A team performance prediction model

National Tsing Hua University

Authors：Sheue-Ling Hwang, Tzu-Chung Yen
Guo-Feng Liang, Chong-Cheng Hsu
Jhih-Tsong Lin, Chang-Fu Chuang
Yi-Jan Yau

2008.05.19

Outline

- Introduction
- Method
  - Participants
  - Apparatus
  - Experimental tasks
  - Experimental variables
- Results and Discussion
  - Team mental workload
  - Team performance prediction model
  - A pre-alarm device
  - Model validation
- Conclusions

Introduction (1/4)

- Computer-supported cooperative work (CSCW)
  - an automated system
  - shared environment to support teamwork
- Team members have to monitor tasks and share responsibility.
- Two problems
  - how to maintain high team performance ?
  - how to ensure human and system safety when sharing responsibility in monitoring tasks ?

Introduction (2/4)

- Various methods can be taken to measure team performance (Artman, 2000; Sebok, 2000; Shu and Furuta, 2002; Marseguerra, 2006; DiDomenico and Nussbaum, 2005)
  - Human reliability analysis (HRA)
  - Cognition
  - Team interactions
  - Objective performance
  - Mental workload

Introduction (3/4)

- Diffusion of responsibility (Skitka and Mosier et. al., 2000; Rentsch and Klimoski, 2001)
  - With a computer for system monitoring and decision making tasks may achieve shared team workload and shared team mental models
  - Diffusion of responsibility may reduce the effort and workload of group members
  - The underload of each team member may influence the overall team performance especially in monitoring tasks.

Introduction (4/4)

- Way to result this problem
  - HRV (heart rate variability)
    - Have continuous, on-line recordings.
    - Suitable for constructing a real-time predictive model
- Purpose
  - Design a predictive teamwork performance model using the group method of data handling (GMDH) algorithm
  - Determine the safety threshold by fuzzy logic when team members were underloaded mentally.

Method (1/5)

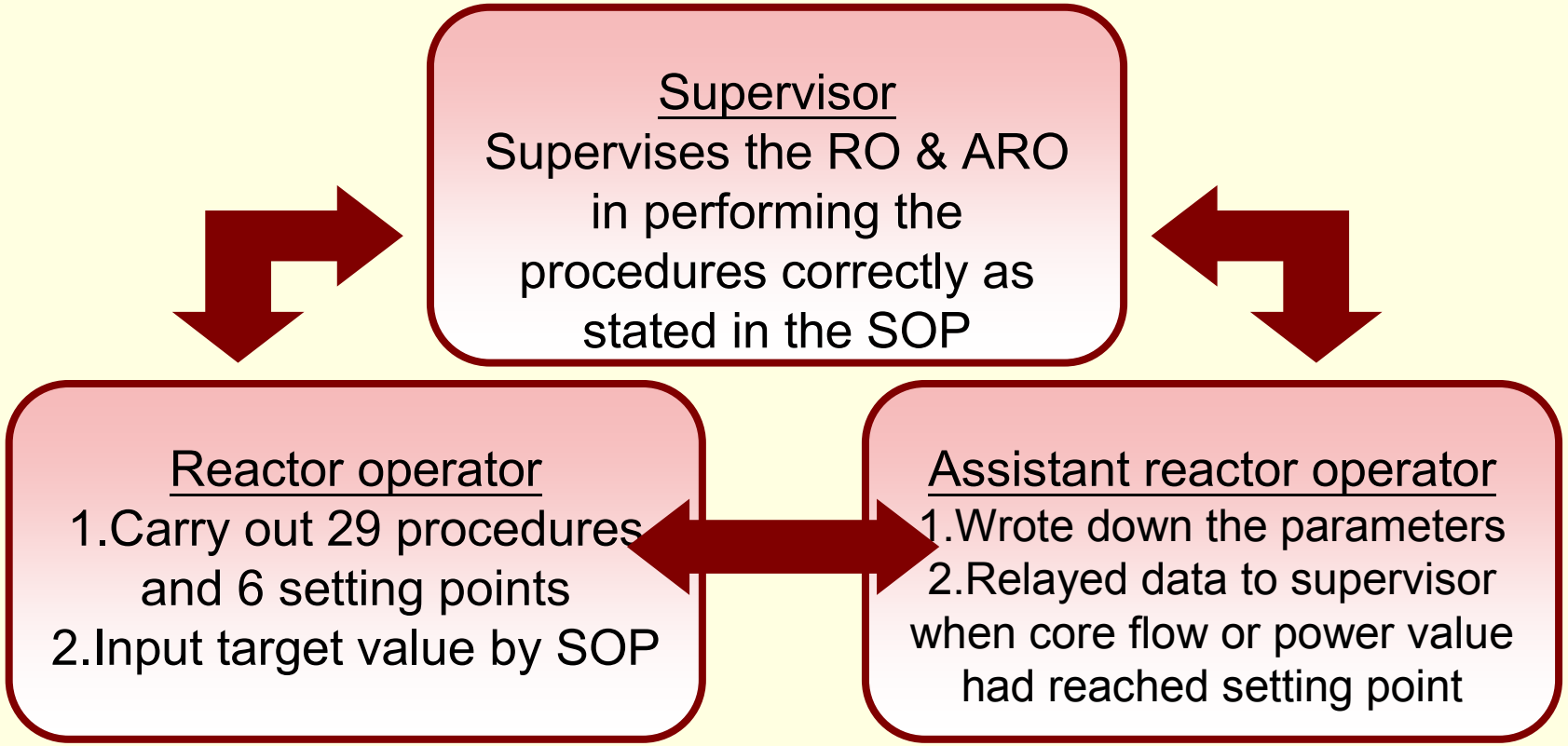
- Participants
  - Forty-five participants in fifteen teams took part in the experiment.
    - 28 students (National Tsing Hua University)
    - 14 experts (Institute of Nuclear Energy Research)
    - 3 operators (Fourth Nuclear Power Plant in Taiwan)
  - 6 students in two teams joined a preliminary experiment.
  - Remaining 39 participants attended the formal experiment.

