Preliminary Findings from APR1400 HuREX data collection and analysis

HRA Data Workshop

Yochan Kim / KAERI
Jinkyun Park / KAERI
Mary Presley / EPRI

US NRC, Rockville, MD
12.MAR.2020

Abbreviation

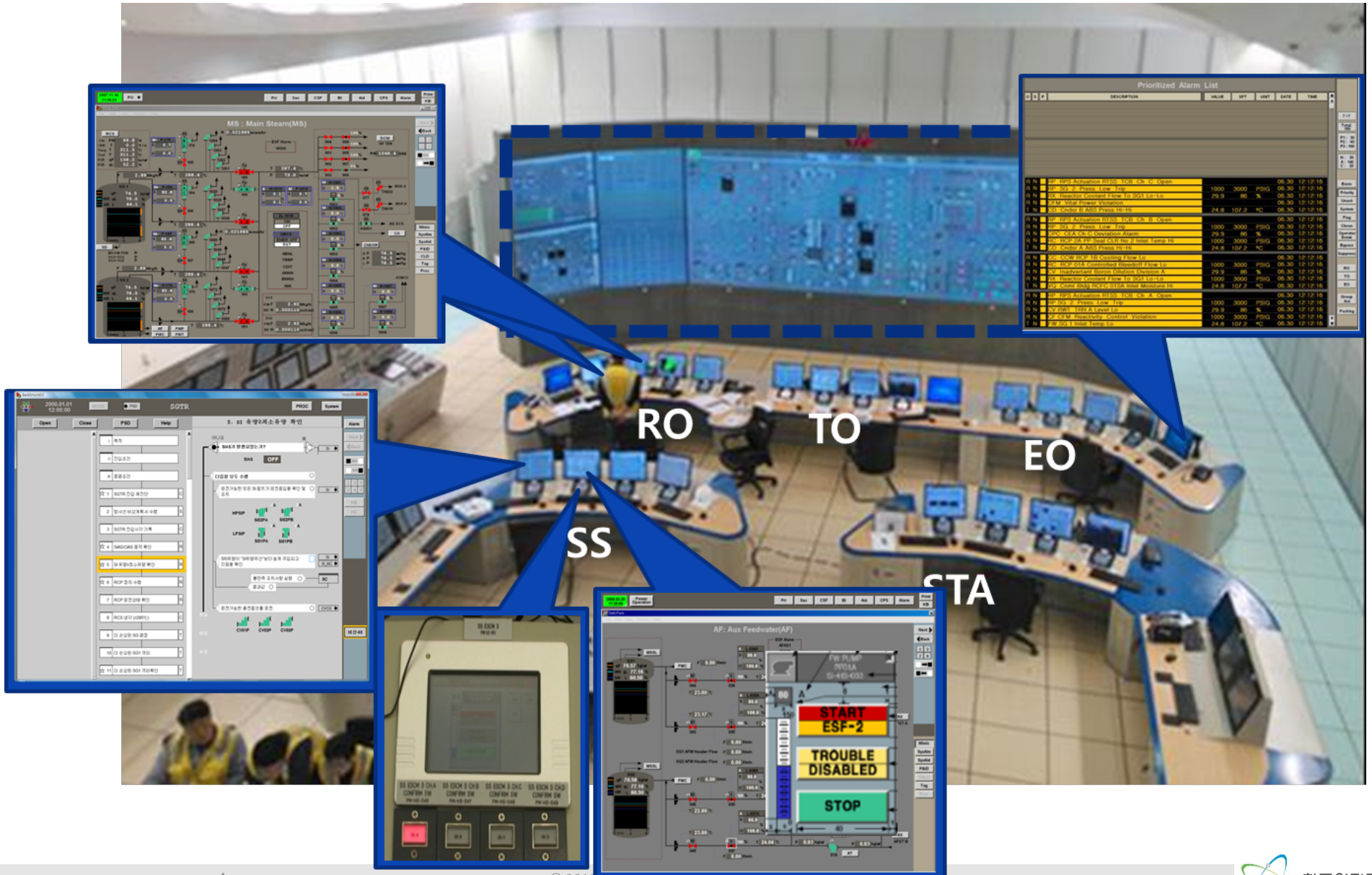
- APR1400: Advanced Power Reactor 1400 MW
- CBDTM: Cause-Based Decision Tree Method
- CPS: computerized procedure system
- FRP: functional recovery procedure
- HEP: human error probability
- HuREX: human reliability extraction
- IE: initiating event
- IGT: information gathering template
- IPS: information processing system
- KHNP: Korea Hydro & Nuclear Power Co.
- LDP: large display panel
- MCR: main control room
- PSF: performance shaping factor
- SS: shift supervisor
- UA: unsafe act (≒human error)

Contents

- Background / APR1400 Data
- Data Analysis with EPRI
- Preliminary Statistical Results
- Insights Regarding HRA Data Science

Part 1. Background / APR1400 Data

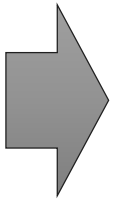
Background: Computer-Based Control Room in APR1400



Background: Human Factors Issues in DI&C systems

- Change of Interfaces

Conventional MCR	Computer-based MCR
Paper-based procedure	Computer-based procedure
Hard-wired indicators in analog panel	Digital information system
	Large display panel
Hard-wired control interfaces	Soft control
Alarm tile	Advanced alarm system



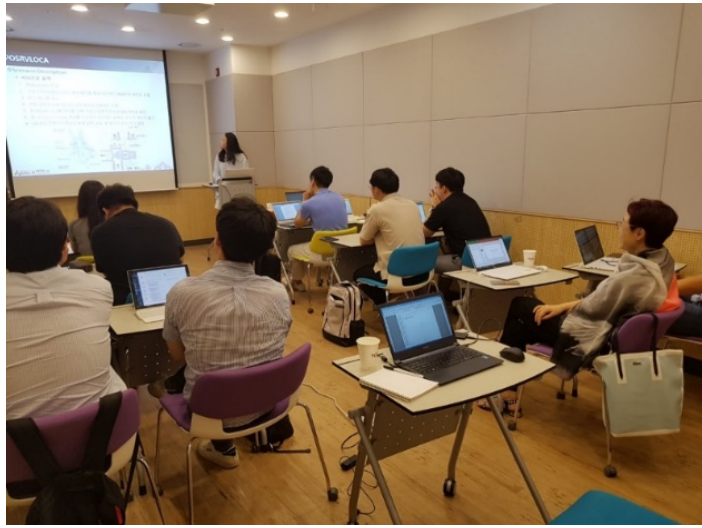
- Human performance issues in digital interface environments
  - Instrumentation quality
  - Instrumentation complexity
  - Control interface complexity
  - Situation awareness
  - Task complexity
  - Communication and coordination
  - Digital Fatigue
  - Digital system failure
  - Recovery
  - Trust/Reliance
  - Stress
  - Control interface quality

Background: Human Factors Issue examples

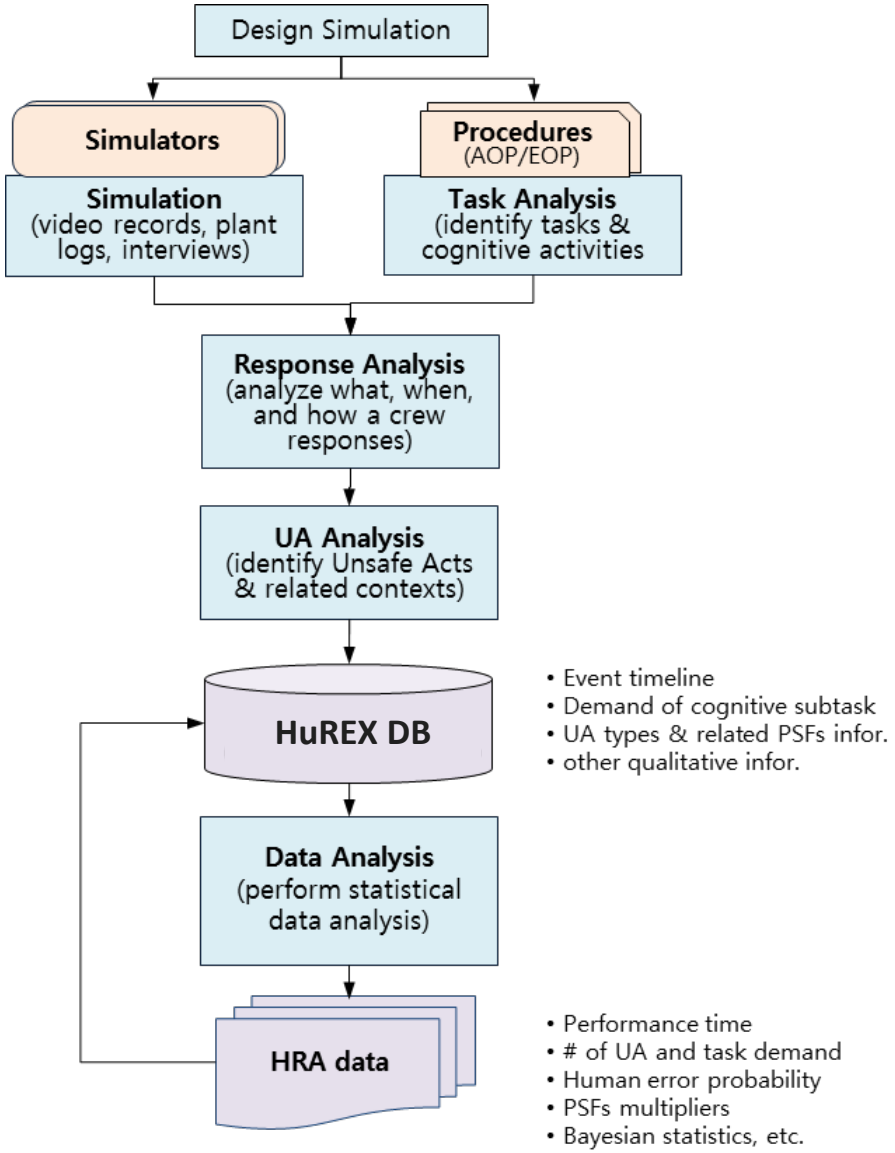
- Distributed information
- Confusing and unstructured presentation of display
- Loss of contextual information (spatial/functional information, visual patterns etc.)
- Misplaced salience (inappropriate HMI design)
- Weak correlations between alarms and the associated process parameters or actions
- Requisite memory trap (over reliance on previous memory)
- Missing task critical information
- Lack of early detection support (monitoring failure, loss of vigilance)
- Lack of feedback information (including time delay)
- Mode error (a type of slip where a user performs an action appropriate to one situation in another situation, common in software with multiple modes)
- Decrease of the range of vision (visual momentum)
- Difficulty understanding automation (visibility of automation system)
- Out-of-the-loop with the level of automation
- Lack of big picture (e.g., Process overview)
- Lack of in-depth insight of critical process dynamics
- Keyhole effect (attentional tunneling)
- Change in the role/function of human operators with respect to the use of new digital systems
- The effects of HMI design on crew coordination and cooperation
- Coordination among crew members and group decision making
- Communications among crew members
- Information hand-off among different crews

