Aalto-yliopisto
Perustieteiden
korkeakoulu

Selection of Air Combat Tactics using a Multi-Attribute Decision Analysis Model with Incomplete Preference Information

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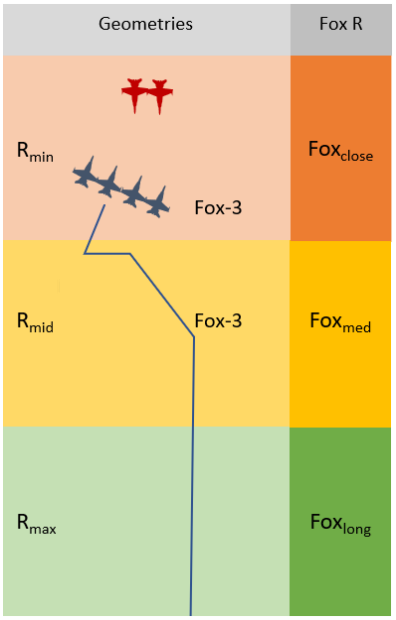
Decision Making in Air-to-Air Combat

- A **flight** comprises four fighter aircraft
- Fighter controllers and Fighter allocators
- Tactics, Techniques and Procedures (TTP)
  - Geometry alternatives (Range)
  - Launch range alternatives (Fox)

”Viper 1, Wizard, single group straight ahead, two contacts, hostile.”

Photos by Finnish Defense Forces (puolustusvoimat.fi)

”Viper 1, fox 3 on eastern.”
”Viper 3, fox 3 on western.”
”Viper 1, splash, bugging out.”



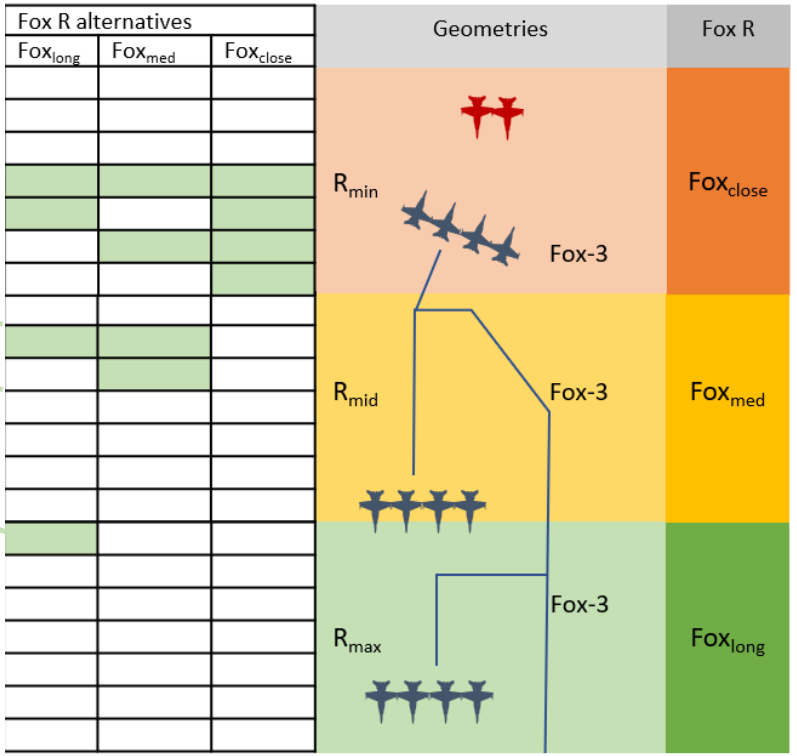
Course of Action (COA)

- COA consists of four separate TTPs – one for each flight
- Seven viable TTPs

4 close-range TTPs

2 mid-range TTPs

1 long-range TTP



⇒ 7×7×7×7 = 2401 COAs

Commander's Intent

Which COA should we choose?

Objective: Multi-Attribute Decision Analysis Model Providing "Best" COAs

- Additive value function to measure and rank COAs

Overall value of COA *x*: $$v(x) = \sum_{i=1}^{n} w_i v_i(x_i),$$

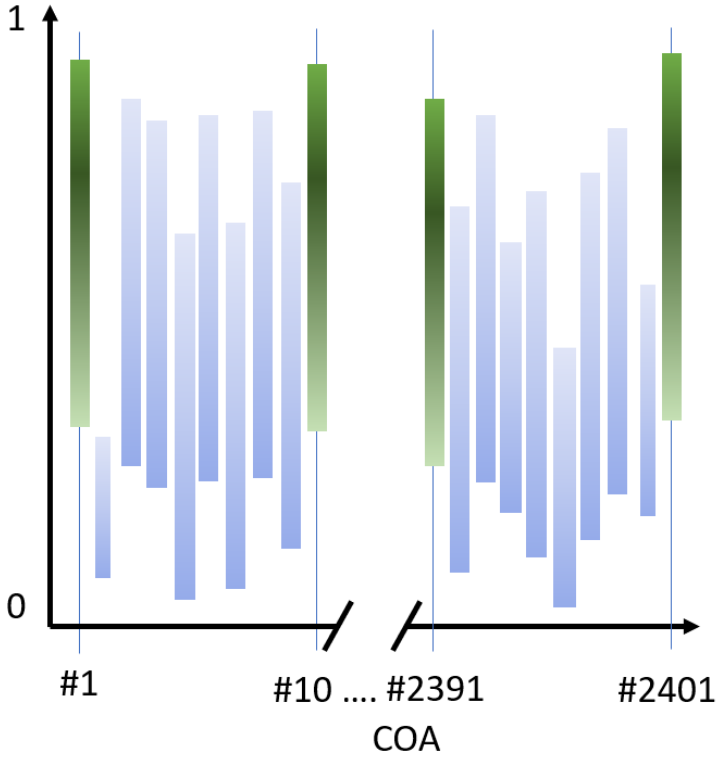
w_i weight of attribute i; x_i measurement level of x w.r.t. attribute i;

