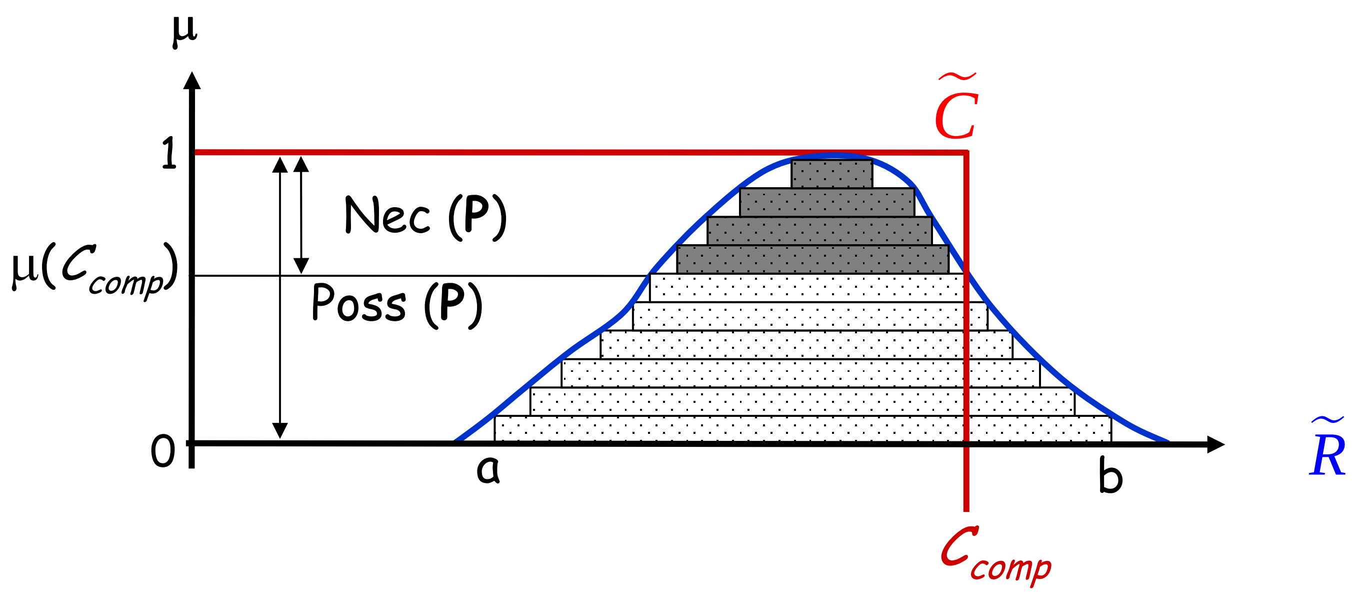
Is the fuzzy risk **acceptable** with respect to this compliance criterion ?

or

validity of P

P: "the fuzzy risk, R is smaller than or equal to the compliance criterion, C_{comp}"

The Possibility and The Necessity Measures



Any evidence that supports **P** → Poss (**P**) = 1
(dotted sections)

Evidence that supports impossibility of **not P** → Nec (**P**) = 1-μ(C_{comp})
(shaded sections)