Method (2/5)

- Apparatus
  - Electrocardiogram (ECG) signals were calculated using the software from Cardio Visions
  - Personal Computer Transient Analyzer (PCTRAN) system were used to simulate the startup reactor task.
    - Power Generator Control System (PGCS)
    - Reactor Recirculation System (RCIR)
    - Rod Control and Information System (RCIS)
  - A program in the training simulator was designed to represent the procedures of Integrated Operating Procedure (IOP) 201.2, Reactor Startup- with PGCS, and 202.2, Power Changes- with PGCS.

Method (3/5)

- Experimental tasks



Method (4/5)

- The interface layouts of teamwork

Method (5/5)

- Experimental variables
  - Independent variable
    - Interval of event arrival time
  - Dependent variables
    - Physiological indices
      - HRV indices
        - Time-domain metrics
        - Frequency-domain metrics
    - Teamwork performance
      - Response time and correct rates
    - Mental workload

Results and Discussions (1/12)

- Mental workload
  - NASA-TLX was used as a subjective workload measure. Six subscales:
    - mental demand, physical demand, temporal demand, performance, effort, and frustration
  - The mental workload scores
    - Reactor operator $w_R = 37.96 \pm 14.29$
    - Assistant reactor operator $w_A = 39.37 \pm 10.08$
    - Supervisor $w_S = 35.65 \pm 16.46$

Results and Discussions (2/12)

- The fuzzy membership
  - Reactor operator

$$\{w_{\mathrm{R}}, \mu_{\mathrm{i}}(w_{\mathrm{R}})\} = \{(\mu_2(w_{\mathrm{R}}), 0.6), (\mu_2(w_{\mathrm{R}}), 0.66), (\mu_2(w_{\mathrm{R}}), 0.13)\}$$

  - Assistant reactor operator

$$\{w_{\mathrm{A}}, \mu_i(w_{\mathrm{A}})\} = \{(\mu_2(w_{\mathrm{A}}), 0.52), (\mu_3(w_{\mathrm{A}}), 0.7), (\mu_4(w_{\mathrm{A}}), 0.16)\}$$

  - Supervisor

$$\{w_{\mathrm{S}}, \mu_{\mathrm{i}}(w_{\mathrm{S}})\} = \{(\mu_2(w_{\mathrm{S}}), 0.71), (\mu_3(w_{\mathrm{S}}), 0.58), (\mu_4(w_{\mathrm{S}}), 0.02)\}$$