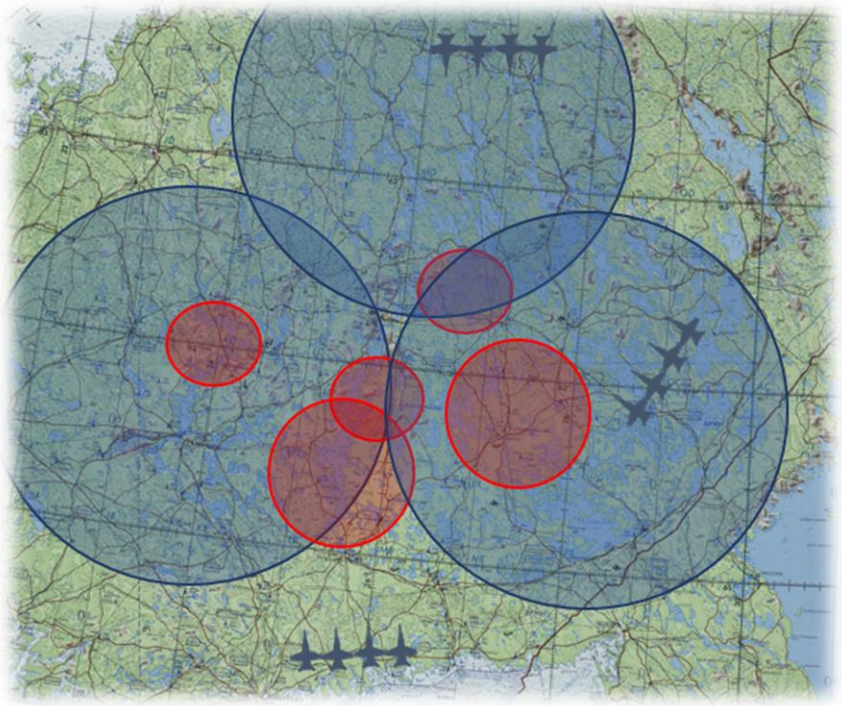
v_i single attribute value function of attribute i – attribute scoring

- Attributes: Probability of Kill (PK), Probability of Survival (PS), Efficiency of Missiles (EM)
- Commander's intent represented as **incomplete** preference information - Feasible weights $$w_{PK} \geq w_{PS} \geq w_{EM}$$