Currently recommended

- Comé et al. (1997) suggested → possibility measure
  <u>necessity measure</u>

  ↑ conservative

  Human health risk assessment

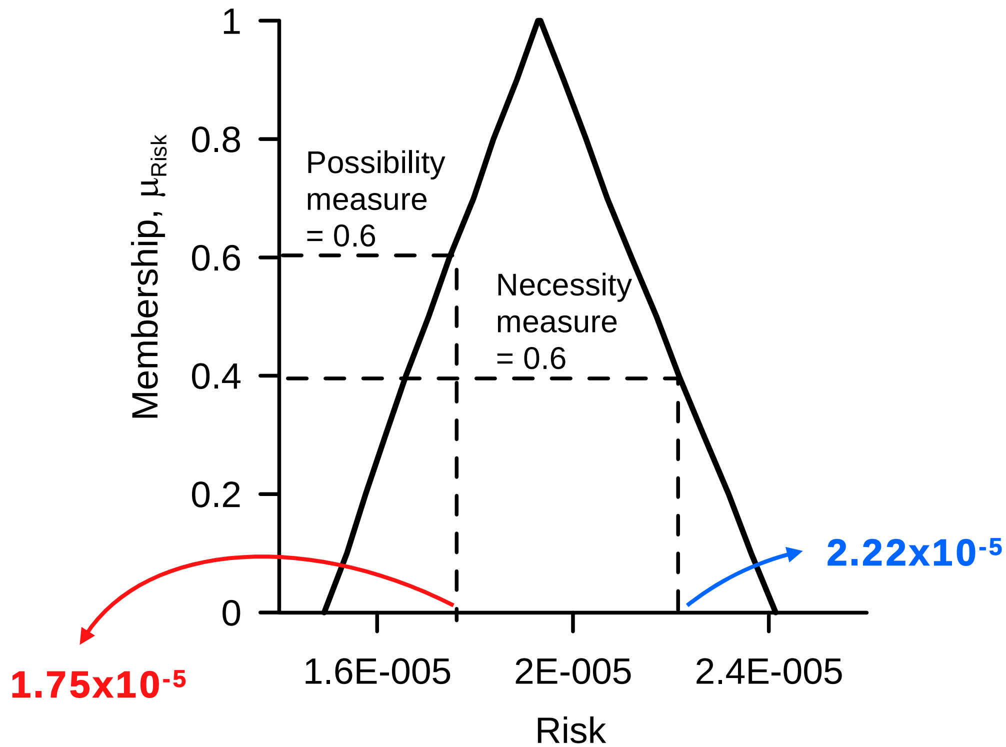
- Only necessity measure → some valuable information lost

  ↓ more informative

  Combined measure

Compliance for Possibilistic RA

- Guideline: the fuzzy risk R should not exceed 2.0×10^{-5} for a possibility/necessity measure of 0.6



ris… …ty

The necessity measure of a proposition is always smaller than its possibility measure

risk correspon…g to a necessity

The necessity measure is conservative

NOT acceptable

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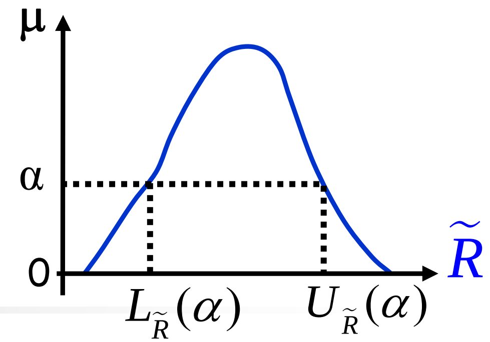
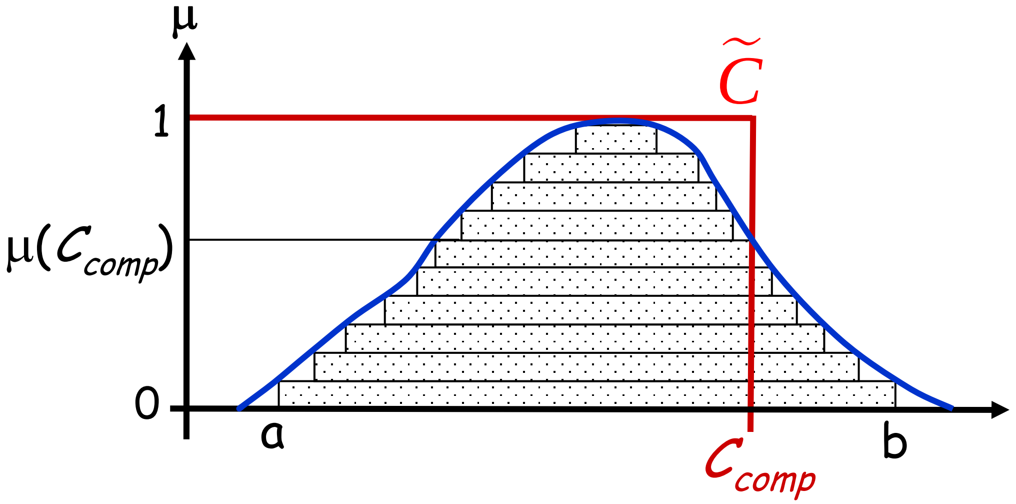
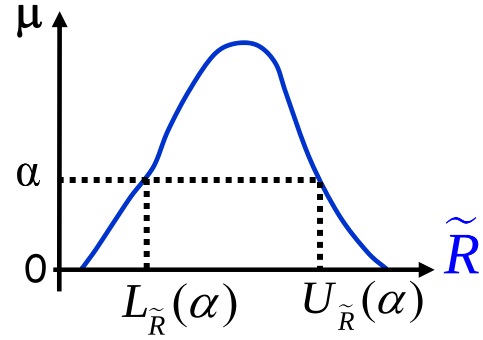
The risk tolerance measure