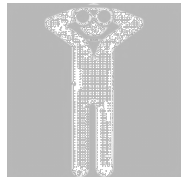
HuREX Data Collection Project (KHNP Project)

- Period: Jan. 1, 2017 ~ June 31, 2019
- Sponsor: Operating company (Korea Hydro & Nuclear Power)
- Research expenses:
- Research participants: KAERI (with UNIST and Chosen university)
- Raw data
  - Full-scope simulator of APR1400 (Shingori unit #3 and #4)
  - Records from regular training with licensed operators
- HuREX data generation
  - 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

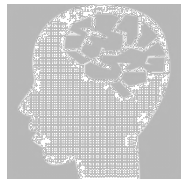


HuREX Framework

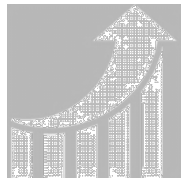




Full-scope simulator



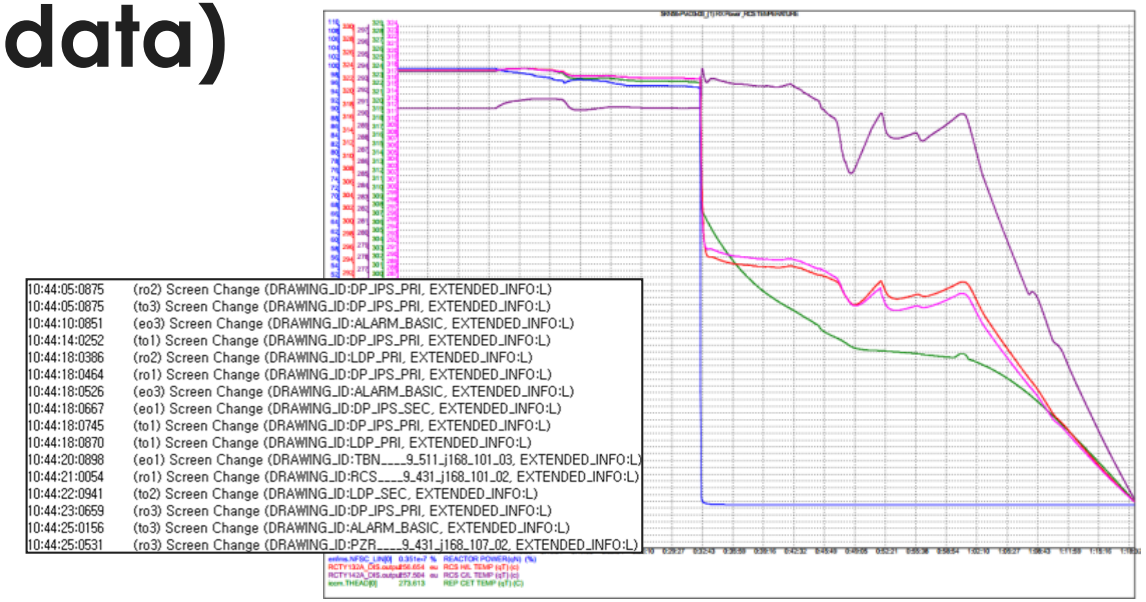
Subjectivity minimalism



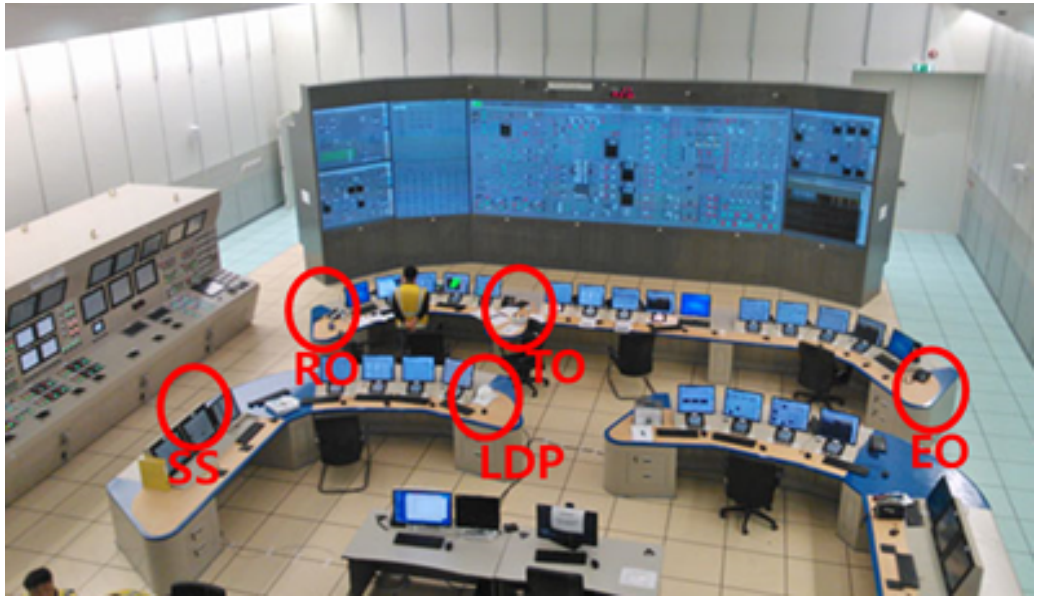
Statistical evidence

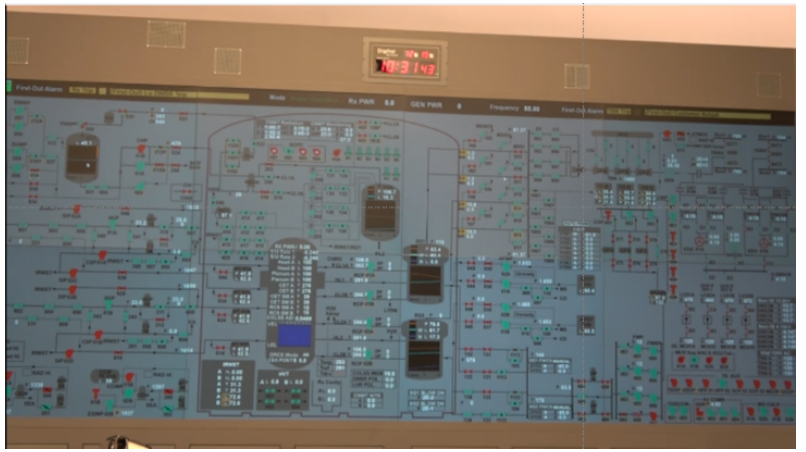
Simulation Records (Raw data)

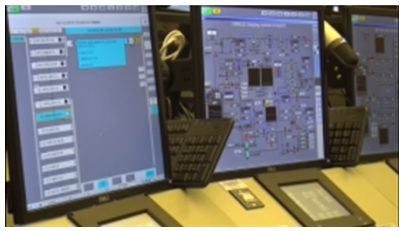
- Data from full-scope simulator
  - Audio-video records (from 5 cameras)
  - Plant parameter log
  - Screen navigation log
  - Procedure progression log (CPS)
  - Alarm/malfunction log
  - Questionnaires (Career/experience)

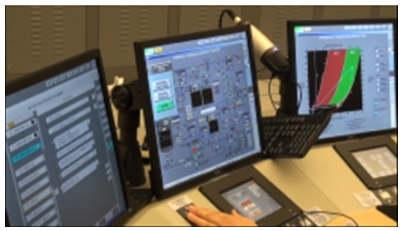


```
10:44:05:0875   (ro2) Screen Change (DRAWING_ID:DP_IPS_PRI, EXTENDED_INFO:L)
10:44:05:0875   (to3) Screen Change (DRAWING_ID:DP_IPS_PRI, EXTENDED_INFO:L)
10:44:10:0851   (eo3) Screen Change (DRAWING_ID:ALARM_BASIC, EXTENDED_INFO:L)
10:44:14:0252   (to1) Screen Change (DRAWING_ID:DP_IPS_PRI, EXTENDED_INFO:L)
10:44:18:0386   (ro2) Screen Change (DRAWING_ID:LDP_PRI, EXTENDED_INFO:L)
10:44:18:0464   (ro1) Screen Change (DRAWING_ID:DP_IPS_PRI, EXTENDED_INFO:L)
10:44:18:0526   (eo3) Screen Change (DRAWING_ID:ALARM_BASIC, EXTENDED_INFO:L)
10:44:18:0667   (eo1) Screen Change (DRAWING_ID:DP_IPS_SEC, EXTENDED_INFO:L)
10:44:18:0745   (to1) Screen Change (DRAWING_ID:DP_IPS_PRI, EXTENDED_INFO:L)
10:44:18:0870   (to1) Screen Change (DRAWING_ID:LDP_PRI, EXTENDED_INFO:L)
10:44:20:0898   (eo1) Screen Change (DRAWING_ID:TBN____9_511_j168_101_03, EXTENDED_INFO:L)
10:44:21:0054   (ro1) Screen Change (DRAWING_ID:RCS____9_431_j168_101_02, EXTENDED_INFO:L)
10:44:22:0941   (to2) Screen Change (DRAWING_ID:LDP_SEC, EXTENDED_INFO:L)
10:44:23:0659   (ro3) Screen Change (DRAWING_ID:DP_IPS_PRI, EXTENDED_INFO:L)
10:44:25:0156   (to3) Screen Change (DRAWING_ID:ALARM_BASIC, EXTENDED_INFO:L)
10:44:25:0531   (ro3) Screen Change (DRAWING_ID:PZR____9_431_j168_107_02, EXTENDED_INFO:L)
```



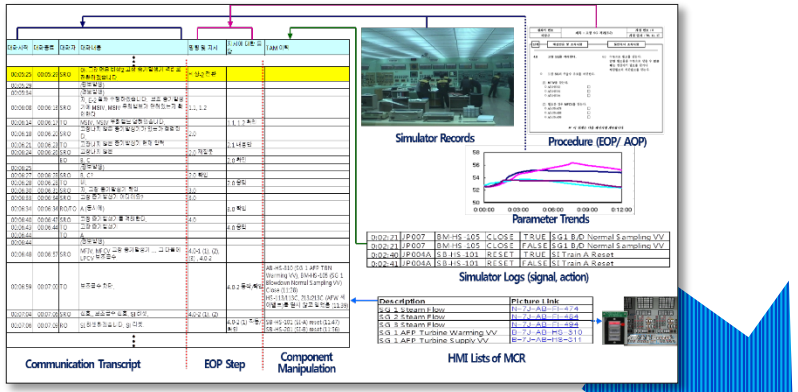






HuREX Data Generation

- IGT data from simulation records



Information from Overview IGT

General information including a plant name, plant type, operating mode, crew information (e.g., work experience), and training/education experience