Results and Discussions (3/12)

- Teamwork performance prediction model
  - The predictors of the eight heart rate variability (HRV) indices were adopted to predict the performance index
    - NN count (X_1)
    - NN average (X_2)
    - SDNN (X_3)
    - pNN50 (X_4)
    - HRVti (X_5)
    - RMSSD (X_6)
    - LF/HF (X_7)
    - TP (X_8)

Results and Discussions (4/12)

- The performance index is combined with the correct rate and the response time of teamwork

$$[(y_1)^3/\sqrt{y_2}]\times 10 = Y$$

- Team performance predictive model can be expressed by

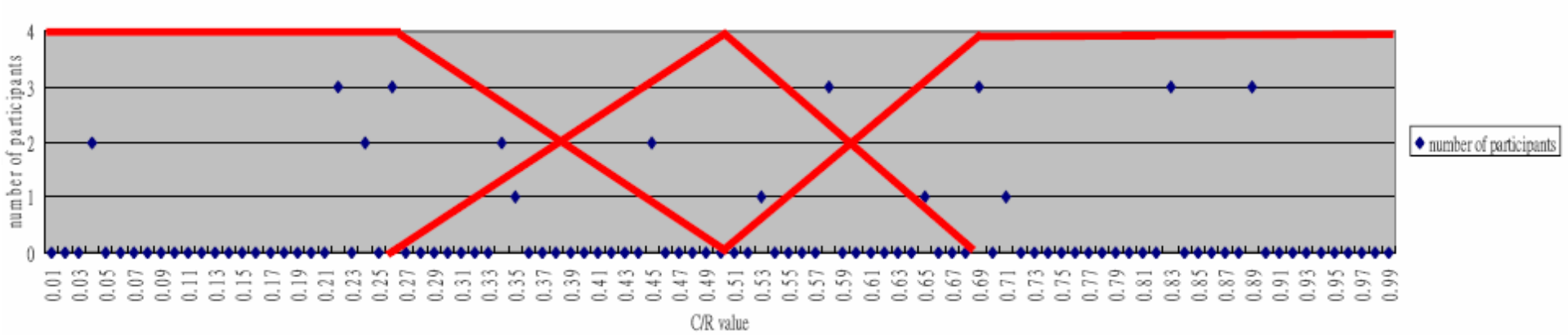
$$Y=0.68+0.99X_5+0.24X_8-4.7X_2+0.67X_4-19X_1^2-0.15X_7^2-0.51X_4^3-5.1X_1X_4-6.6X_1X_7+0.47X_4X_7$$
$$+15X_1X_4X_7+5X_6^2+2.2^{0.002}X_2^3-8.9X_6^3-2.6X_5^2-1.1X_8^2+3.4X_5X_8-8X_2^2$$

Results and Discussions (5/12)

- A pre-alarm device
  - Seven steps could be conducted
    - Draw the correct rate / response time (C/R) value
    - Determine the membership function
    - Transfer the linguistic variable (Fuzzification)
    - Construct the inference engine and rule base
    - Execute the aggregation
    - Calculate the Defuzzification
    - Determine the signal of the Safety Index

Results and Discussions (6/12)

- Draw the correct rate / response time (C/R) value
  - The performance index of C/R in 10 teams were sorted from low to high
  - The meaning of each dot represents the number of participants whose C/R was the same value.



Results and Discussions (7/12)

- Determine the membership function
  - Three fuzzy numbers and membership function

$$\mu_{low}(Y_i)=\begin{cases}1, & Y_i<0.26\\ (0.5\text{-}Y_i)/0.24\ , & 0.26\le Y_i<0.5\\ 0, & Y_i\ge 0.5\end{cases}$$

