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**Findings from APR1400 Human Reliability Data Analysis
: Human Performance in Digitalized Control Room**

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Computer-Based Control Room in APR1400

Digital information system

Large display panel

Advanced alarm system

Computer-based procedure

RO

TO

EO

SS

STA

Soft control

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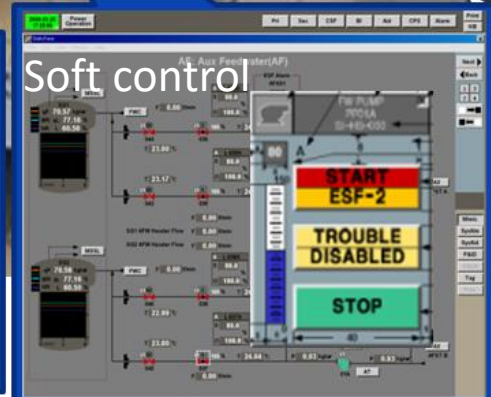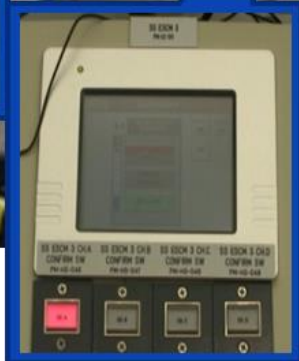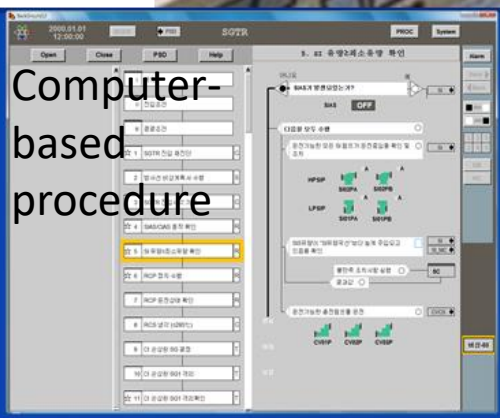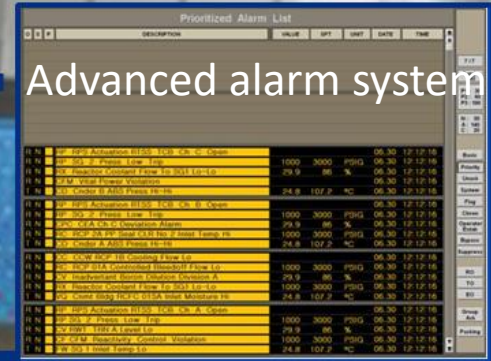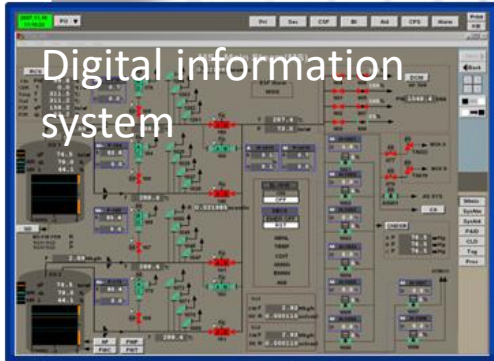
HuREX Data Collection in APR1400 Simulators
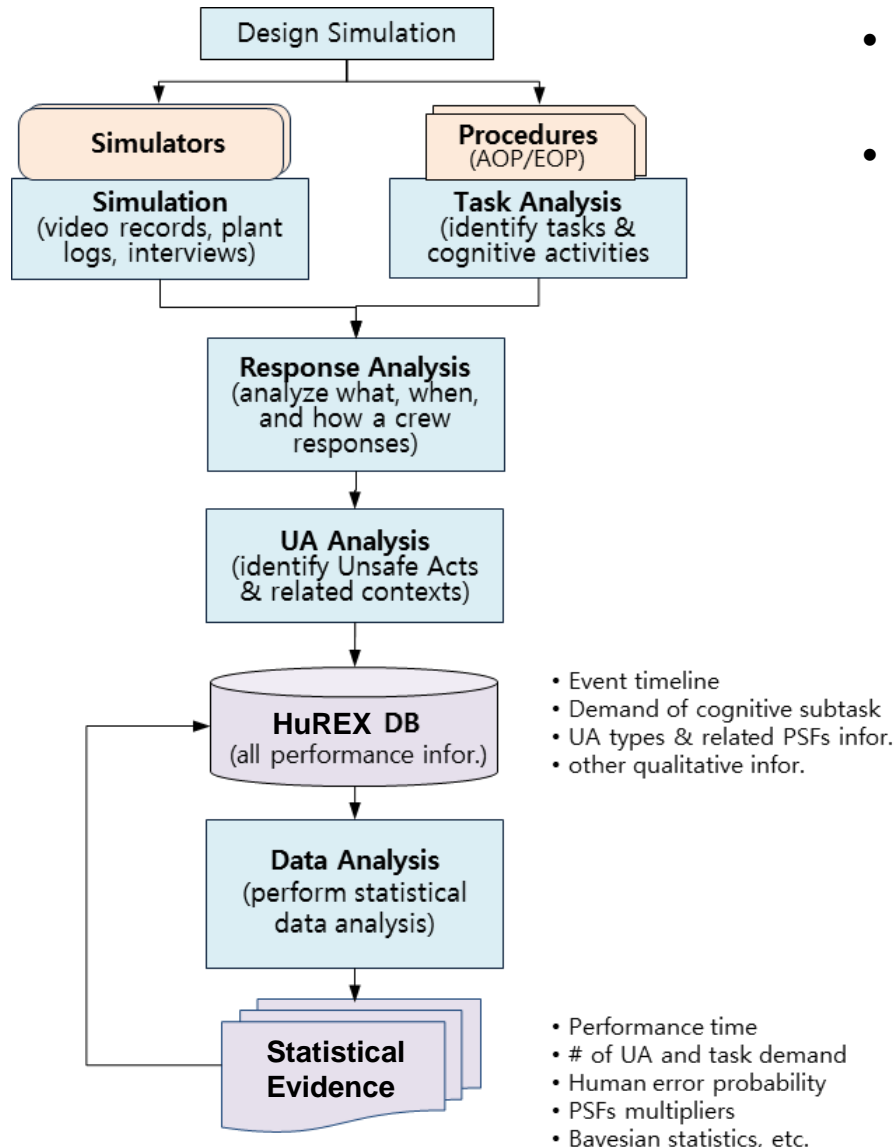
- Period: Jan. 1, 2017 ~ June 31, 2019