$$T(\boldsymbol{P}) = \begin{cases} 0 & C_{comp} \le L_{\tilde{R}}(0) \\ \frac{1}{2}\left(\beta Poss\left(\boldsymbol{P}\right) + \gamma Nec\left(\boldsymbol{P}\right)\right) & L_{\tilde{R}}(0) < C_{comp} < U_{\tilde{R}}(0) \\ 1 & C_{comp} \ge U_{\tilde{R}}(0) \end{cases}$$



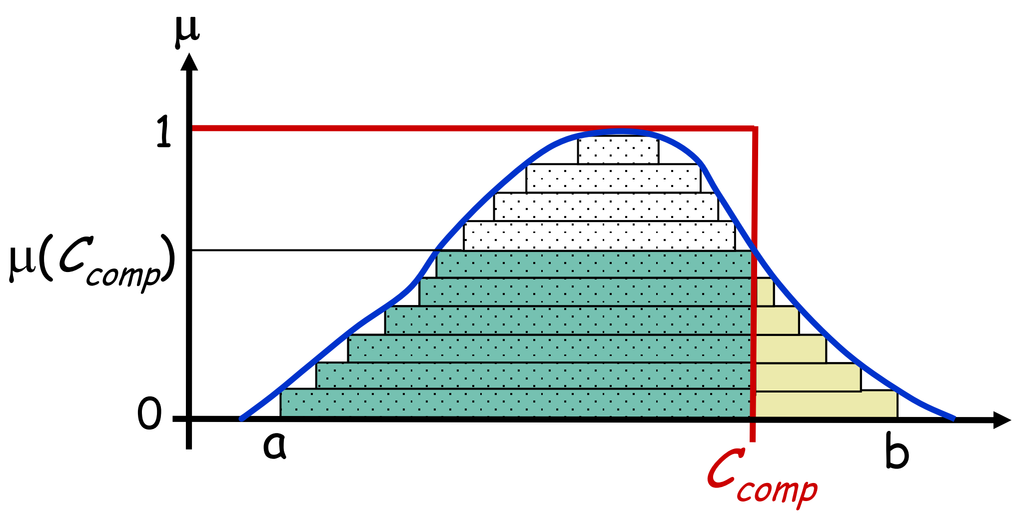
The risk tolerance measure

$$T(\boldsymbol{P}) = \begin{cases} 0 & C_{comp} \le L_{\tilde{R}}(0) \\ \frac{1}{2}\left(\beta Poss(\boldsymbol{P}) + \gamma Nec(\boldsymbol{P})\right) & L_{\tilde{R}}(0) < C_{comp} < U_{\tilde{R}}(0) \\ 1 & C_{comp} \ge U_{\tilde{R}}(0) \end{cases}$$