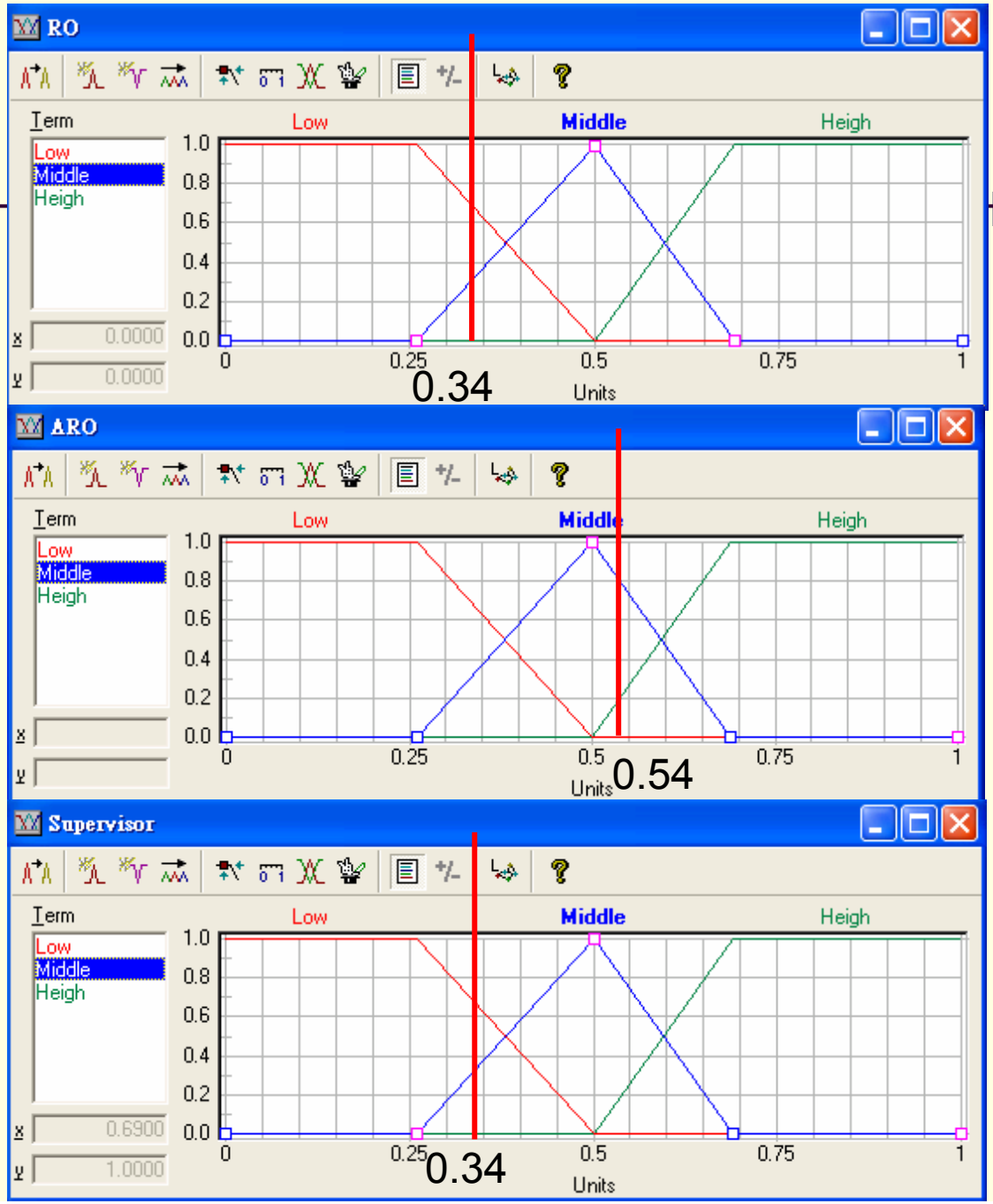
$$\mu_{middle}(Y_i)=\begin{cases}0, & Y_i<0.26 \text{ or } Y_i\ge 0.69\\ (Y_i\text{-}0.26)/0.24, & 0.26\le Y_i<0.5\\ (0.69\text{-}Y_i)/0.19, & 0.5\le Y_i<0.69\end{cases}$$

$$\mu_{high}(\mathrm{Y}_i)=\begin{cases}0, & \mathrm{Y}_i<0.5\\ (\mathrm{Y}_i\text{-}0.5)/0.19\ , & 0.5\le \mathrm{Y}_i<0.69\\ 1, & \mathrm{Y}_i\ge 0.69\end{cases}$$

(9)

Results and Discussions (8/12)