Information from Response IGT

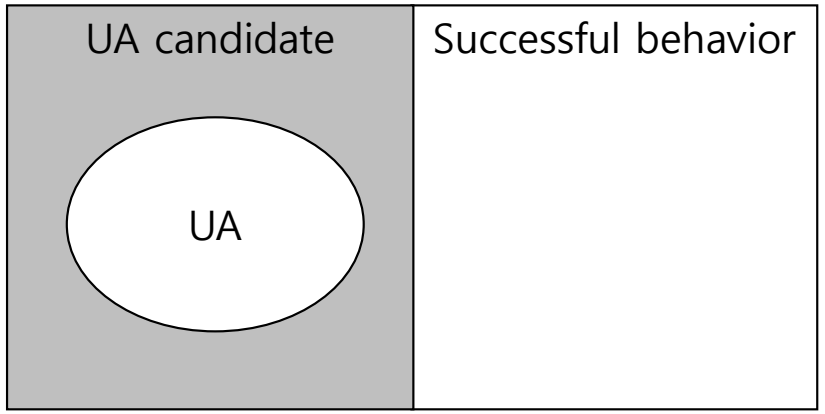
Response (i.e., success or failure) of human operators for given tasks in the scenarios and the relevant task characteristics (e.g., task type and target component to be manipulated)

Information from unsafe act (UA) IGT

Detailed information on erroneous behaviours (i.e., UA) observed from a simulation record such as a UA recovery, task complexity, task familiarity, and procedure quality

UA (Human Error) Definition

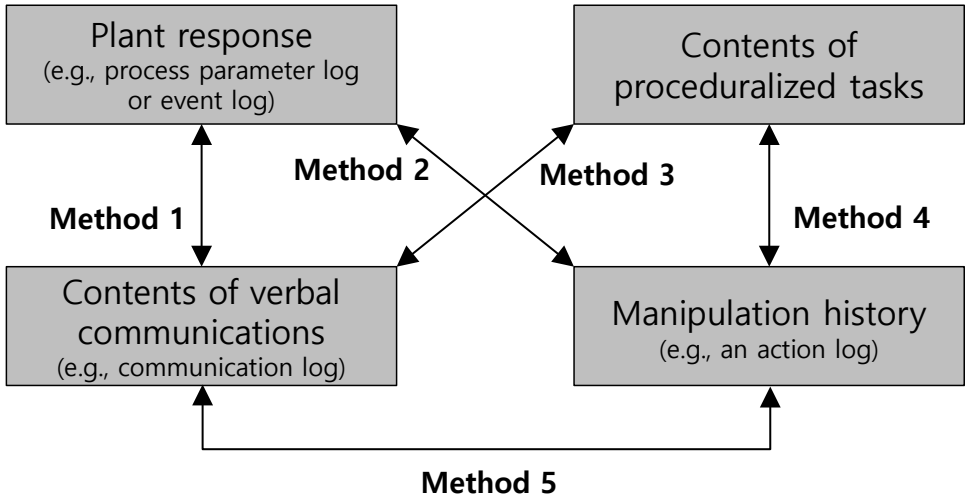
- Definition of Unsafe Act (UA)
  - An erroneous behavior that negatively affects the safety of a plant (= human error + a part of routine violation)



UA: A human behavior that could have a negative influence on the operational safety of NPPs in a direct or indirect way.

UA (Human Error) Identification

- First, identify all UA candidates (any kind of deviation from an expected procedural path)



- Second, select UAs from UA candidates based on their consequences.

Three Consequence	Detailed example
Inappropriate component manipulation	• A wrong component is operated. • A targeted component is not operated when its operational condition was satisfied.
Inappropriate procedure performance	• A wrong procedural step is performed. • A procedure transfer is omitted.
Inappropriate notification/request	• An important announcement or request to other department and/or or ganizations is omitted • A wrong announcement is proclaimed.

66 Supportive UA Identification Rules (Examples)

When a BO did not immediately start an ordered task that was directly instructed by a SS: (1) If the BO accomplished the ordered task before initiating a new procedural step, the BO's behavior should not be marked as an UA; (2) If the BO accomplished the ordered task after the initiation of a new procedural step, this behavior should be marked as an UA; (3) If the BO cannot immediately follow the SS's instruction due to the performance of an another task.(e.g., a previous task ordered by the SS), the BO's behavior should not be marked as an UA; (4) If the BO manifested rationales explaining why the ordered task is not immediately conducted (e.g., this value needs to keep closed because of a high temperature), the BO's behavior should not be marked as an UA.
When a SS did not instruct a certain task that was already conducted (a repeated task completed), if the SS did not order a BO to conduct the repeated task completed, the SS's behavior should not be marked as an UA;
When a SS did not instruct a certain task that was not finished (a repeated task not finished), if the SS did not order a BO to conduct the repeated task completed, the SS's behavior should be marked as an UA;
When a SS has to order a series of instructions combined by AND logic (e.g., 'IF A and B and C are TRUE, THEN perform D'), if the SS did not command a BO to carry out one or more instructions after identifying there is an unsatisfied instruction (e.g., 'A is FALSE'), then the SS's behavior should not be marked as an UA.
The number of UAs should be counted by the following rules: (1) When an UA has occurred as the result of a SS's instruction, the number of UAs should be one. (2) When an UA is related to the reporting of process parameters or the manipulation of specific components, the number of UAs should be counted based on the number of process parameters inappropriately reported or specific components inappropriately manipulated.
When an UA and its recovery behavior were observed during the performance of an identical procedural step, instead of considering the occurrence of an UA and its Recovery, the corresponding behaviors should be marked as successful behavior.
When an UA and its recovery behavior were observed during the performance of different procedural step, the corresponding behaviors should be marked as an UA and Recovery, respectively.
When a SS has to order an instruction according to the availability of a certain system , equipment and component, the availability should be determined based on the required function of the target system, equipment, and component.

Human Error Taxonomy of HuREX Data

Cognitive activity	Task type	Abbreviation	Error mode*
Information gathering and reporting	Checking discrete state - Verifying alarm occurrence	IG-alarm	EOO, EOC
	Checking discrete state - Verifying state of indicator	IG-indicator	EOO, EOC
	Checking discrete state - Synthetically verifying information	IG-synthesis	EOO, EOC
	Measuring parameter - Reading simple value	IG-value	EOO, EOC
	Measuring parameter - Comparing parameter	IG-comparison	EOO, EOC
	Measuring parameter - Comparing in graph constraint	IG-graph	EOO, EOC
	Measuring parameter - Comparing for abnormality	IG-abnormality	EOO, EOC
	Measuring parameter - Evaluating trend	IG-trend	EOO, EOC
Response planning and instruction	Entering step in procedure	RP-entry	EOO
	Transferring procedure	RP-procedure	EOO, EOC
	Transferring step in procedure	RP-step	EOO, EOC
	Directing information gathering	RP-information	EOO, EOC
	Directing manipulation	RP-manipulation	EOO, EOC
	Directing notification/request	RP-notification	EOO, EOC
Situation interpreting	Diagnosing	SI-diagnosis	EOO, EOC
	Identifying overall status	SI-identification	EOO, EOC
	Predicting	SI-prediction	EOO, EOC
Execution	Manipulation - Simple (discrete) control	EX-discrete	EOO, EOC
	Manipulation - Simple (continuous) control	EX-continuous	EOO, EOC
	Manipulation - Dynamic manipulation	EX-dynamic	EOO, EOC
	Notifying/requesting to MCR outside	EX-notification	EOO, EOC
Other	Unauthorized control - Unguided response planning and instruction	OT-planning	EOC
	Unauthorized control - Unguided manipulation	OT-manipulation	EOC
	Timing error (too fast/too late)		-

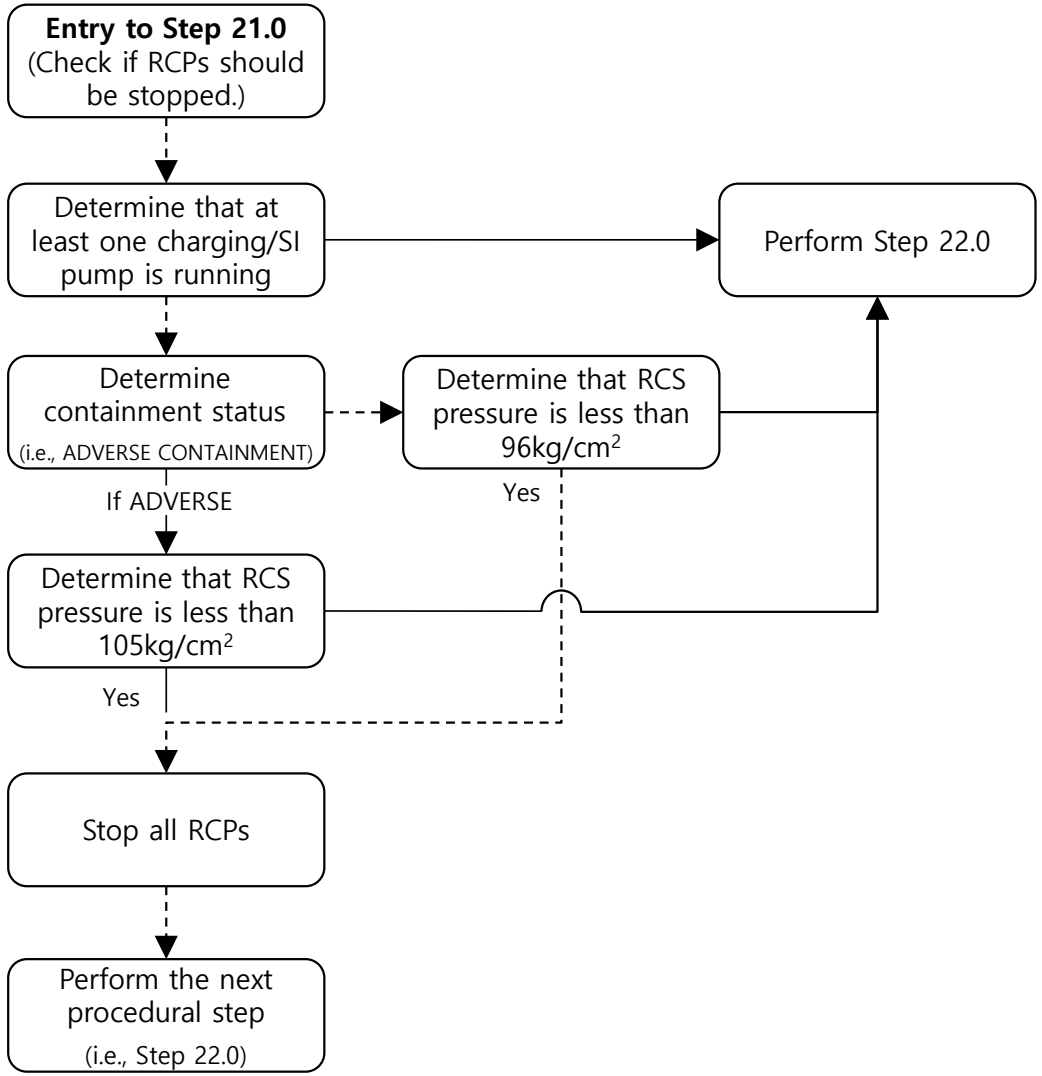
*EOO (Error of Omission); EOC (Error of Commission)