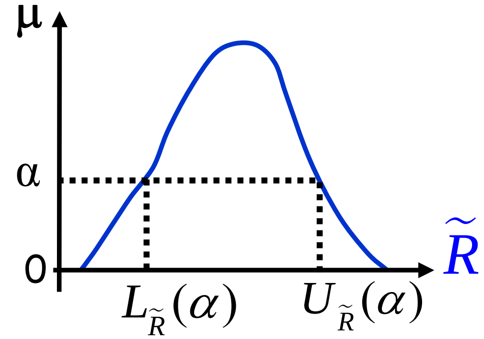
$$\beta = \frac{A_{poss\_l}}{A_{poss\_T}}$$

$$A_{poss\_l} = \int_0^{\mu_{\tilde{R}}(C_{comp})} \alpha[C_{comp} - L_{\tilde{R}}(\alpha)]d\alpha$$

$$A_{poss\_T} = \int_0^{\mu_{\tilde{R}}(C_{comp})} \alpha[U_{\tilde{R}}(\alpha) - L_{\tilde{R}}(\alpha)]d\alpha$$



The risk tolerance measure

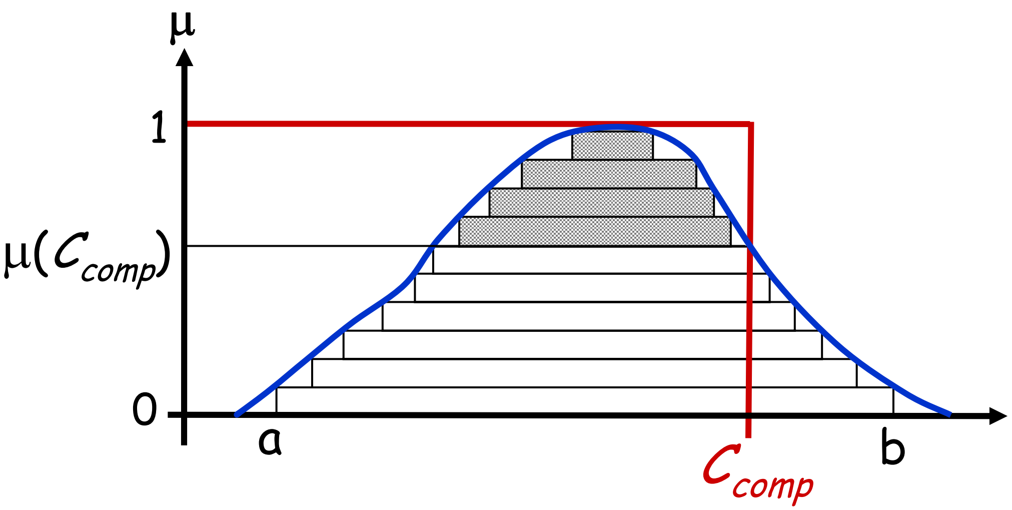


$$T(\boldsymbol{P}) = \begin{cases} 0 & C_{comp} \le L_{\tilde{R}}(0) \\ \frac{1}{2}\left(\beta Poss(\boldsymbol{P}) + \gamma Nec(\boldsymbol{P})\right) & L_{\tilde{R}}(0) < C_{comp} < U_{\tilde{R}}(0) \\ 1 & C_{comp} \ge U_{\tilde{R}}(0) \end{cases}$$

$$\gamma = \frac{A_{nec\_l}}{A_{nec\_T}}$$

$$A_{nec\_l} = \int_0^{\mu_{\tilde{R}}(C_{comp})} \alpha[C_{comp} - L_{\tilde{R}}(\alpha)]d\alpha$$

$$A_{nec\_T} = \int_0^{\mu_{\tilde{R}}(C_{comp})} \alpha[U_{\tilde{R}}(\alpha) - L_{\tilde{R}}(\alpha)]d\alpha$$



both areas are defined for $U_{\tilde{R}}\left(\mu_{\tilde{R}}\left(C_{comp}\right)\right) = C_{comp}$