- Transfer the linguistic variable (Fuzzification)
  - The performance index of the team members from the crisp value into the fuzzy set a process
  - For instance,
    - the C/R ratio of RO and supervisor was 0.34,
      $\mu_{low}(0.34)$ =0.66; $\mu_{middle}(0.34)$ =0.32
    - the C/R ratio of ARO was 0.54
      $\mu_{middle}(0.54)$ =0.79; $\mu_{\text{heigh}}(0.54)$ =0.21


RO
Term
Low
Middle
Heigh
x
0.0000
y
0.0000
Low
Middle
Heigh
1.0
0.8
0.6
0.4
0.2
0.0
0
0.25
0.5
0.75
1
Units
0.34
ARO
Term
Low
Middle
Heigh
Low
Middle
Heigh
Units
0.54
Supervisor
Term
Low
Middle
Heigh
x
0.6900
y
1.0000
Low
Middle
Heigh
Units
0.34

Results and Discussions (9/12)

- Construct the inference engine and rule base
  - The rule base is derived from the combination of fuzzy sets and the fuzzy numbers of $\mu_j(\mathrm{Y}_i)$, where i = R, A, S; j=low, middle, high, which has $3\times3\times3=27$ different combinations.

- Execute the aggregation
  - the output of the aggregation process becomes the combined output fuzzy set by

$$\mu_{SI}(Y) = \max[\mu'_{1l}(Y), \mu'_{2l}(Y), \mu'_{3l}(Y), ..\mu'_{kl}(Y).., \mu'_{nl}(Y)]$$

Results and Discussions (10/12)

- Calculate the Defuzzification
  - The center of gravity (COG) method introduced by Mamdami in 1975 was applied in this system.

$$SI = \{\sum_{t=1}^{q} \mathrm{Y}_t \mu_{SI}(Y_t)\} / \sum_{t=1}^{q} \mu_{SI}(Y_t) = \frac{0.66\times(1+2+3)+0.33\times 4+0\times 5+0.32\times(6+7)+0\times 8}{0.66\times 3+0.33+0\times 2+0.32\times 2} = 3.37$$

- Determine the signal of the Safety Index of the teamwork
  - The signal (Red, Bule, and Green) can be decided by the maximum of the $\mu_{\mathrm{Red}}(SI)$, $\mu_{Blue}(\mathrm{SI})$, and $\mu_{\mathrm{Green}}(\mathrm{SI})$

Results and Discussions (11/12)

- Model validation
  - teamwork performance prediction model

Team No.	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	Estimated value	Real value	Low bound of 95% CI	Upper bound of 95% CI
11	0.07	0.03	0.47	1.00	0.40	0.13	0.26	0.78	0.70	0.72	0.67	0.75
	0.05	0.00	0.20	1.00	-0.05	0.21	0.23	0.20	0.70	0.75	0.70	0.78
	0.11	0.01	0.05	0.00	0.11	-0.37	0.28	0.74	0.70	0.68	0.63	0.71
12	0.10	0.08	0.09	0.50	0.44	0.29	0.42	0.59	0.48	0.46	0.42	0.50
	0.01	0.04	-0.39	0.00	-0.20	0.05	0.00	0.32	0.48	0.44	0.41	0.49
	0.18	-0.03	0.08	-0.54	0.00	-0.53	0.67	-0.23	0.30	0.33	0.29	0.37
13	0.22	0.20	0.16	0.85	0.00	0.21	0.71	0.58	0.61	0.63	0.59	0.67
	-0.15	0.10	0.56	0.91	0.55	0.37	0.32	0.42	0.61	0.64	0.60	0.68
	0.02	0.07	0.32	0.63	0.25	0.20	0.21	0.75	0.61	0.64	0.60	0.68

Results and Discussions (12/12)

- A pre-alarm device
  - The Pearson Correlation analysis between the estimated and real Safety Index

Team No.	RO	ARO	supervisor	Safety Index	Membership			Signal	
					Red	Blue	Green	Estimated	Real
11(e)	0.70	0.70	0.70	8.41			1		Green
12(e)	0.48	0.48	0.30	2.72	1				Red
13(e)	0.61	0.61	0.61	6.93		0.36	0.64		Green
11(r)	0.72	0.75	0.68	8.26			1	Green	
12(r)	0.46	0.44	0.33	3.24	0.59	0.41		Red	
13(r)	0.63	0.64	0.64	7.21		0.26	0.74	Green	

(e) represents the estimated value; (r) represents the real value.

