Neuro-Fuzzy Prediction of Decision Making in Cyber Defense Exercises

Karina Kulikauskaitė

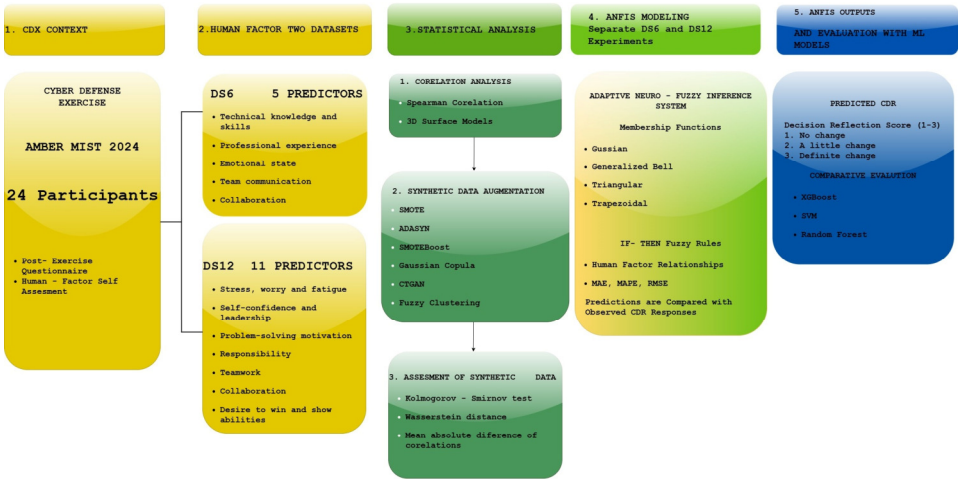
Vilnius Gediminas Technical University, Saulėtekio av. 11, Vilnius, Lithuania

Summary: This research presents a **Human-Centered Neuro-Fuzzy** modeling framework for analyzing and predicting **Decision-Making** behavior in cyber defense exercises coordinated by the **Lithuanian Armed Forces** using two complementary datasets that capture technical, emotional, motivational, and collaborative huma. factors. The obtained results demonstrate that decision reflection outcomes in **CDX** are not primarily determined by technical competencies alone, but instead emerge from complex nonlinear interactions among psychological, cognitive, and team oriented variables.

1. RESEARCH OBJECTIVES

Model and predict **Counterfactual Decision Reflection (CDR)** a participant's willingness to revise a decision made during CDX from human-factor variables. **CDX Data collection instrument** was two self assessment datasets (24 complete responses each) were built from the post exercise questionnaire, using 5 point Likert-scale and a **3 level CDR** outcome.

2. RESEARCH WORKFLOW FOR MODELING SELF-REPORTED DECISION REFLECTION



3. STATISTICS OF DATASETS

Variable Name	Mean	SD	Min	Mdn	Max	Range
TKS	4.42	0.78	3	5	5	1–5
PE	4.25	1.15	1	5	5	1–5
ES	2.63	1.14	1	2	5	1–5
WTC	4.50	0.66	3	5	5	1–5
COL	4.33	0.92	2	5	5	1–5
CDR	1.88	0.68	1	2	3	1–3

Tab. 1. Descriptive statistics of **DS6** dataset.

Variable Name	Mean	SD	Min	Mdn	Max	Range
STR	3.13	1.30	1	3	5	1–5
DWE	3.50	1.35	1	4	5	1–5
TIM	4.00	0.89	2	4	5	1–5
WOR	2.46	1.14	1	2.5	5	1–5
DLE	3.04	1.37	1	3	5	1–5
FAT	3.42	1.14	1	3	5	1–5
DAB	3.38	1.06	1	3.5	5	1–5
MSP	4.38	0.82	2	5	5	1–5
RST	4.46	0.78	2	5	5	1–5
TWK	4.08	0.50	3	4	5	1–5
COL	4.21	0.66	3	4	5	1–5
CDR	1.88	0.68	1	2	3	1–3