- Collection of human reliability data in APR1400 by HuREX framework
  - Full-scope simulator of APR1400 (Shingori unit #3 and #4)
  - Records from regular training with licensed operators
  - Procedure-based task definition
  - Data points collected to date : 44,585
  - About 50 PSF (performance shaping factor) variables
  - Statistical evidence for HEP, PSF effect, recovery action, etc.
  - All human error identification/characterizations were peer-reviewed

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Definitions of Task and Human Error in HuREX

- Task
  - Action-level task based on the procedure instructions

Abstraction level		
Plant level	Reactivity Control RCS Inventory control RCS Pressure Control Core Heat removal …	RCS Heat Removal Containment isolation Combustible gas control Indirect radioactivity release control
Scenario level	Confirming the accident diagnosis Delivery of a sufficient SI flow Checking criteria for RCP stoppage Initial cooling down the hot-leg temperature of RCS …	
Action level	Checking discrete state - Verifying alarm occurrence Checking discrete state - Verifying state of indicator Manipulation - Simple (discrete) control Notifying/requesting to MCR outside …	
Interface operation level	Board selection Control device selection Operation execution Confirmation …	Screen selection Control device selection Operation execution Confirmation …
Keystroke level	Walking to board Button press Turning wheel Turning rotary knob …	Button press Pointing target Homing the hands Drawing line segments …