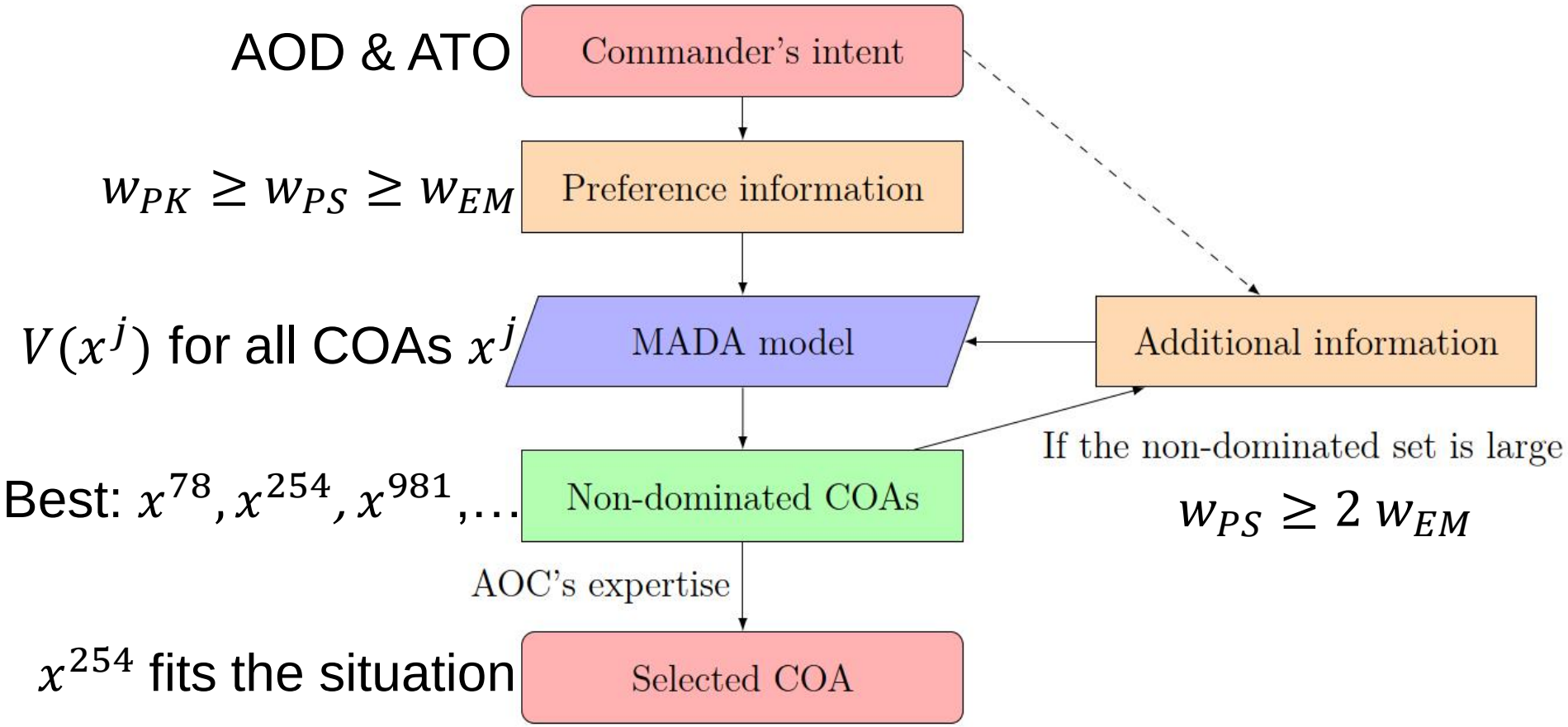
Specifications and Restrictions

- Find a set of non-dominated COAs
- Ignore all geographical / additional restrictions





Multi-Attribute Decision Analysis (MADA) Model in Action



Implementation in MATLAB and Excel

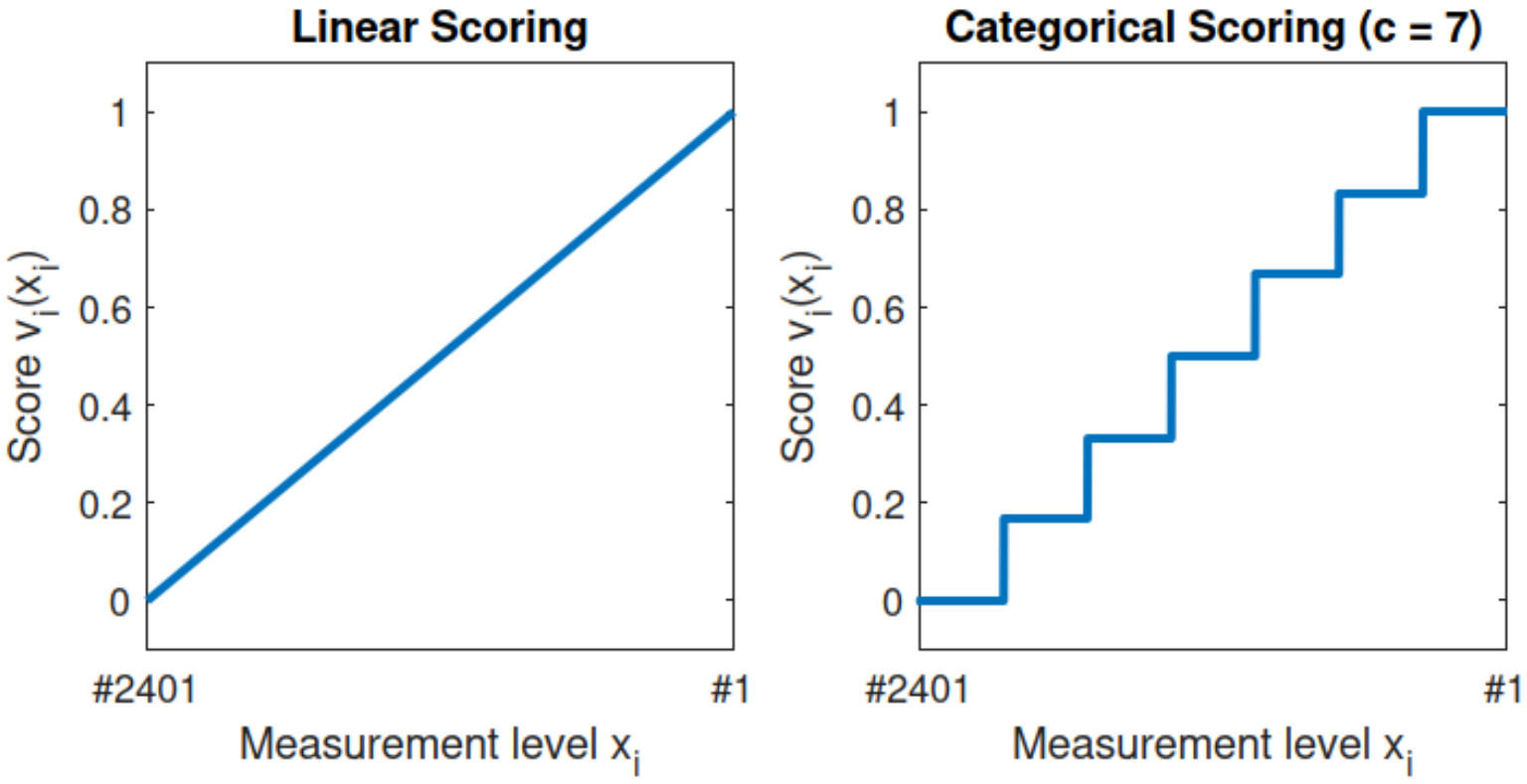
- Attribute-specific rankings of COAs from Excel to MATLAB
- Computation in MATLAB, output results to Excel

```
56
57      % scores from attribute-specific ordinal rankings
58 -    for i=1:n
59 -        for j=1:m
60              % T_in(i,4+2*j) is the position of COA i wrt att j
61 -            v(i,j) = scores(T_in(i,4+2*j)); %fill v with appropriate scores
62 -        end
63 -    end
64
65      % Define the set of feasible weights of the form
66      % S={w\in R^n | A*w <= b, Aeq*w = beq, LB <= w <= UB}
67 -    weight_option=1; % binary attribute weight set definition parameter
68      % 0 => weights share linear inequality restrictions (to be defined below)
69      % 1 => weights only have their own interval restrictions
70
71      % weights share linear inequality restrictions
72 -    if weight_option == 0
73 -        A=[0 1 -1;1 -1 0];
74          %A=[-1 1 0;1 -3 0;-1 0 1;1 0 -2];
75 -        b=[0;0];
76 -        [A,b,Aeq,beq,LB,UB] = constFromWeightInequalities(m,A,b);
77
78      % weights only have their own interval restrictions
79 -    elseif weight_option == 1
80 -        W_intvl = [0 1; 0 1; 0 1];
81 -        [A,b,Aeq,beq,LB,UB] = constFromWeightIntervals(m,W_intvl);
82 -    end
```