Tab. 2. Descriptive statistics of the **DS12** dataset

4. CORRELATION ANALYSIS OF DATASETS

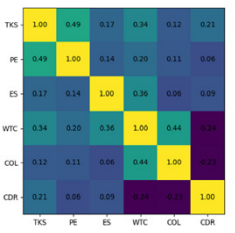


Fig. 1. Spearman correlation matrix of (a) dataset **DS6**

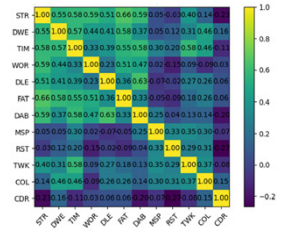


Fig. 2 Spearman correlation matrix of (b) dataset **DS12**

5. ANALYSIS OF AUGMENTED DATASETS

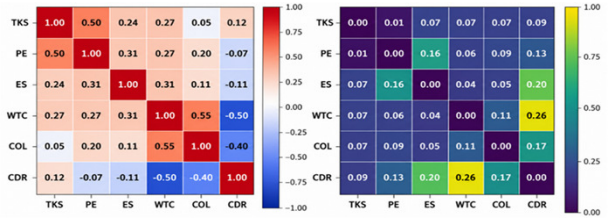


Fig. 5. Spearman correlation matrix of (a) **DS6** Gaussian Copula synthetic dataset (a) and correlation differences between original **DS6** and Gaussian Copula synthetic dataset (b)

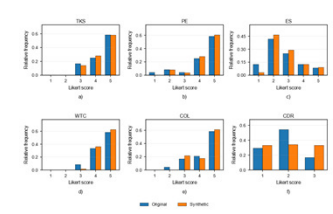


Fig. 6. Comparison of the realitive frequency distributions between the original DS6 dataset and Gaussian Copula augmented dataset variables for: (a) TKS, (b) PE, (c) ES, (d) WTC, (e) COL, (f) CDR.

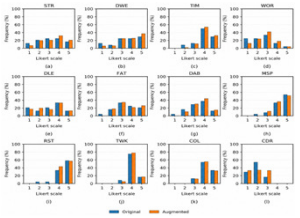


Fig.7. Comparison of the realitive frequency distributions between the original DS12 dataset and Gaussian Copula augmented dataset variables for: (a) STR, (b) DWE, (c)TIM, (d) WOR, (e) DLE, (f) FAT, (g) DAB, (h) MSP, (i) RST, (j) TWK, (k) COL, (l) CDR.

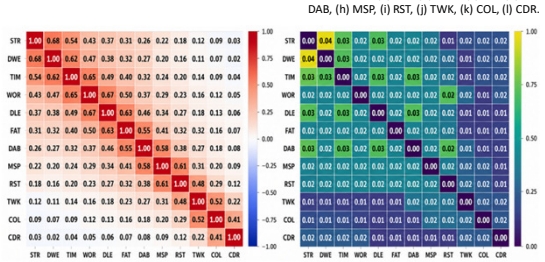


Fig 8. Spearman correlation matrix of (a) DS12 Gaussian Copula synthetic dataset and (b) correlation differences between original DS12 and Gaussian Copula synthetic dataset.

6. 3D SURFACE PLOTS OF VARIABLES RELATIONSHIP

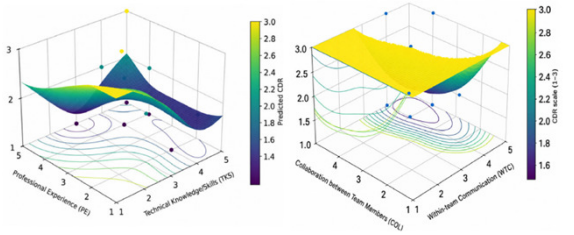


Fig.3. 3D surface plots of variables relationship in dataset **DS6**: (a) WTC-ES-CDR; (b) COL-WTC-CDR.

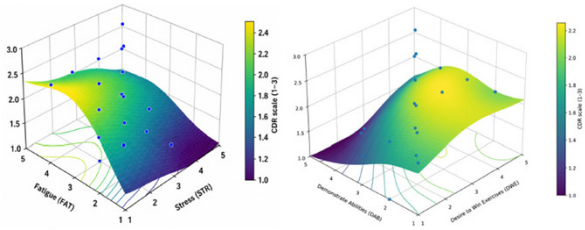


Fig. 4. 3D surface plots of variables relationship in dataset DS12: (a) FAT-STR-CDR; (b) DAB-DWE-CDR.