Application Example of Taxonomy (1)

Instructions	Response Not Obtained (RNO)
21.0 Check **IF** RCPs should be stopped.	
21.1 Determine **IF** at least **ONE** charging/SI pump is running	21.1 Perform Step 22.0
21.2 Determine IF RCS pressure is less than 96kg/cm^2 (105kg/cm^2 for **ADVERSE CONTAINMENT***)	21.2 Perform Step 22.0
21.3 Stop **ALL** RCPs	

RCP: Reactor Coolant Pump
RCS: Reactor Coolant System
SI: Safety Injection

***ADVERSE CONTAINMENT** denotes the specific condition of containment when either its pressure is greater than 0.35kg/cm^2 or its radiation dose is greater than 10^5R/hr.



Application Example of Taxonomy (2)

Instruction*	ID	Cognitive activity	Task type
Check if RCPs should be stopped	1	Response planning and instruction	Entering step in procedure
Determine that at least one charging/SI pump is running	2	Response planning and instruction	Directing information gathering
	3	Information gathering and reporting – checking discrete state	Verifying state of indicator
Determine containment status (i.e., ADVERSE CONTAINMENT)	4	Response planning and instruction	Directing information gathering
	5	Information gathering and reporting – measuring parameter	Comparing for abnormality
Determine RCS pressure	6	Response planning and instruction	Directing information gathering
	7	Information gathering and reporting – measuring parameter	Comparing parameter
Stop all RCPs	8	Response planning and instruction	Directing manipulation
	9	Action – manipulation	Manipulating simple (discrete) control
Perform Step 22.0	10	Response planning and instruction	Transferring step in procedure

IGT Data Example – Overview IGT

Data Field	Meaning	Example
Scenario ID		170208_#1_AFASfalse
Plant/simulator name		SW01
Plant type		APR1400
Crew/shift/team name		Unit 3-#4
Crew	Age work experience of plant operation work experience in current team	45 13 2
Training experience	Inclusion of scenario in the regular training program	True / False
Simulation mode	Type of the simulated situation based on the reactor trip	Abnormal / Emergency
Multiple initiating events	Whether inputted scenarios are single or multiple	True / False
Failed system/component	Existence of additional malfunctions in the system or component	True / False
Failed alarm/indicator	Existence of masked or failed indicators or alarms	True / False
Leadership of SS	Leadership style of shift supervisor	Commanding / Democratic
Cooperative attitude of BOs	Whether board operators showed active responses or communications during the simulations	True / False
Supervising level of STA	Whether the STA actively checked the operations of the systems	True / False
Independent checker	Existence of independent review during significant system controls	True / False
Procedure compliance	How the shift supervisor gave directions based on the procedures	Mission Goal Only / Instruction in Detail / Instruction Selectively
Overall communication strategy	Communication strategy that is frequently observed during the simulation	One-Way / Two-Way / Three-Way

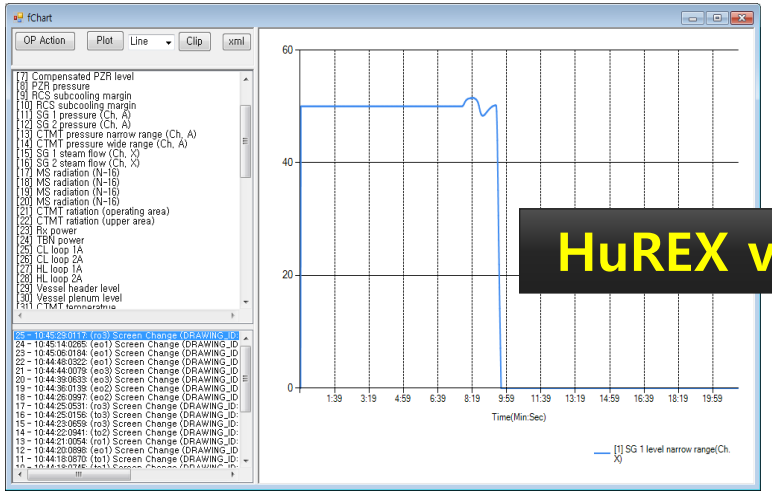
IGT Data Example – Response IGT

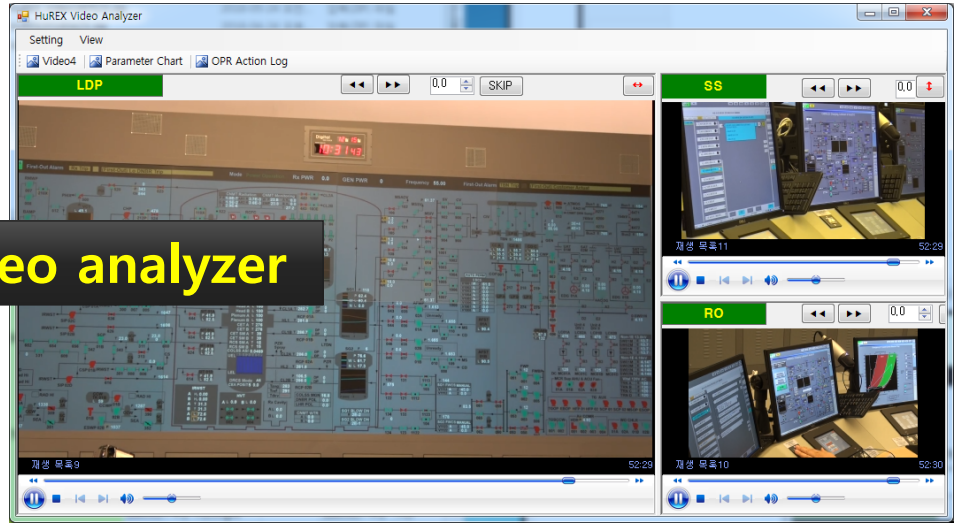
Scenario ID	Time	GT_ID	Proce-dure	Step	Sub-step	Contents	Cognitive Activity	Task Type	Success (#)	EOO	EOC		UA Code	Desc.
170314_#1_SGTR	13:00:02	APRSW_012	DA	2	0	Goal: Check reactivity	RP	Entry	1	0	0			…
170314_#1_SGTR		APRSW_012	DA	2	1	Is reactivity criteria satisfied?	RP; IG; RP/RP	Information; Synthesis; Step/Procedure	1; 1; 1/0	0; 0; 0	0; 0; 0		UA-01	
170314_#1_SGTR	13:00:02	APRSW_012	DA	3	0	Goal: Check electric supply	RP	Entry	1	0	0			
170314_#1_SGTR		APRSW_012	DA	3	1	…	RP; IG; RP/RP	Information; Indicator; Step/Procedure	1; 4; 1/0	0; 0; 0	0; 0; 0	…		…
170314_#1_SGTR	13:00:02	APRSW_012	DA	4	0	Goal Check RCS subcooling margin	RP	Entry	1	0	0			…
170314_#1_SGTR		APRSW_012	DA	4	1	Is RCS subcooling margin lower than 15 degree?	RP; IG; RP/RP	Information; Comparison; Step/Procedure	1; 4; 1	0; 0; 0	0; 0; 0			…

IGT Data Example – UA IGT

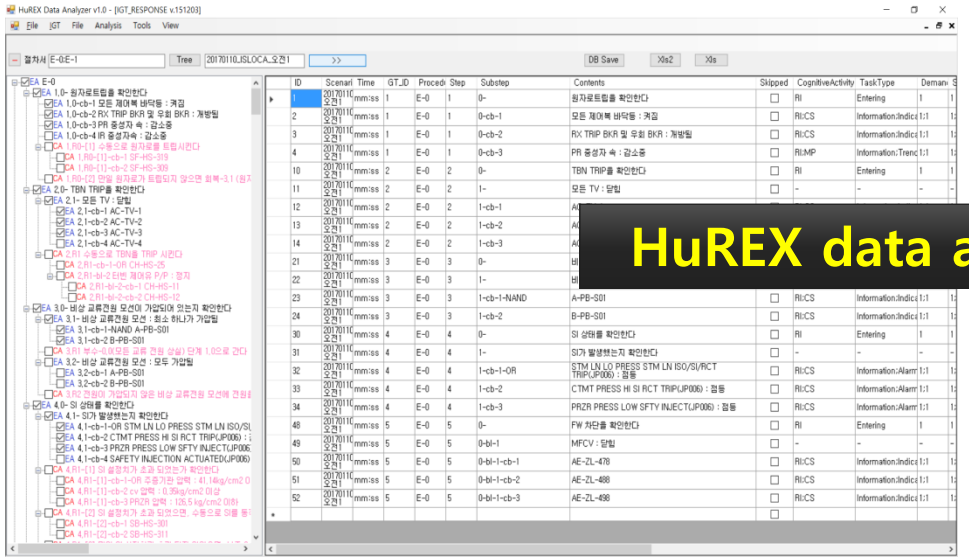
Data Field	Meaning	Example
UA code	Code to identify each UA	UA-1
UA overall description	UA information including context information	Free description
Effected component type	Type of component being affected by an UA	Pump (RCP-01)
Effected system type	System being affected by an UA	None
Recovered UA	Yes for a recovered UA	Yes
Recovery timing	Actual timing of recovery	After step.
Failed system/component	System/component already failed at the simulation starting stage	None
Time pressure	- Before the completion of diagnosis during EOP operation - Before the completion of initial response in EOP operation - After the completion of initial response in EOP operation - During AOP operation	After the completion of initial response in EOP operation
Contingency action	Yes if an UA has occurred during the performance of a contingency action part, if MCR operators used two-column format EOPs	No
Note OR Caution	Yes if Note or Caution is related to the occurrence of an UA	No
Change of procedure strategy	Yes if an UA has occurred during the transfer to other procedure or step	No
Procedure conformity	Procedure conformity to a simulated situation; - Good if there is no sudden/unexpected change in process parameter - Bad if there is sudden/unexpected change in process parameter	Good
Number of sub steps	The number of sub steps or detailed actions included in a step in which an UA has occurred.	3
The number of manipulations	The number of component manipulations included in a step in which an UA has occurred.	3