HuREX taxonomy

Impact on Task

Change of man-machine system

# Definitions of Task and Human Error in HuREX

- Task
  - Action-level task based on the procedure instructions

- Human error
  - "An action inappropriately taken by plant personnel, or not taken when needed, resulting in a degraded plant safety condition." - unsafe act by James Reason
  - Deviated behaviors from standards (e.g., procedures) causing the following consequences
    - Inappropriate component operations
    - Inappropriate changes of procedural steps
    - Inappropriate communications with an MCR outside

Purpose of This Study

- Data analysis projects
  - KHNP, 디지털 환경의 인적오류확률 및 안전소프트웨어 신뢰도 평가, 2016. 12. 23 ~ 2019. 6. 30.
  - EPRI, HRA for Digital I&C – KAERI, 2019. 10. 1 ~ 2021. 9. 30

- Several results derived from the analysis of APR1400 HuREX data
  - Kim Y., Choi, J., Park, J., Lee, S. J., (2018). "Estimating Diagnosis Time of Emergency Situations in Digitalized Control Rooms," International Conference on Applied Human Factors and Ergonomics, 2018, Orlando, FL.
  - Kim, Y., Park, J., Kim, H.E., Shin, S. K., Presley, M., (2020). "Quantifying PSF Effects On Human Reliability In Digital Control Rooms Based On Simulation Records," Proceedings of the 30th European Safety and Reliability Conference and the 15th Probabilistic Safety Assessment and Management Conference, 2020, Venice, Italy, 21 - 26 June.

- Goal: Summarize the results and provide insights regarding human reliability
  - Performance time
  - Reliability in detection/monitoring, procedure following, and execution
  - Recovery factor

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Performance Time

- Diagnosis time
    - APR1400 Emergency operating procedure

Diagnosis time
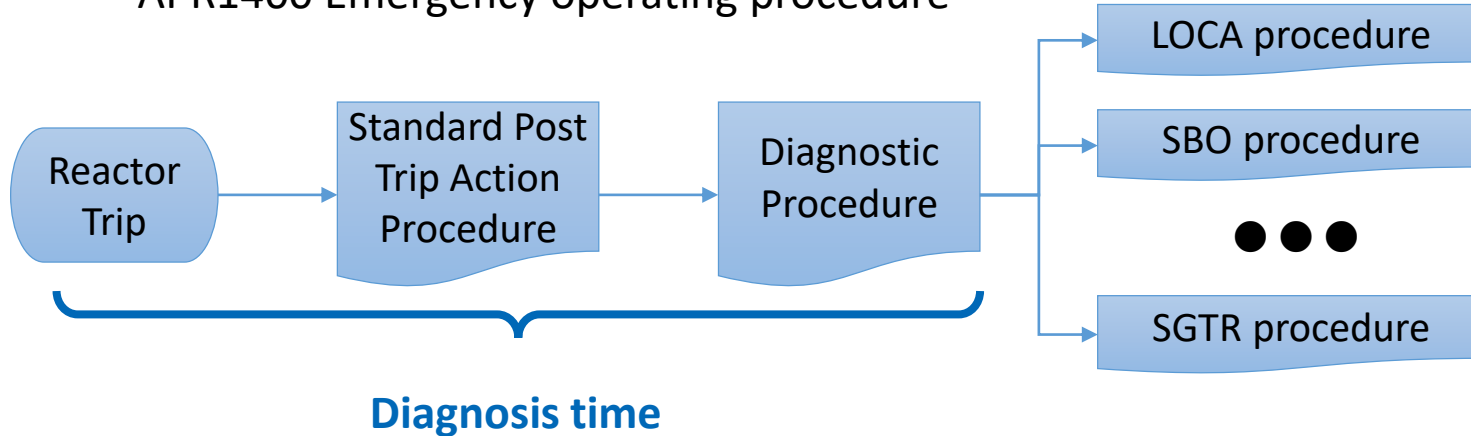
- Time data from training records of a full-scope simulator