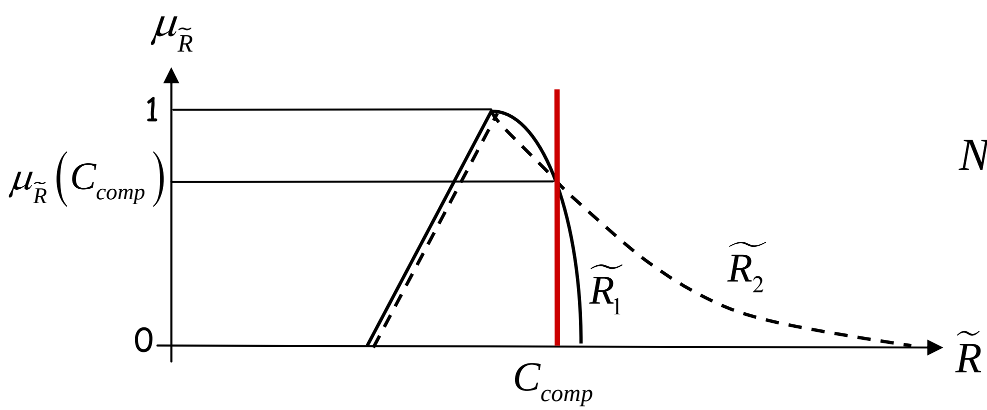
Coefficient for Necessity

$$\gamma = \frac{A_{nec\_l}}{A_{nec\_T}}$$

$$A_{nec\_l} = \begin{cases} 0 & L_{\tilde{R}}\left(M_{\tilde{R}}\left(C_{comp}\right)\right) = C_{comp} \\ \int_0^{\mu_{\tilde{R}}(C_{comp})} \alpha[C_{comp} - L_{\tilde{R}}(\alpha)]d\alpha & U_{\tilde{R}}\left(M_{\tilde{R}}\left(C_{comp}\right)\right) = C_{comp} \end{cases}$$

$$A_{nec\_T} = \int_0^{\mu_{\tilde{R}}(C_{comp})} \alpha[U_{\tilde{R}}(\alpha) - L_{\tilde{R}}(\alpha)]d\alpha$$

Effect of membership function on the measures

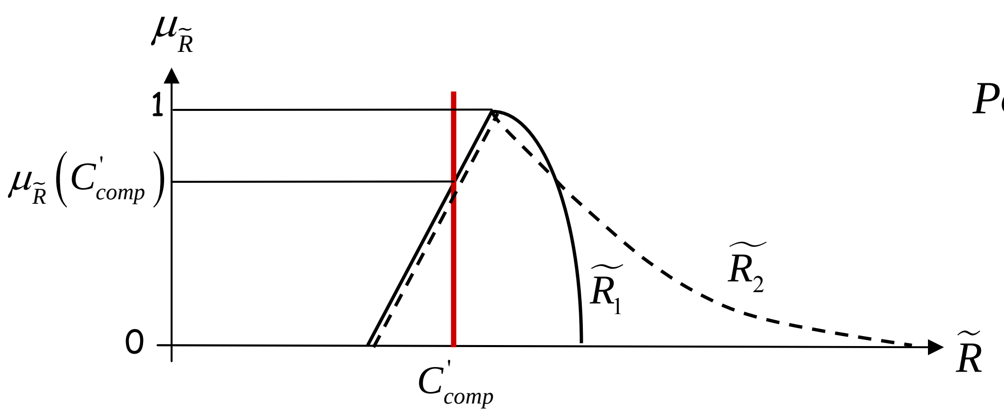


$$Poss\left(\tilde{R}_1 \le \tilde{C}\right) = Poss\left(\tilde{R}_2 \le \tilde{C}\right) = 1$$

$$Nec\left(\tilde{R}_1 \le \tilde{C}\right) = Nec\left(\tilde{R}_2 \le \tilde{C}\right) = 1 - \mu_{\tilde{R}}\left(C_{comp}\right)$$

$$T\left(\tilde{R}_1 \le \tilde{C}\right) > T\left(\tilde{R}_2 \le \tilde{C}\right)$$