HuREX Video Analyzer & Data Analyzer

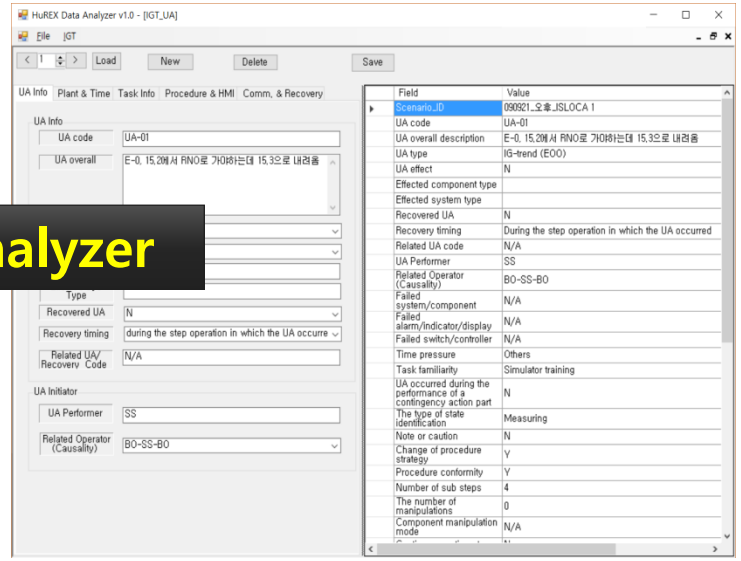




HuREX video analyzer



HuREX data analyzer



Simulated Scenarios

- Abnormal situation (8)
  - False operation of auxiliary feedwater actuation signal
  - Rupture of letdown flow line
  - Simple earthquake
  - Failure of high pressure heater drain valve
  - Letdown pressure control valve close
  - Steam generator tube leak
  - Leak of turbine control oil
  - RCP seal flow control valve failure
- Emergency situation (12)
  - SBO (station black out)
  - SGTR (steam generator tube rupture)
  - SGTR with failure of N-16 radiation indicator
  - SGTR with CPS failure
  - SGTR with safety injection failure
  - LOCA (loss of coolant accident) from RCP (reactor coolant pump) seal
  - Interfacing system LOCA (LTOP valve)
  - Interfacing system LOCA (letdown valve)
  - DVI (direct vessel injection) LOCA
  - LOCA with safety injection failure
  - LOCA from pilot operated safety relief valve
  - Feed and bleed operation in LOAF (loss of all feed water)

Characteristics of Scenarios

Scenarios	Reactor Tripped	Multiple IE	Failed alarm / indicator	Procedure type	FRP Inclusion	Scenario Familiarity
AFAS false	Abnormal	FALSE	FALSE	CBP	Abnormal	TRUE
CV-201 Close	Abnormal	FALSE	FALSE	CBP	Abnormal	TRUE
CVCS letdown Leak	Abnormal	FALSE	FALSE	CBP	Abnormal	TRUE
Earthquake(lower than OBE)	Abnormal	FALSE	FALSE	CBP	Abnormal	TRUE
Failure of high pressure heater drain valve	Abnormal	FALSE	FALSE	CBP	Abnormal	TRUE
RCP01A Seal Flow Valve Fail	Abnormal	FALSE	FALSE	CBP	Abnormal	TRUE
SGTL	Abnormal	FALSE	FALSE	CBP	Abnormal	TRUE
Turbine EHC Leak	Abnormal	FALSE	FALSE	CBP	Abnormal	TRUE
POSRV LOCA	Emergency	FALSE	FALSE	CBP	FALSE	FALSE
DVI LOCA	Emergency	FALSE	FALSE	CBP	FALSE	TRUE
Interfacing system LOCA (letdown valve)	Emergency	FALSE	FALSE	CBP	FALSE	TRUE
RCP seal SBLOCA	Emergency	FALSE	FALSE	CBP	FALSE	TRUE
SBO	Emergency	FALSE	FALSE	CBP	FALSE	TRUE
SGTR	Emergency	FALSE	FALSE	CBP	FALSE	TRUE
LOAF	Emergency	FALSE	FALSE	CBP	TRUE	TRUE
SGTR with CPS failure	Emergency	FALSE	FALSE	PBP	FALSE	TRUE
Interfacing system LOCA (LTOP valve)	Emergency	FALSE	TRUE	CBP	FALSE	FALSE
SGTR with N-16 failure	Emergency	FALSE	TRUE	CBP	FALSE	FALSE
SBLOCA with SI failure	Emergency	TRUE	FALSE	CBP	TRUE	FALSE
SGTR with SI failure	Emergency	TRUE	FALSE	CBP	TRUE	TRUE

Additional Malfunctions in Emergency Scenarios

Scenario	Additional malfunctions
SBO	· Earthquake alarm annunciation
SGTR	· Full strength control elements stuck (emergency boration required) · Failure of SIAS/CIAS
SGTR with failure of N-16 radiation indicator	· Full strength control elements stuck (emergency boration required) · Failure of SIAS/CIAS · Failure of N-16 radiation indicator
SGTR with CPS failure	· Failure of SIAS/CIAS · Anticipated transient without trip · Failure of diverse protection system
SGTR with safety injection failure	· Loss of offsite power · Failure of SIAS/CIAS · Anticipated transient without trip
LOCA from RCP seal	· Failure of SIAS/CIAS
Interfacing system LOCA (LTOP valve)	· Full strength control elements stuck (emergency boration required) · Failure of SIAS/CIAS · Failure of indications regarding leak area
Interfacing system LOCA (letdown valve)	· Full strength control elements stuck (emergency boration required) · Failure of SIAS/CIAS
DVI (direct vessel injection) LOCA	· Full strength control elements stuck (emergency boration required) · Failure of SIAS/CIAS
LOCA with safety injection failure	· Loss of offsite power · Failure of SIAS/CIAS · Anticipated transient without trip
LOCA from pilot-operated safety relief valve	· Anticipated transient without trip · Failure of diverse protection system · Failure of SIAS/CIAS
Feed and bleed operation in LOAF	· Anticipated transient without trip · Failure of diverse protection system · Failure of SIAS

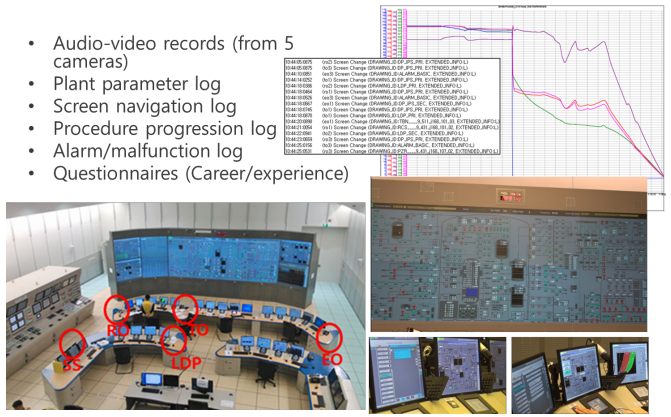
Part 2. Data Analysis with EPRI

EPRI Project Overview: PSF Data Analysis

- Two Projects for HRA data in Digital MCR
  - Basic HEP estimation from HuREX data (collaboration with KHNP)
    - Sep., 2019 ~ Feb., 2021
  - PSF effect estimation from HuREX data (collaboration with KAERI)
    - Oct., 2019 ~ Jan., 2021
- Goal: data collection and analysis of the performance shaping factor-related data
  - Understand the qualitative factors that affect human performance in digital environments
  - Provide some quantitative representation of the effect of these performance shaping factors (PSF)

Data Analysis Process

- Audio-video records (from 5 cameras)
- Plant parameter log
- Screen navigation log
- Procedure progression log
- Alarm/malfunction log
- Questionnaires (Career/experience)



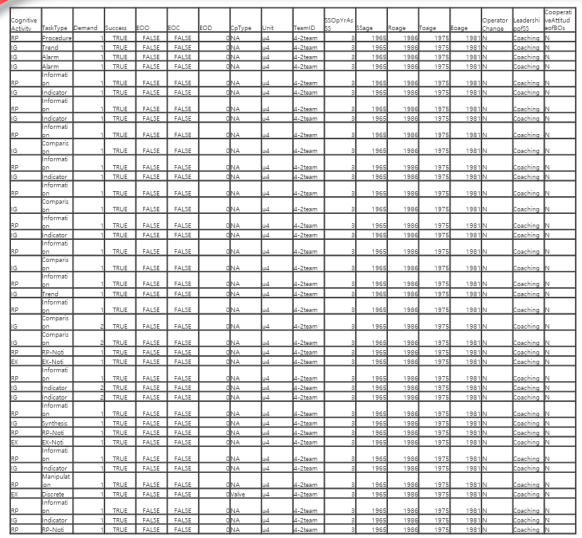
Raw data (simulation records)

KHNP Project

- **Information from Overview IGT**: General information including a plant name, plant type, operating mode, crew information (e.g., work experience), and training/education experience
- **Information from Response IGT**: Response (i.e., success or failure) of human operators for given tasks in the scenarios and the relevant task characteristics (e.g., task type and target component to be manipulated)
- **Information from unsafe act (UA) IGT**: Detailed information on erroneous behaviours (i.e., UA) observed from a simulation record such as a UA recovery, task complexity, task familiarity, and procedure quality

HuREX **IGT data** (165 sets of excel files)