Scenario	Number of records
Station black out	5
Steam generator tube rupture	9
Loss of coolant accident in a coolant pump seal	6
Loss of coolant accident in a safety relief valve	4
Interfacing system loss of coolant accident	6
Loss of all feedwater	6

- Basic statistics
    - Mean: 8.166 min; Standard deviation: 2.888 min; coefficient of variation: 0.354

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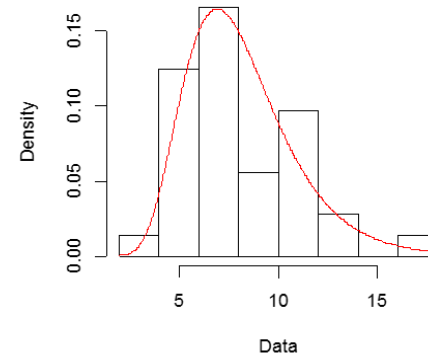
Performance Time

- Log-normal distribution could be preferred for description of the diagnosis time of operators
  - Goodness-of-fit

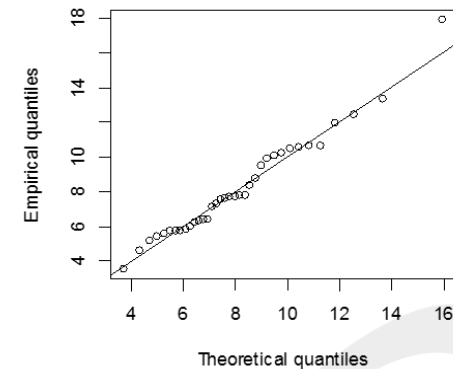|	Log-normal	Normal	Gamma	Weibull
Log-likelihood	-84.810	-88.755	-85.489	-88.521
AIC	173.619	181.510	174.979	181.043
BIC	176.786	184.677	178.146	184.210

- ln $(X) \sim N(\mu, \sigma^2)$
  - μ : 2.044 (standard error: 0.055)
  - σ: 0.330 (standard error: 0.039)

- Cf. reactor trip ~ End of 8th step of ORP
  - μ : 2.545 (standard error: 0.058)
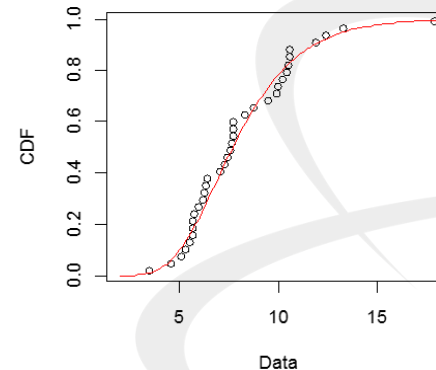 - σ: 0.318 (standard error: 0.041)
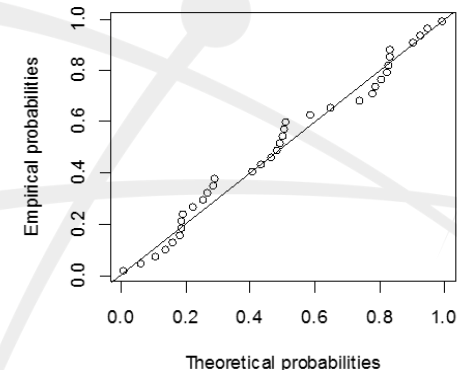
AIC: Aikake's Information Criterion
BIC: Bayesian Information Criterion