Degree of compliance of $\tilde{R}_1$ is greater than that of $\tilde{R}_2$



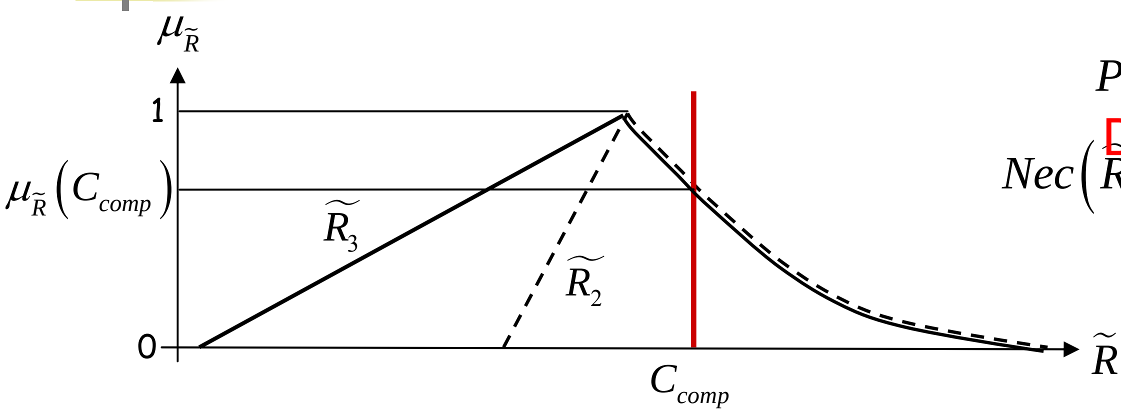
$$Poss\left(\tilde{R}_1 \le \tilde{C}'\right) = Poss\left(\tilde{R}_2 \le \tilde{C}'\right) = \mu_{\tilde{R}}\left(C'_{comp}\right)$$

$$Nec\left(\tilde{R}_1 \le \tilde{C}'\right) = Nec\left(\tilde{R}_2 \le \tilde{C}'\right) = 0$$

$$T\left(\tilde{R}_1 \le \tilde{C}'\right) > T\left(\tilde{R}_2 \le \tilde{C}'\right)$$

Degree of compliance of $\tilde{R}_1$ is greater than that of $\tilde{R}_2$

Effect of membership function on the measures

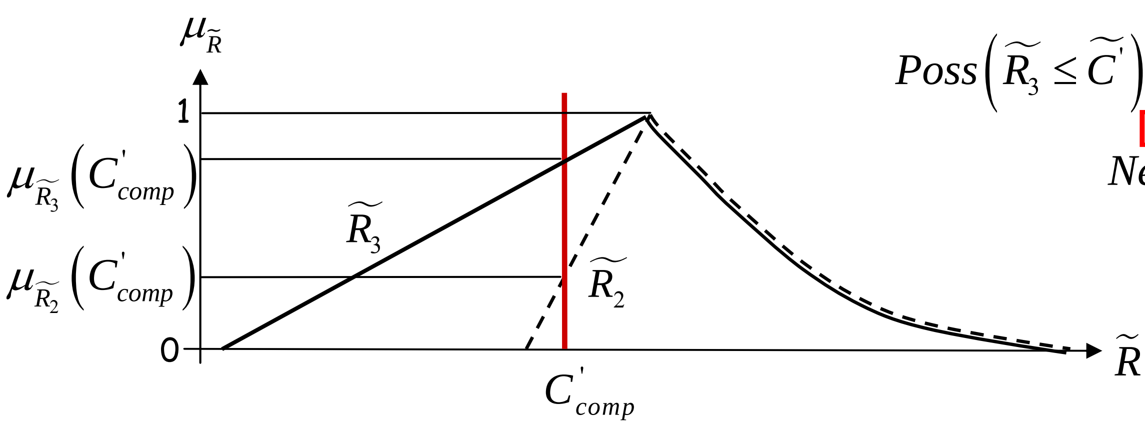


$$Poss\left(\widetilde{R}_3 \le \widetilde{C}\right) = Poss\left(\widetilde{R}_2 \le \widetilde{C}\right) = 1$$

$$Nec\left(\widetilde{R}_3 \le \widetilde{C}\right) = Nec\left(\widetilde{R}_2 \le \widetilde{C}\right) = 1 - \mu_{\widetilde{R}}\left(C_{comp}\right)$$