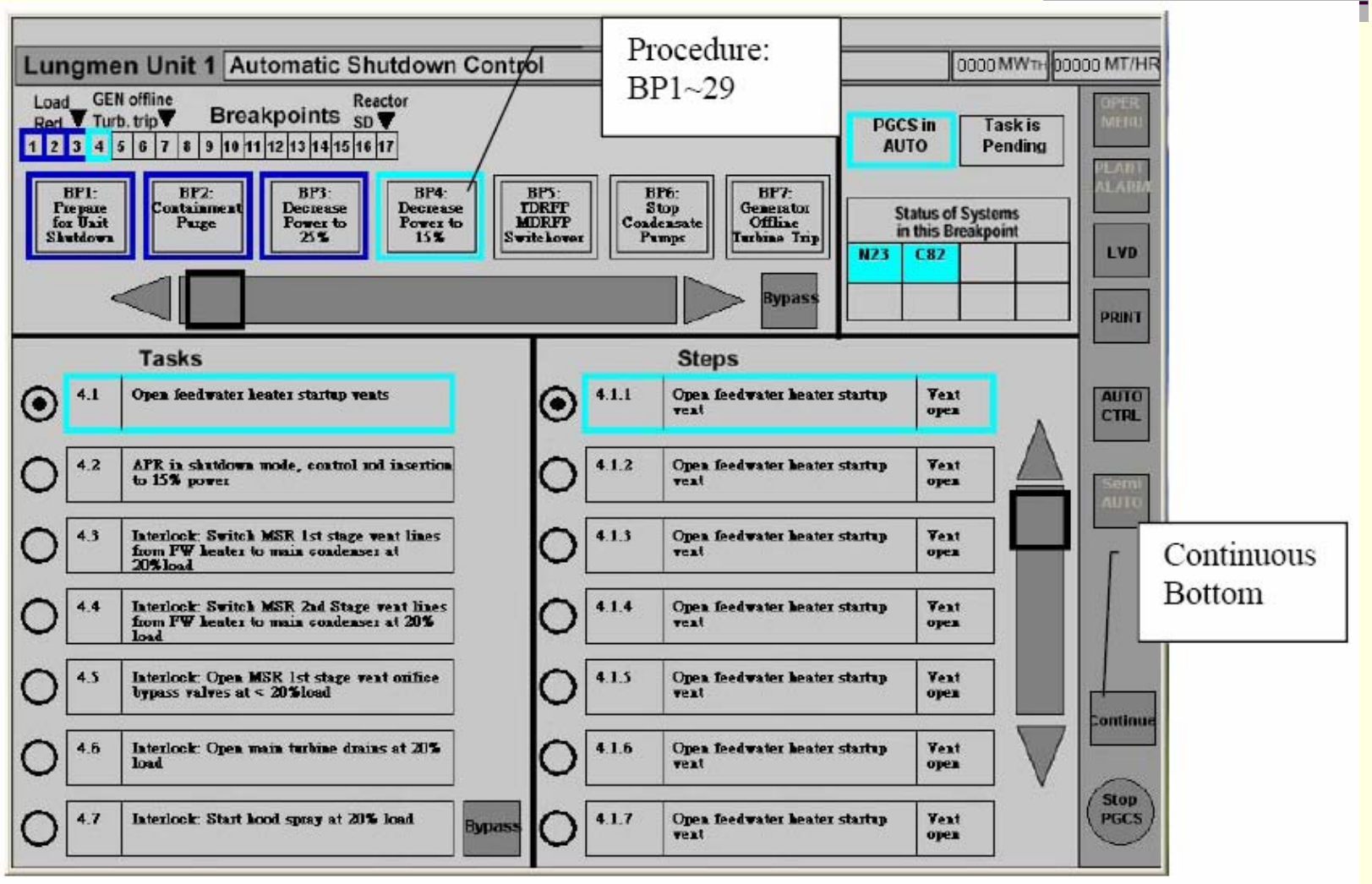
Conclusions

- The operators' psychological status changed according to the degree of complexity of the tasks,
- The team members made more errors when the interval of the event arrival time increased.
  - Thus, in such computer-supported cooperative work (CSCW), one of the important things is to avoid the low mental workload of any team member which may result in human errors and accidents.
- Therefore, the teamwork performance prediction model and the pre-alarm device have been developed in this study.
- The proposed model can efficiently predict teamwork performance in real-time to increase both system and human safety.