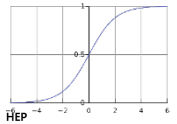
EPRI Project

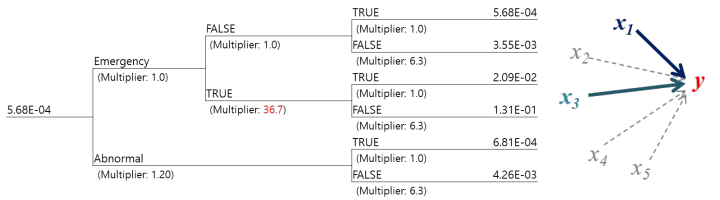


HuREX **PSF data**

Data Analysis Techniques

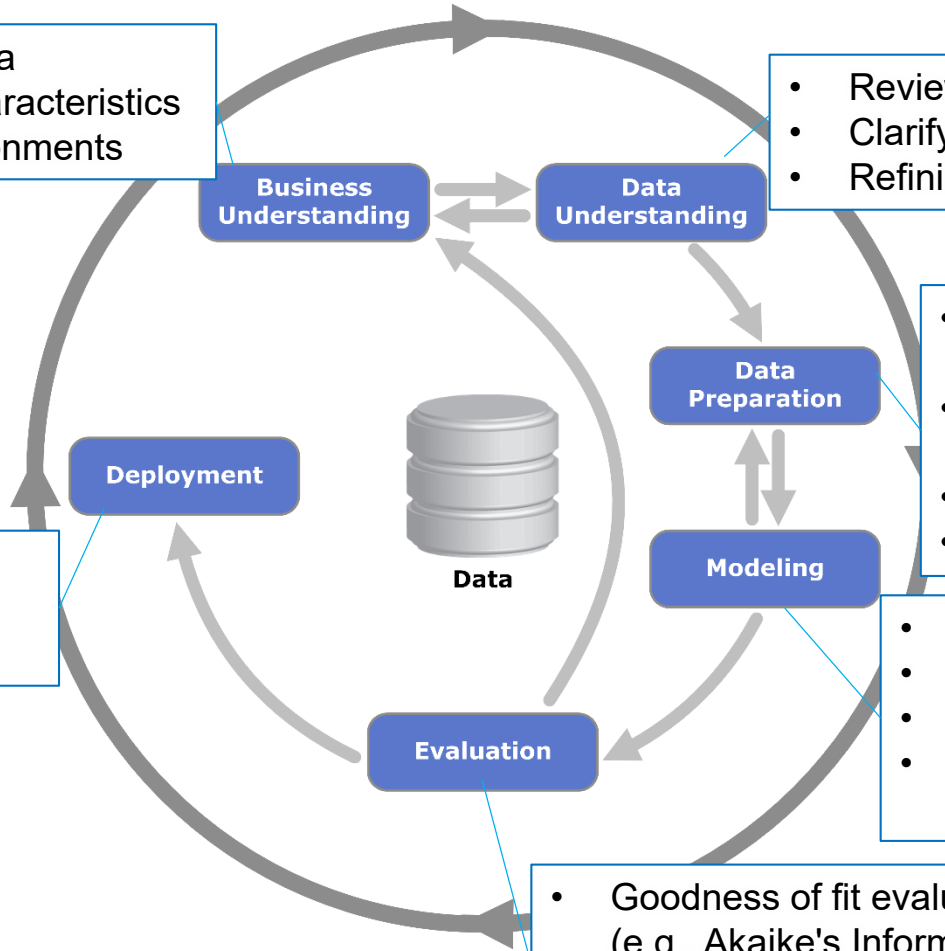
$$p(x) \approx \frac{p(x)}{1-p(x)} = e^{\beta_0} \cdot e^{\beta_1 x_1} \cdot \ldots \cdot e^{\beta_v x_v}$$





Qualitative/quantitative insights regarding impacts of PSFs

Data Analysis Framework based on Data Science Process



- Reviewing raw data
- Understanding characteristics of APR1400 environments

- Reviewing IGT data
- Clarifying PSF-related items
- Refining IGT data

- Defining PSF variables / PSF states
- Generating PSF values in success cases
- Merging IGT data
- Generating PSF data

- Basic statistics
- Correlation analysis
- Regression analysis
- Other data science techniques

- Goodness of fit evaluation (e.g., Akaike's Information Criterion)
- Comparison of predicted estimates with existing estimates

- Interim report
- Final report
- Presentation

[Jonathan, 2

Data Preparation: PSF Variable Generation

Response IGT in IGT data

Scenario ID	Time	GT_ID	Procedure	Step	Sub step	Contents	Cognitive Activity	Task Type	Success (#)	EOO	EOC		UA Code	Desc
170314_#1_SGTR	13:00:02	APRSW_012	DA	2	0	Goal: Check reactivity	RP	Entry	1	0	0			...
170314_#1_SGTR		APRSW_012	DA	2	1	Is reactivity criteria satisfied?	RP; IG; RP/RP	Information; Synthesis; Step/Procedure	1; 1; 1/0	0; 0; 0	0; 0; 0		UA-01	
170314_#1_SGTR		APRSW_012	DA	3	0	Goal: Check electric supply	RP	Entry	1	0	0			
170314_#1_SGTR		APRSW_012	DA	3	1	...	RP; IG; RP/RP	Information; Indicator; Step/Procedure	1; 4; 1/0	0; 0; 0	0; 0; 0	...		...
170314_#1_SGTR		APRSW_012	DA	4	0	Goal Check RCS subcooling margin	RP	Entry	1	0	0			...
170314_#1_SGTR		APRSW_012	DA	4	1	Is RCS subcooling margin lower than 15 degree?	RP; IG; RP/RP	Information; Comparison; Step/Procedure	1; 4; 1	0; 0; 0	0; 0; 0			...

Simulation ID or initiating event

- Operator Unit
- Team ID
- SS's operating yr. as SS
- SS age
- RO age
- TO age
- EO age
- Op
- Le
- Cc
- Su
- Independent checker
- Procedure compliance
- Overall communication strategy
- IE (initiating event)
- Abnormal vs emergency
- Multiple initiating events
- Failed system / component
- Failed alarm / indicator
- Procedure type
- FRP Inclusion
- Scenario Familiarity
- Simulation day

Procedure

- Procedure
- Procedure Type I
- Procedure Type II

Procedure step

- Continuous action step
- Key step
- Hold Step

Primitive task type

- TaskType1
- TaskType2
- TaskType3

Common Procedural Step

- The number of tasks in a sentence
- Number of tasks in a step
- Number of tasks in a step(RNO)
- Number of manipulations(RNO)
- Negation
- Condition Set Check
- Negative State Satisfaction
- Description of object
- Task familiarity (power reduction/elevation)
- Multiple constraints
- Clarity of decision-making criteria
- Specification of manipulation means
- Diagnostic information clarity
- Information salience (information in LDP)
- Logic of the state identification or instructions
- Change of procedure strategy
- CPS-IPS direct link
- Design consistency of back up procedure
- The type of control device for component manipulation
- The type of alarm display
- Contingency action
- Note or caution

Data Preparation: Defined PSF Variables

- Simulation ID –related variable (from overview IGT) (1)

Variable	Source	Description	Example
Unit name	[Document]	Unit name	Unit3
Team ID	[Document]	Team code	Unit3-#4
SS's operating year as SS of the team	[questionnaire]	SS's operating year since becoming the SS in APR1400	(positive real number)
SS age (birth year)	[questionnaire]	The birth year of SS	(positive integer)
RO age (birth year)	[questionnaire]	The birth year of RO	(positive integer)
TO age (birth year)	[questionnaire]	The birth year of TO	(positive integer)
EO age (birth year)	[questionnaire]	The birth year of EO	(positive integer)
Existence of Operator Change	[questionnaire]	Whether any operator was absent or changed his/her role during training	TRUE / FALSE
Leadership style of SS	[Judgement]	Leadership style of shift supervisor	Affiliative / Coaching / Commanding / Democratic
Cooperative attitude of BOs	[Judgement]	Whether board operators showed active responses or communications during the simulations	TRUE / FALSE
Supervising level of STA	[Judgement]	Whether the STA actively checked the operations of the systems	TRUE / FALSE
~~Independent checker~~	~~[Judgement]~~	~~Existence of independent review during significant system controls~~	~~(Failed to evaluate)~~
Procedure compliance	[Judgement]	How the shift supervisor gave directions based on the procedures	Mission Goal Only / Instruction in Detail / Instruction Selectively
Overall communication strategy	[Judgement]	Communication strategy that is frequently observed during the simulation	2-way / 3-way

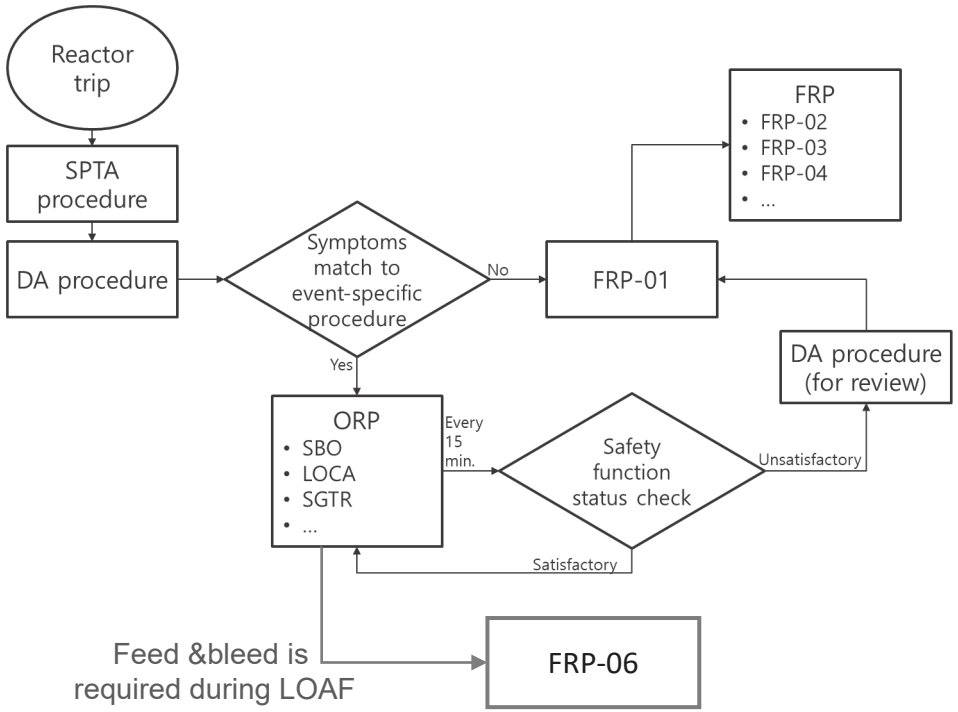
Data Preparation: Defined PSF Variables

- Simulation ID –related variable (from overview IGT) (2)

Variable	Source	Description	Example
IE (initiating events)	[Document]	Name of IE	LOCA / … / SBO
Situation: abnormal vs emergency	[Document]	IE inducing the reactor trip	TRUE / FALSE
Multiple initiating events	[Document]	Two or more initiating events (SBO, LOOP, LOAF, LOCA, etc.)	TRUE / FALSE
~~Existence of failed system / component~~	~~[Document]~~	~~Inclusion of additional malfunction in system or component~~	~~TRUE / FALSE~~
Existence of failed alarm / indicator	[Document]	Inclusion of additional malfunction in indicator or alarm	TRUE / FALSE
Procedure type	[Document]	CPS or paper-based procedure	CBP / PBP
FRP Inclusion	[Document]	Whether the scenario requires to proceed to FRP	TRUE / FALSE
Scenario familiarity	[Document]	Regular training scenario vs newly introduced scenario	TRUE / FALSE
Simulation day	[Document]	Training period	2017spring / … / 2018fall