Degree of compliance of $\widetilde{R}_3$ is greater than that of $\widetilde{R}_2$

$$T\left(\widetilde{R}_3 \le \widetilde{C}\right) > T\left(\widetilde{R}_2 \le \widetilde{C}\right)$$



$$Poss\left(\widetilde{R}_3 \le \widetilde{C'}\right) = \mu_{\widetilde{R}_3}\left(C'_{comp}\right) > Poss\left(\widetilde{R}_2 \le \widetilde{C'}\right) = \mu_{\widetilde{R}_2}\left(C'_{comp}\right)$$

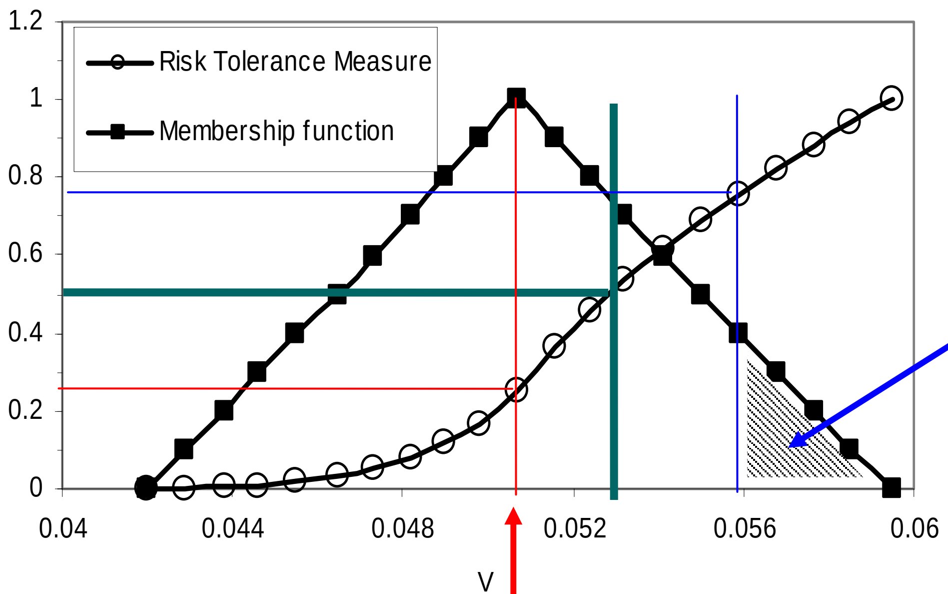
$$Nec\left(\widetilde{R}_3 \le \widetilde{C'}\right) = Nec\left(\widetilde{R}_2 \le \widetilde{C'}\right) = 0$$

Degree of compliance of $\widetilde{R}_3$ is greater than that of $\widetilde{R}_2$

$$T\left(\widetilde{R}_3 \le \widetilde{C'}\right) > T\left(\widetilde{R}_2 \le \widetilde{C'}\right)$$

Reasonable Minimum Risk Tolerance Value

$\mu_{\tilde{V}}$, *Risk Tolerance*



To have a RT of 0.75 only this shaded region is allowed to lie on the right of the design criteria

If the design criteria is here the RT=0.25

A minimum risk tolerance value of 0.5 seems reasonable

Conclusions for Risk Tolerance Measure

- To make decisions about compliance of a fuzzy risk with respect to a crisp guideline
- Include all available information: possibility measure & necessity measure
- Establishment of a standard procedure needs careful examination of the results of real case possibilistic and hybrid risk assessment studies. For ex., necessity measure might be preferable for decision making in a school district.