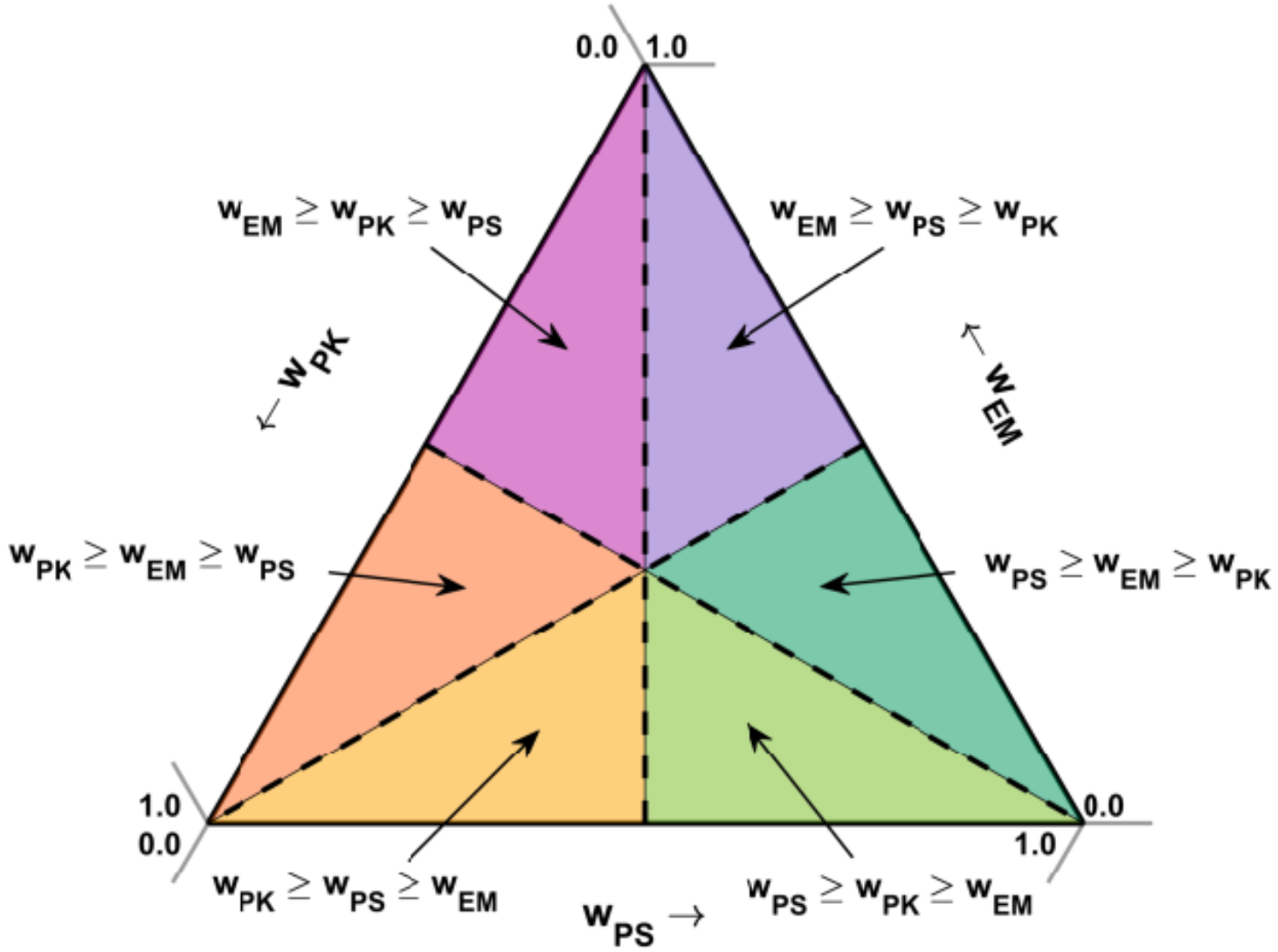
B	C	D	E	F	G	H
#	a	b	c	d	Rule 1: Ammu paljon	#Shots
1201	LMC	LMC	LMC	LMC		12
1887	MC	LMC	LMC	LMC		11
1299	LMC	MC	LMC	LMC		11
1215	LMC	LMC	MC	LMC		11
1203	LMC	LMC	LMC	MC		11
1544	LC	LMC	LMC	LMC		11
1250	LMC	LC	LMC	LMC		11
1208	LMC	LMC	LC	LMC		11
1202	LMC	LMC	LMC	LC		11
515	LM	LMC	LMC	LMC		11
1103	LMC	LM	LMC	LMC		11
1187	LMC	LMC	LM	LMC		11
1199	LMC	LMC	LMC	LM		11
1985	MC	MC	LMC	LMC		10