Data Preparation: Defined PSF Variables

- Procedure–related variable

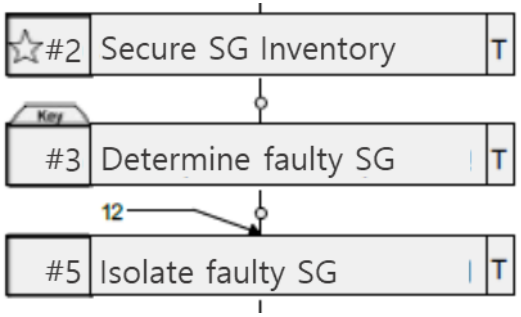


Procedure	Proc. Class I	Proc. Class II	Proc. Class III
DA	Non-SPTA	BeforeDA	Non-SPTA
ESDE	Non-SPTA	afterDA	Non-SPTA
FRP-1	Non-SPTA	afterDA	Non-SPTA
FRP-6	Non-SPTA	afterDA	Non-SPTA
LOAF	Non-SPTA	afterDA	Non-SPTA
LOCA	Non-SPTA	afterDA	Non-SPTA
LOOP	Non-SPTA	afterDA	Non-SPTA
SBO	Non-SPTA	afterDA	Non-SPTA
SGTR	Non-SPTA	afterDA	Non-SPTA
SPTA	SPTA	BeforeDA	SPTA
AOP-3515	Abnormal	Abnormal	Non-SPTA
AOP-3530-01	Abnormal	Abnormal	Non-SPTA
AOP-3451-04	Abnormal	Abnormal	Non-SPTA
AOP-3542-03	Abnormal	Abnormal	Non-SPTA
AOP-3522-02	Abnormal	Abnormal	Non-SPTA
AOP-3431-03	Abnormal	Abnormal	Non-SPTA
AOP-3500-01	Abnormal	Abnormal	Non-SPTA
AOP-3762	Abnormal	Abnormal	Non-SPTA
AOP-3451-05	Abnormal	Abnormal	Non-SPTA
AOP-3431-05	Abnormal	Abnormal	Non-SPTA

Data Preparation: Defined PSF Variables

- Step–related variable
  - Continuous action step : APR1400 procedures distinguish some steps with pentagrams
    - Operators have to continuously check the procedure sentences after ingress of the step
  - Key step : APR1400 procedures distinguish some steps with “key” on the step goal.
    - Operators have to carefully follow the procedure sentences in the step
  - Hold Step : APR1400 procedures distinguish some steps with “hold” on the step goal.
    - Operators cannot proceed the next step before completion of the step

Procedure	Step	Continuous action step	Key step	Hold Step
L#$#$	31	Emergency-TRUE	Emergency-FALSE	Emergency-FALSE
L#$#$	34	Emergency-TRUE	Emergency-FALSE	Emergency-FALSE
L#$#$	35	Emergency-FALSE	Emergency-FALSE	Emergency-FALSE
L#$#$	36	Emergency-FALSE	Emergency-FALSE	Emergency-FALSE
L#$#$	37	Emergency-FALSE	Emergency-FALSE	Emergency-FALSE
…	…	…	…	…



Data Preparation: Defined PSF Variables

- Task type variable

TaskType1	TaskType2	TaskType3
Alarm	Alarm	Alarm
Indicator	Discrete	Indicator
Synthesis	Discrete	Else
Value	Continuous	Else
Comparison	Continuous	Else
Graph	Continuous	Else
Abnormality	Continuous	Else
Trend	Continuous	Else
Entry	Procedure	Else
Procedure	Procedure	Else
Step	Procedure	Else
Information	IG-instruction	Else
Manipulation	EX-instruction	Manipulation
RP-Noti	EX-instruction	Else
Diagnosis	Diagnosis	Diagnosis
Identification	Identification	Identification
Prediction	Prediction	Prediction
Discrete	Simple	Manipulation
Continuous	Simple	Manipulation
Dynamic	Complex	Manipulation
EX-Noti	Communication	Communication

Data Preparation: Defined PSF Variables

- Instruction–related variable (1)

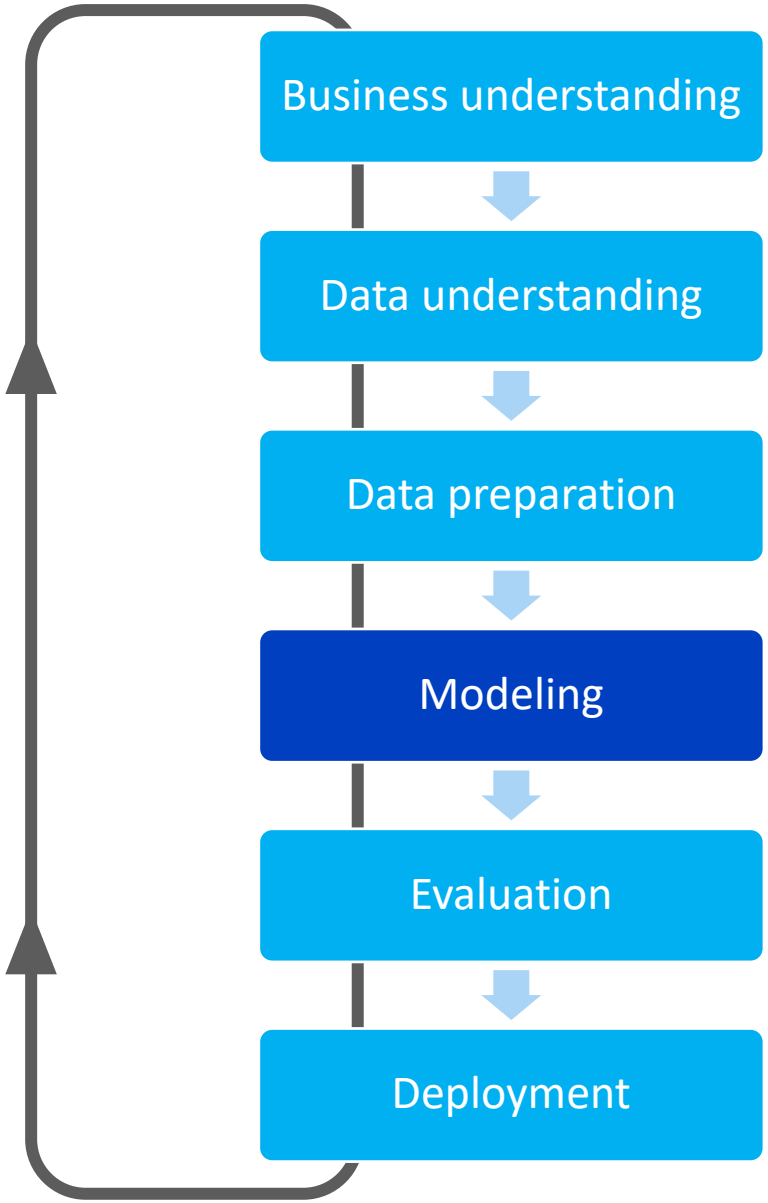
Variable	Source	Description	Example
The number of tasks in a sentence	[Document]	The number of tasks in a sentence	(positive integer)
Number of tasks in a step	[Document]	The number of tasks in the ongoing step	(positive integer)
Number of tasks in a step (counted by separating RNO)	[Document]	The number of tasks in the ongoing step (counted by separating RNO)	(positive integer)
Number of manipulations (counted by separating RNO)	[Document]	The number of manipulations to be controlled during performance of the ongoing step	(positive integer)
Negation	[Document]	Existence of negation in a sentence	TRUE / FALSE
Condition Set Check	[Document]	Whether the sentence is related to check of a high level status	TRUE / FALSE
Negative State Satisfaction	[Document]	Whether the negative safety state is checked (e.g., is there leak in outside of contnmnt?)	TRUE / FALSE
Description of object	[Document]	Description of component ID to be manipulated/checked in the procedure	TRUE / FALSE
Task familiarity (power reduction/elevation)	[Document]	Whether the task can be experienced during the power reduction or raise	TRUE / FALSE
Multiple constraints	[Document]	Existence of two or more conditions checked in a procedure sentence	TRUE / FALSE
Clarity of decision-making criteria	[Document]	Inclusion of the specific criteria in procedure for the state identification during IG-synthesis or SI-* tasks	TRUE / FALSE
Specification of manipulation means	[Document]	Existence of detailed method description for dynamic manipulation	Dynamic-TRUE / Dynamic-FALSE / Simple
Information salience (information in LDP)	[Document]	Whether the required information can be obtained by LDP only	LDP only / with IPS

Data Preparation: Defined PSF Variables

- Instruction–related variable (2)

Variable	Source	Description	Example
Logic of the state identification or instructions	[Document]	Logic of tasks within a procedure sentence	AND / AND/OR / NOT / NOT/AND / NOT/AND/OR / NOT/OR / OR / Simple statement
Change of procedure strategy	[Document]	Relation of RP-procedure or RP-step with the sentence	TRUE / FALSE
CPS-IPS direct link	[Document]	Existence of a link button to IPS screen related to instructions in CPS	TRUE / FALSE
~~Design consistency of back-up procedure~~	~~[Document]~~	~~Whether the CPS is exactly same with the back-up procedure~~	~~TRUE~~
The type of control device for component manipulation	[Document]	The type of manipulation (touch panel, mouse, analog button)	Console / External / Non-safety / Safety
The type of alarm display	[Document]	Whether the alarm occurs in alarm tile during IG-alarm tasks	Alarm Tile / Other Alarm
Contingency action	[Document]	Inclusion of the task in the contingency action part when the emergency procedure is used	AOP / EOP-TRUE / EOP-FALSE
Note or caution	[Document]	Inclusion of the task in the note or caution part in the procedure	TRUE / FALSE
Logic of inter-instruction	[Document]	Logic of between sentences in a step	AND / ATOM / OR
Number of Check-off	[Document]	The number of check-off buttons in a step (counted by separating RNO)	(positive integer)
(Number of Check-off) / (Number of tasks in a step)	[Document]	The ratio between Number of Check-off and Number of tasks in a step	(real number btw 0 and 1)
Caution of manipulation	[Document]	When caution should be provided for dynamic manipulation, provision of it in the ongoing step	TRUE / FALSE