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Performance Time

- Diagnosis time in analog MCRs
  - Source: OPERA (operator performance and reliability analysis) database
  - Basic statistics
    - Mean: 5.807 min;
      Standard deviation: 3.078 min;
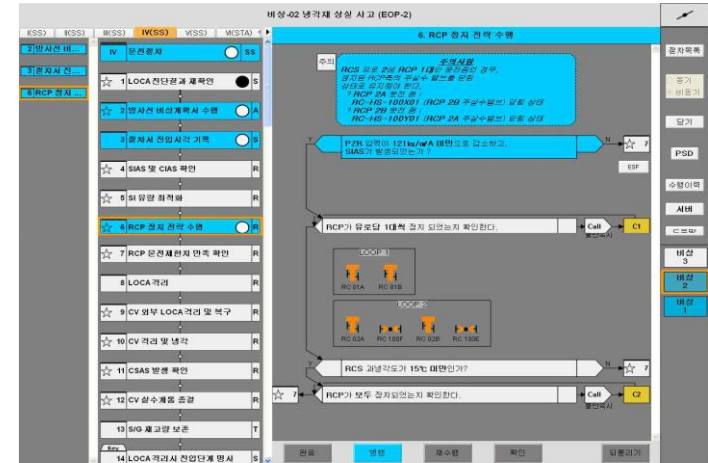   coefficient of variation: 0.530
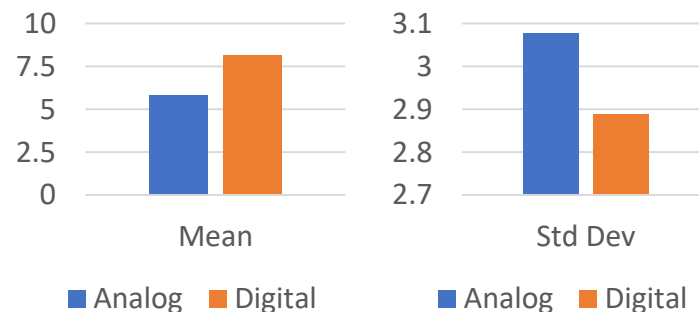
- Insights
  - Average time increased
    - Computer-based procedure requires the operators to click placekeepings in procedures one by one
  - Variation decreased
    - Computer-based procedure equally requires all operators to click placekeepings in procedures one by one

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Detection and Monitoring Errors

- Summary of human error data regarding detection/monitoring
  - Attempts: 22792
  - Omission error: 0
  - Commission error: 27
    - Most errors were related to the initial emergency situations
    - Concurrent task required during initial situation
    - Additional malfunctions
      - Full strength control elements stuck (emergency boration required) or Anticipated transient without trip
      - Failure of SIAS (safety injection actuation signal)
      - Failure of CIAS (containment isolation actuation signal)

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- EOO: error of omission
- EOC: error of commission

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Cognitive Errors in Procedure Followings

- HEPs differ according to task types
    - Entering a step in a procedure
    - Transferring procedures
    - Transferring steps in a procedure
    - Directing information gathering
    - Directing manipulation
    - Directing notification/request

- The clarity of labels, instructions, or structures between instructions can have a significant impact
    - Quality of procedure is emphasized in APR1400

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Execution Errors

- HEPs differ according to task types
    - Manipulating simple (discrete) control
    - Manipulating simple (continuous) control
    - Manipulating dynamically
    - Notifying to outside the MCR

- Secondary tasks or screen navigation during execution
    - No errors causing the wrong component manipulation was observed
    - Compared to the previous studies participating student subjects, the skillful operators had less difficulty in navigation
    - Digital information system is designed to be able to reach any screens from the main screen by one or two conversions of screens.

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Recoverability

- A small number of recovery successes were observed
    - The recording period of raw data was mostly within 3-40 minutes
    - Initial emergency situation continuously demand new tasks

- Several types of recovery opportunities (need to investigate long-term recovery)
    - Recovery by peer/self check
    - Recovery by a procedure step confirming the action
    - Recovery by a shift change
    - Recovery by an apparent cue
    - Procedure recheck in a stable status
    - Monitoring of safety-critical functions by the shift technical advisor

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Conclusion

- The digital interface systems can provide a new opportunity to improve operator reliability and performance
- The joint performance of the man-machine system can be enhanced
  - if the system is optimized through continuous human behavior observations and analyses
- The operation experience of the APR1400 is still relatively small
  - Additional collection and analysis of human reliability data is desirable

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