Experiment 1:
Preference Order and Attribute Scoring 1/2

- How many non-dominated (ND) COAs are identified?
- How does attribute scoring affect number of ND COAs?



Experiment 1:
Preference Order and Attribute Scoring 2/2



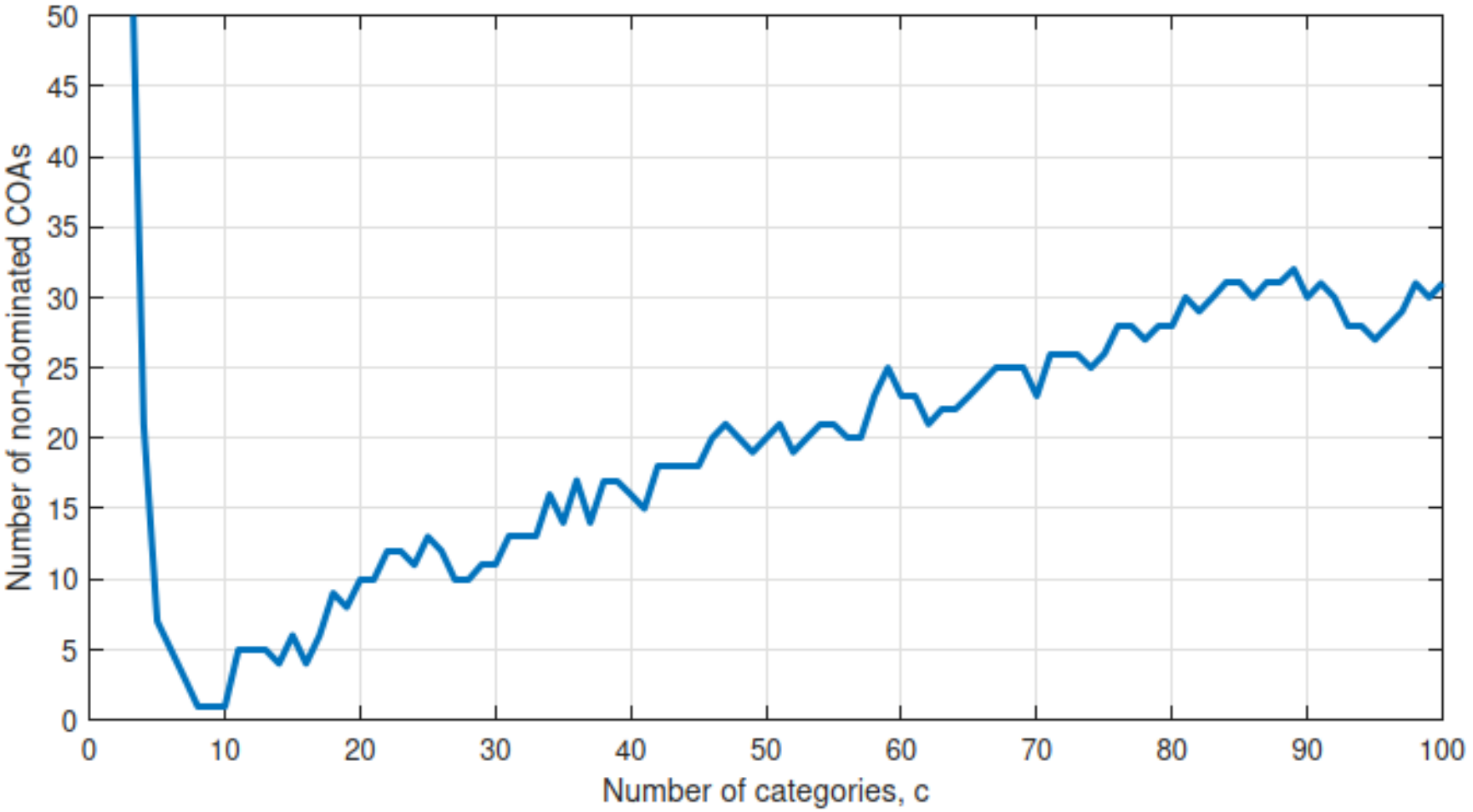
Results of Experiment 1 1/2

- Preference orders with linear scoring produce a feasible number of ND COAs
- Shape of the single attribute value function matters