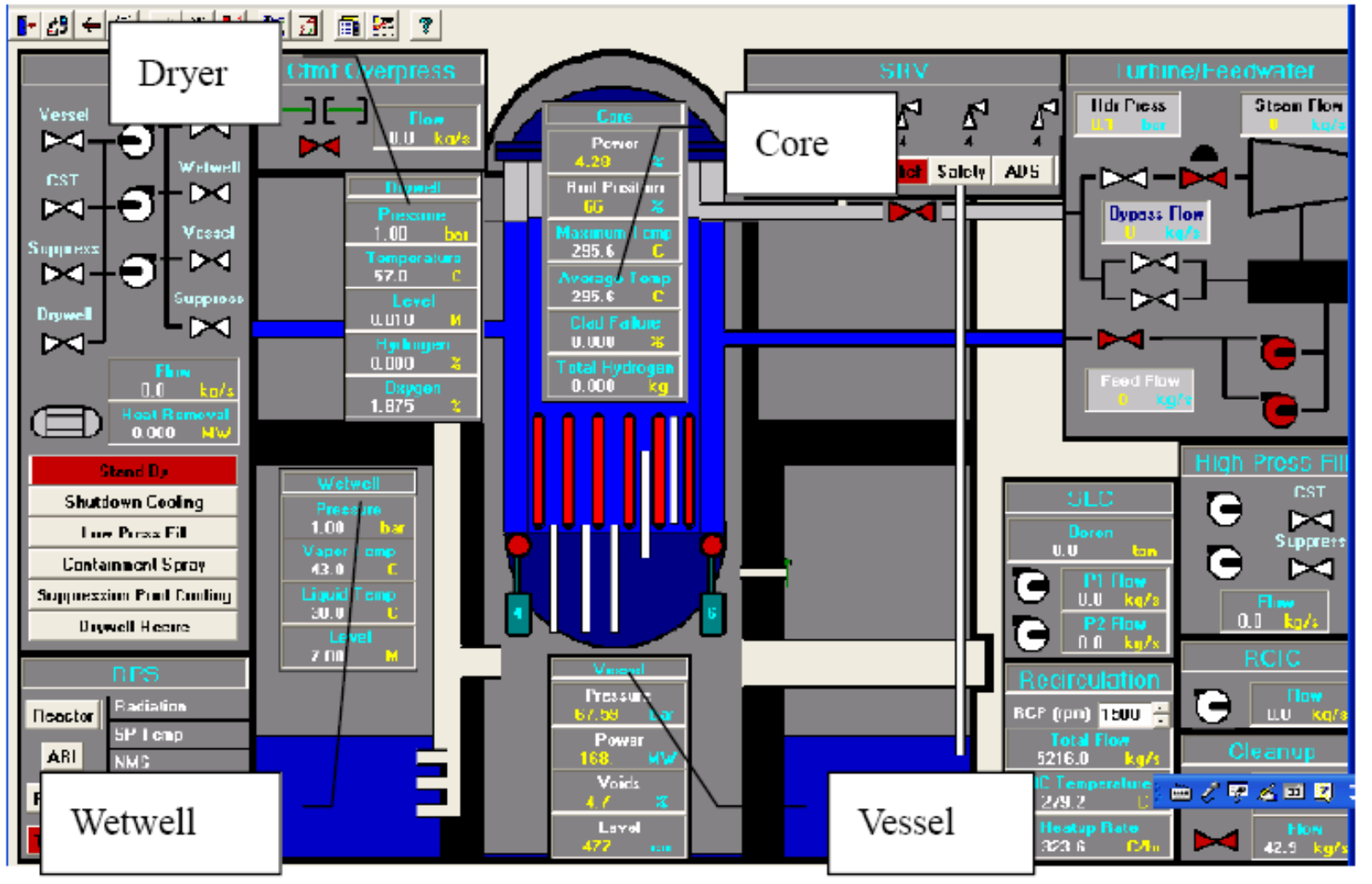
Thanks for your attention

Q & A

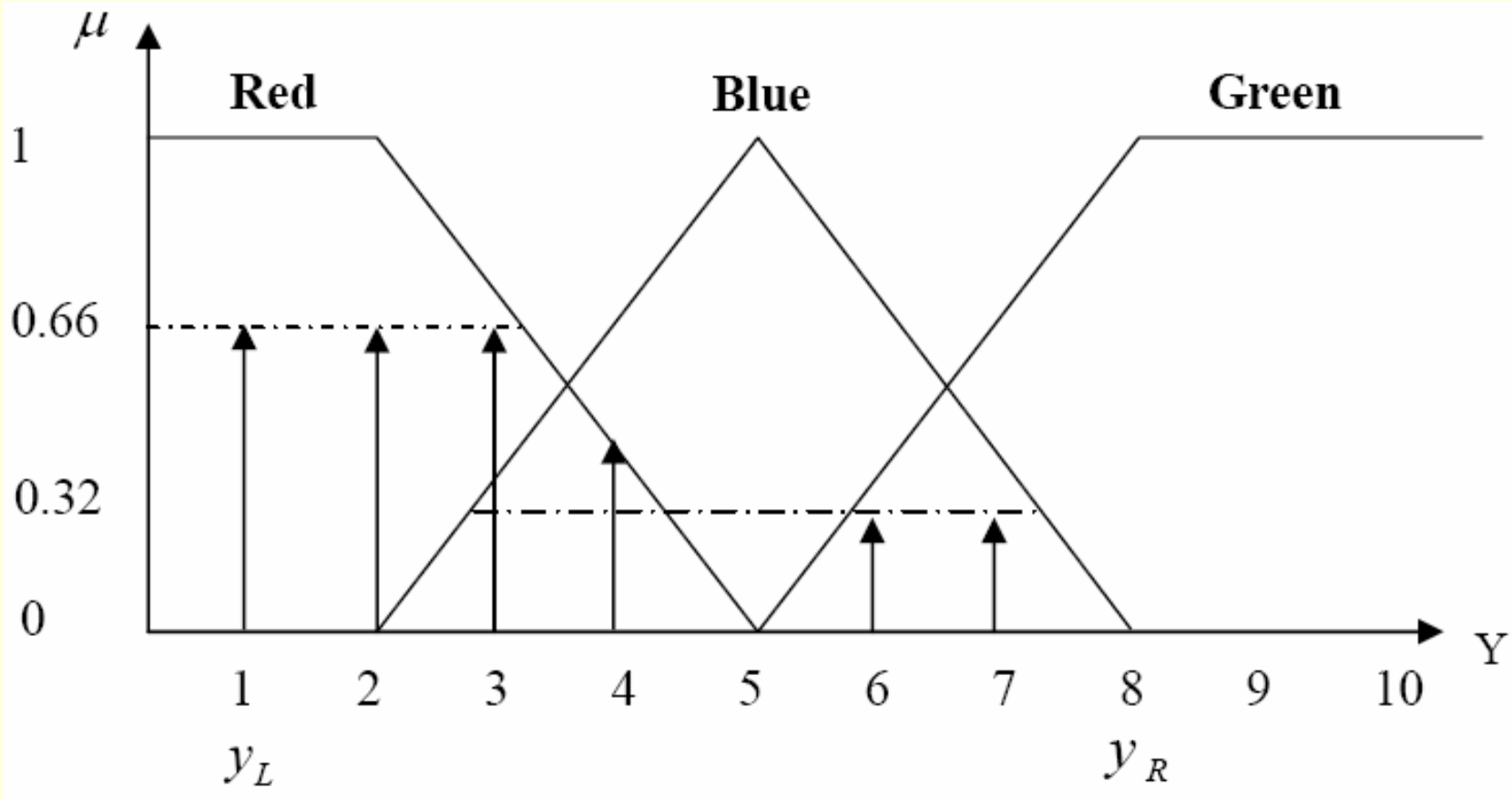
Power Generator Control System (PGCS)



Reactor parameters display



Defuzzification of Safety Index



Group Method of Data Handling (GMDH)