7. DERIVED FUZZY RULES

Rule	IF Conditions	THEN (CDR)	Confidence	Coverage
R1	TKS is High AND PE is High AND ES is Medium AND WTC is High AND COL is High	2.000	1.0000	0.1250
R2	TKS is High AND PE is High AND ES is Medium AND WTC is High AND COL is Medium	2.000	0.3333	0.1250
R3	TKS is High AND PE is High AND ES is High AND WTC is High AND COL is High	2.000	1.0000	0.0833
R4	TKS is High AND PE is High AND ES is Medium AND WTC is Medium AND COL is Medium	2.000	0.5000	0.0833
R5	TKS is High AND PE is High AND ES is Low AND WTC is Medium AND COL is High	3.000	1.0000	0.0417

Tab. 8 Representation of the fuzzy rules derived from dataset **DS6**

Membership Function	Theoretical Rule Count	Activated Rules	Avg. Rule Coverage	Rule Overlap	Interpretability
Triangular	243	16	Medium–High	Low	Very High
Trapezoidal	243	18	High	Low–Medium	High
Gaussian	243	28	Low–Medium	High	Medium
Generalized Bell	243	26	Medium	High	Medium–High

Tab. 9. Comparison of fuzzy rules characteristics for dataset **DS6**

Rule	IF Conditions	THEN (CDR)	Confidence	Coverage
R1	STR is High AND DWE is High AND TIM is High AND WOR is High AND DLE is High AND FAT is High AND DAB is High AND MSP is High AND RST is High AND TWK is Medium AND COL is High	2.000	1.000	0.0417
R2	STR is High AND DWE is High AND TIM is High AND WOR is Medium AND DLE is Medium AND FAT is High AND DAB is High AND MSP is High AND RST is Medium AND TWK is Medium AND COL is High	1.000	1.000	0.0417
R3	STR is Low AND DWE is Low AND TIM is Medium AND WOR is Low AND DLE is Low AND FAT is Low AND DAB is Medium AND MSP is High AND RST is High AND TWK is Medium AND COL is High	1.000	1.000	0.0417
R4	STR is Low AND DWE is Medium AND TIM is Medium AND WOR is Low AND DLE is High AND FAT is Medium AND DAB is Medium AND MSP is Medium AND RST is High AND TWK is Medium AND COL is High	3.000	1.000	0.0417
R5	STR is Medium AND DWE is Medium AND TIM is High AND WOR is Medium AND DLE is Medium AND FAT is Medium AND DAB is Medium AND MSP is High AND RST is Medium AND TWK is High AND COL is High	3.000	1.000	0.0417

Tab.10 Representation of the fuzzy rules derived from dataset **DS12**

Membership Function	Theoretical Rule Count	Activated Rules (DS12)	Avg. Rule Coverage	Rule Overlap	Interpretability
Triangular	177,147	22	Very low	Low	Very high
Trapezoidal	177,147	20–24	Low–Medium	Low–Medium	High
Gaussian	177,147	30–45	Medium	High	Medium
Generalized Bell	177,147	28–42	Medium	High	Medium–High

Tab. 11. Comparison of fuzzy rules characteristics for dataset **DS12**

8. ANFIS PERFORMANCE

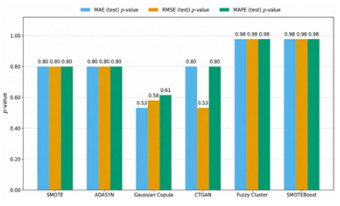


Fig. 9. p-values for **DS6** dataset test metrics across membership functions

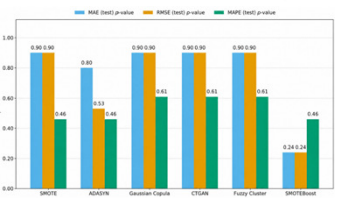


Fig. 10. p-values for **DS12** dataset test metrics across membership functions