Preference information	# of ND COAs
$w_{PK} \geq w_{PS} \geq w_{EM}$	11
$w_{PK} \geq w_{EM} \geq w_{PS}$	12
$w_{PS} \geq w_{PK} \geq w_{EM}$	18
$w_{PS} \geq w_{EM} \geq w_{PK}$	13
$w_{EM} \geq w_{PK} \geq w_{PS}$	15
$w_{EM} \geq w_{PS} \geq w_{PK}$	7

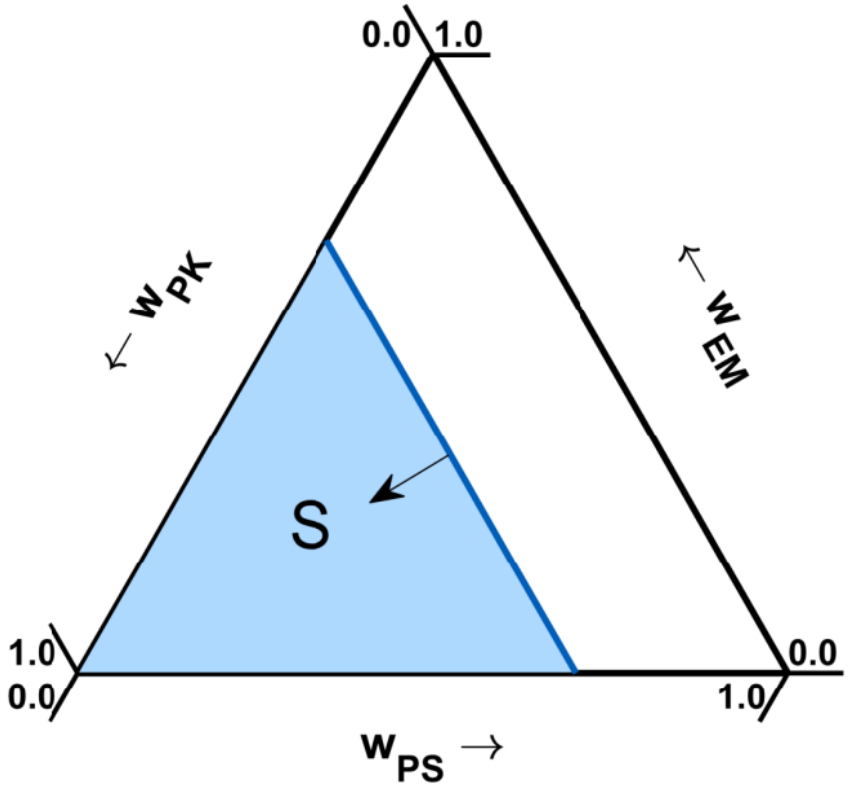
Results of Experiment 1 2/2

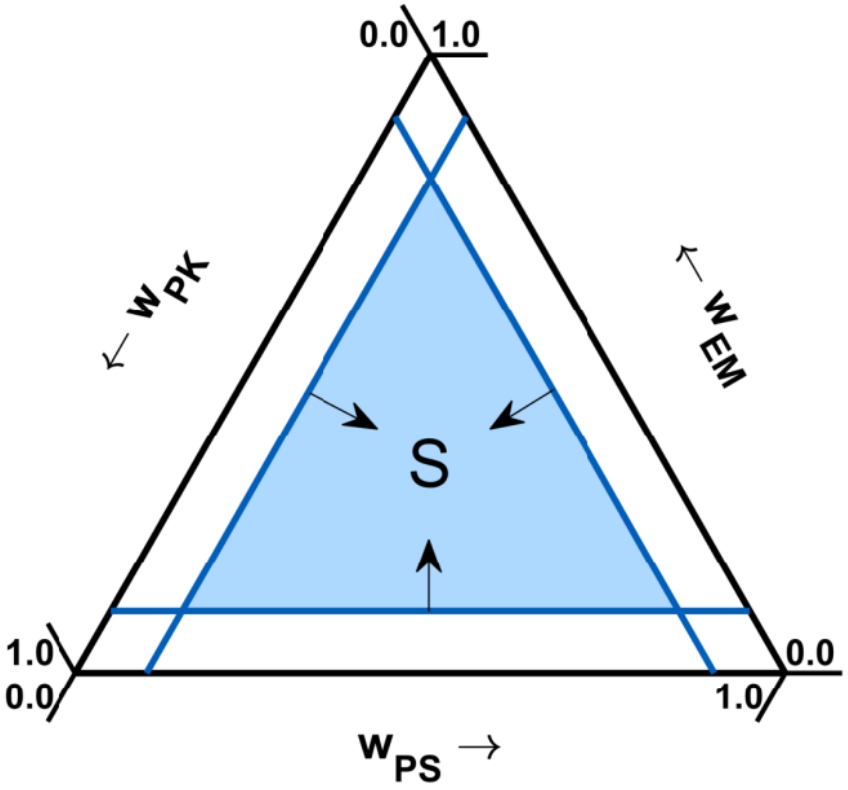
- Preference orders with linear scoring produce a feasible number of ND COAs
- Shape of the single attribute value function matters



Experiment 2:
Convergence of Weight Intervals

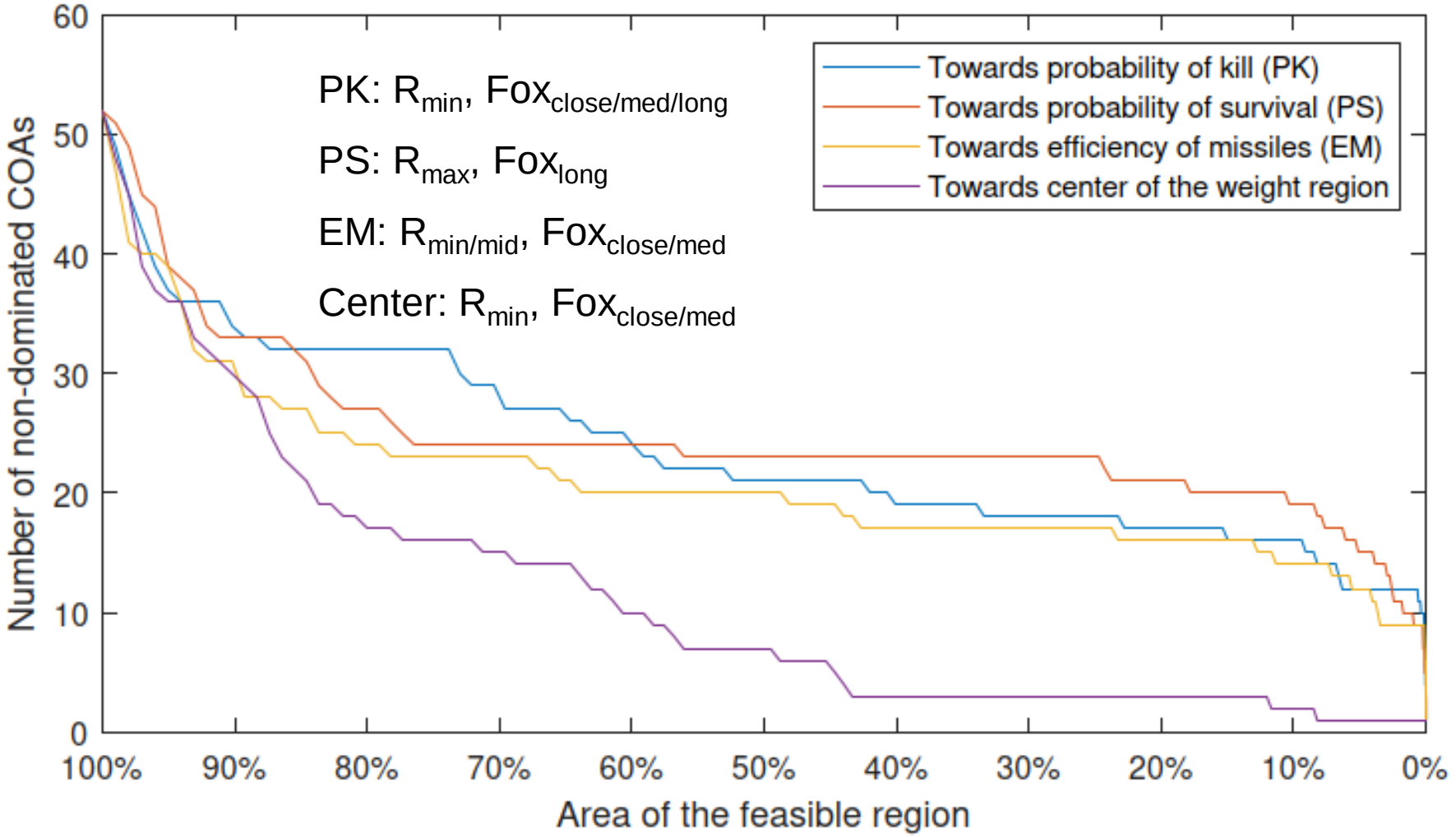
- How many non-dominated COAs are identified?
- Do non-dominated COAs fit given preference information?





Results of Experiment 2

- Number of non-dominated COAs decreases as given preference information gets stricter and stricter
- Non-dominated COAs fit the preference information

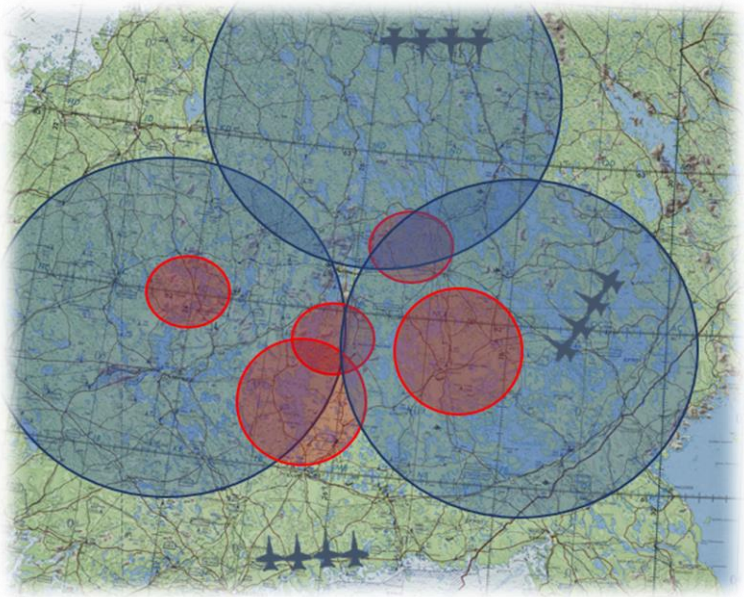


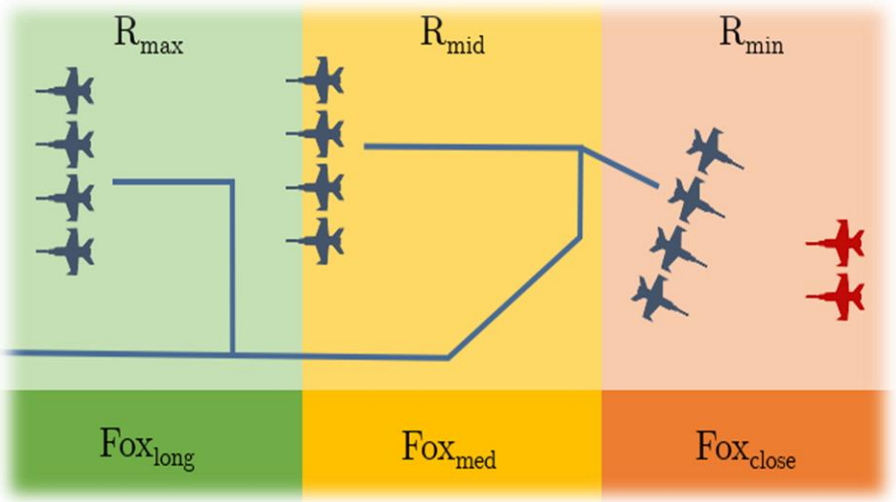
Conclusions

- Incomplete preference information suffices to reduce the number of COAs in consideration (2401 → ~15)
- Close attention must be paid to choosing the shape of single attribute value functions
- The MADA model provides COA recommendations that match given preference information
- Model fulfills its intended purpose and opens up avenues for future research

Going Forward

- Develop an accessible, easy-to-use user interface
- Incorporate geographical restrictions to the MADA model





References 1/3

- **H. Mansikka, K. Virtanen and M. Kankaisto (forthcoming)** Chinese Whispers in Air Combat: Multi-Criteria Decision Analysis Framework for Converting Commander's Intent into Air Combat Course of Action. *Manuscript.*
- **A. Salo and R.P. Hämäläinen (2010)** Preference Programming – Multicriteria Weighting Models under Incomplete Information. *Handbook of Multicriteria Decision Analysis, Springer, New York.*
- **J. Mustajoki and R.P. Hämäläinen (2005)** Decision Support by Interval SMART/SWING - Incorporating Imprecision in the SMART and SWING Methods. *Decision Sciences, Vol. 36, No. 2, 317-339.*
- **M. Weber (1987)** Decision Making with Incomplete Information. *European Journal of Operational Research, 28, 44-57.*

References 2/3

- **R. L. Keeney, H. Raiffa, and R. F. Meyer (1993).** *Decisions with multiple objectives: preferences and value trade-offs.* Cambridge University Press, New York.
- **H. Mansikka, K. Virtanen, D. Harris, and M. Jalava (2021).** Measurement of team performance in air combat – have we been underperforming? *Theoretical Issues in Ergonomics Science,* 22(3):338–359.
- **J. Liesiö, P. Mild, and A. Salo (2007).** Preference programming for robust portfolio modeling and project selection. *European Journal of Operational Research*, 181(3):1488–1505.
- **A. Arbel (1989).** Approximate articulation of preference and priority derivation. *European Journal of Operational Research*, 43(3):317–326.

References 3/3

- **AJP-3.3 (2016).** Allied Joint Doctrine for Air and Space Operations. *Allied Joint Publication-3.3*, NATO Standardization Office.
- **J. M. Holmes (1995).** *The counterair companion: short guide to air superiority for joint force commanders.* Air University Press, Maxwell Air Force Base, Alabama.
- **JP 3-30 (2019).** *Joint Air Operations. Joint Publication 3-30*, United States Armed Forces, Joint Chiefs of Staff.
- **CNATRA P-825 (2017).** All Weather Intercept (AWI), Flight Training Instruction, Advanced NFO T-45C/VMTS. *CNATRA P-825 (Rev. 02-17) PAT*, United States Navy, Chief of Naval Air Training.