Modeling Activities

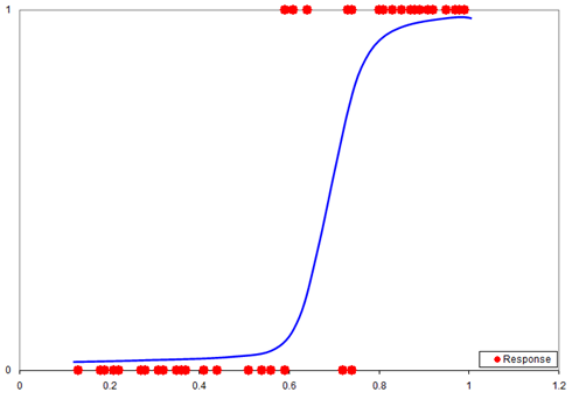


- Regression analysis for relation between HEPs and PSFs
  - Dependent variable: Human error occurrences
    - Human error during information gathering and reporting
    - Human error during response planning and instruction
    - Human error during execution
  - Independent variable
    - PSF variables
  - Methods
    - Logistic regression with variable selection

Algorithm 1) Logistic Regression

- Logistic regression
  - To predict a conditional probability of an event given a set of IVs (Independent variables)
  - The dichotomous DVs (dependent variable) are usually used.
  - Input data example

DV	IVs
Success rate of cancer operation	Age, Sex, Laser treatment, Cancer size, body fat percentage,…
Success (1)	47, male, treated, 5mm, 30%,…
Failure (0)	57, male, untreated, 10mm, 20%,…
Success (1)	45, female, treated, 6mm, 10%,…
…	…



  - Regression model

$$Y = \ln \frac{p(x)}{1-p(x)} = \beta_0 + \beta_1 x_1 + \cdots + \beta_n x_n \qquad p(x) = \frac{exp^{\beta_0+\beta_1 x_1+\cdots+\beta_n x_n}}{1 + exp^{\beta_0+\beta_1 x_1+\cdots+\beta_n x_n}}$$

Here, *p(x)* is the conditional probability of human errors under the certain conditions of independent variables, $x_1,\ldots x_i,\ldots,x_n$, and β_0, …, β_n are regression coefficients indicating the effects of each variables on the *p(x)*.

$$p(x) \approx \frac{p(x)}{1-p(x)} = e^{\beta_0} \cdot e^{\beta_1 x_1} \cdot \ldots \cdot e^{\beta_v x_v}$$

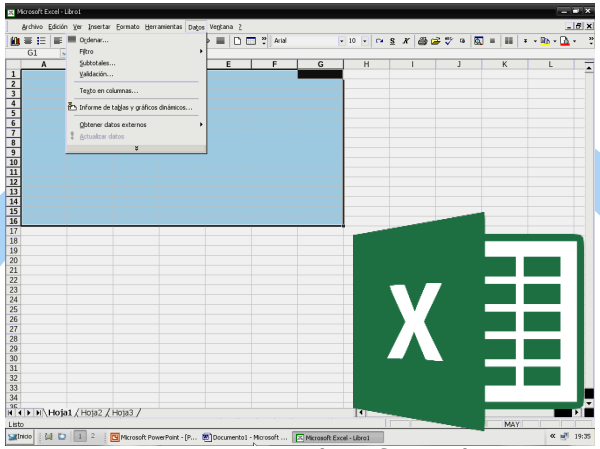
Algorithm 2) Variable Selection

- Stepwise variable selection
  - An automated variable selection strategy to find a subset of the variables which provides a good prediction of the dependent variable
  - From null model, the system repeatedly examines the necessity of adding a new variable or deleting a variable among the pre-chosen variables.
  - If it is shown that adding a new variable improves the model, the variable is added.
  - If it is shown that removing a variable improves the model, the variable is removed.
  - If any variable addition or removal does not improve the model, the current model is the best model.

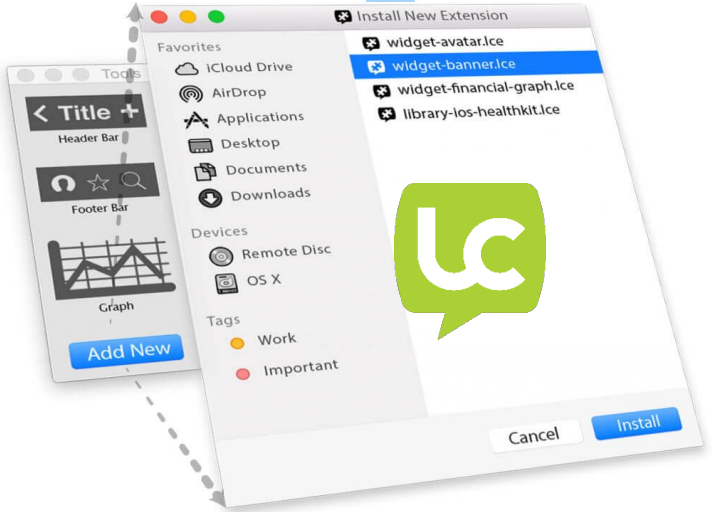
- Variable selection criteria
  - Adjusted R2
  - Mallow's Cp
  - PRESS (Predicted Residual Sum of Squares)
  - AIC (Akaike Information Criterion)
  - BIC (Bayes Information Criterion)

$$BIC = -2 \ln \hat{L} + k \ln m.$$

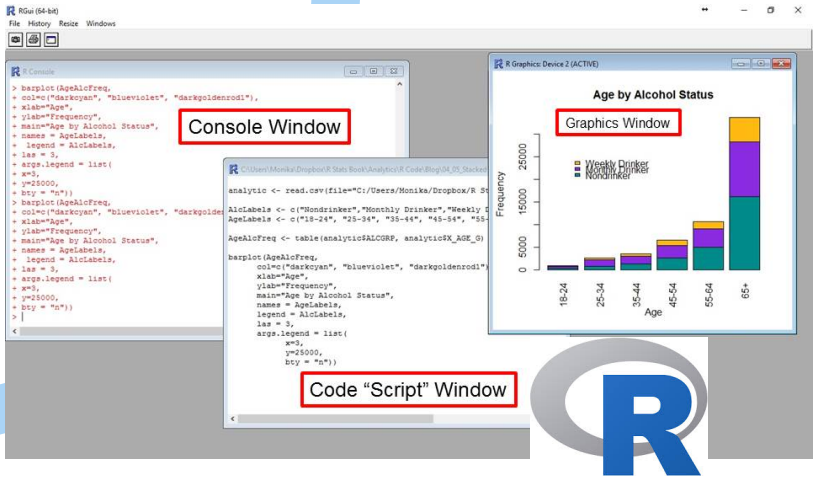
Analysis Tools



MS Excel: data sort / refine / presentation



Livecode: data consolidation / refine



R: elaborated statistical analysis

Part 3. Preliminary Statistical Results

Brief Summary of Statistical Insights

DRAFT
Not for Distribution .

- The HEPs were mainly influenced by the workload or procedure-related variables
  - During SPTA procedure (i.e., entry EOP), the crews were required to manually actuate safety signals and borate.
    - High workload affected the HEP in information gathering and response planning
  - The effect of procedure/step change can affect the HEP in response planning.
    - Some improvements in EOP expressions were found.
  - The abstract and negative states gave a confusion to SSs when they follow EOPs
  - If the crew should carefully manipulate a component, the caution should be described in the step describing the manipulation
- The multiple IE and task in attention are also found as interesting factors affecting HEPs
- The familiarity with the APR1400 could not be distinguished in this study

Part 4. Insights Regarding HRA Data Science

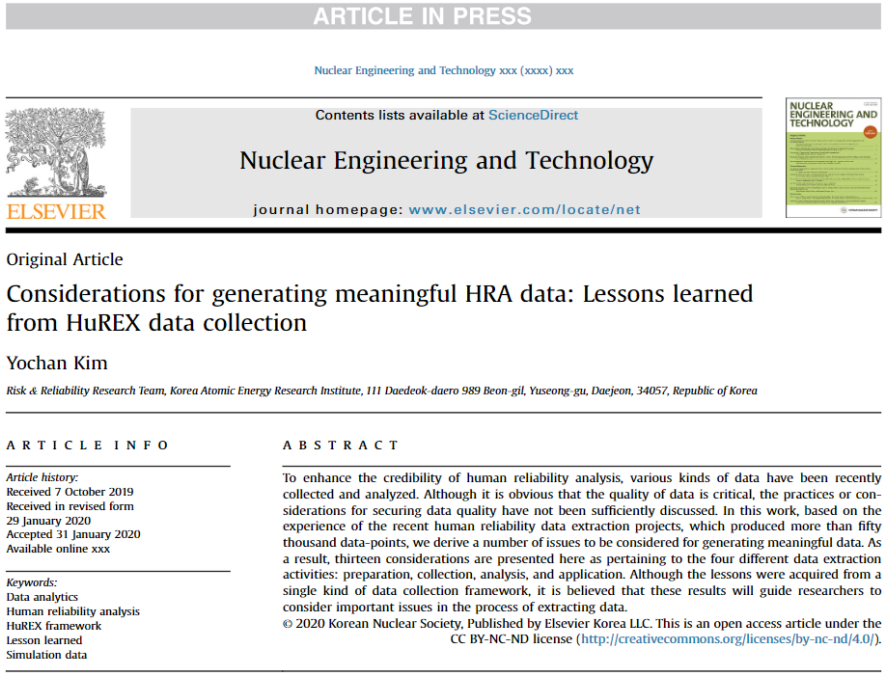
The Quality of HRA Data Matters!

- The importance of data quality has been emphasized in various fields.
- Human errors are entangled with myriad contextual, situational, and organizational factors.
- There are different viewpoints and definitions of human errors and performance shaping factors.
- The HRA data extraction requires a higher level of deliberation than extraction of equipment failure data.

[Data quality dimensions, lean-data, 2018]

13 Considerations for Generating Meaningful HRA Data

- Preparation
  - Consistent framework
  - Abstraction levels of operating tasks
  - Invisibility of cognitive behaviors
- Data collection
  - Interdisciplinary approach to human error identification and PSF rating
  - Consideration of analysis techniques
  - Prevention of errors in data collection
  - Detailed description of context
- Data analysis
  - Statistical analysis
  - Bayesian approach
  - Technique suitable to the analysis purpose
- Data report and application
  - Subjectivity of interpretation
  - Data consolidation
  - Continuous data collection and system improvement



ARTICLE IN PRESS

Nuclear Engineering and Technology xxx (xxxx) xxx

Contents lists available at ScienceDirect

Nuclear Engineering and Technology

journal homepage: www.elsevier.com/locate/net

Original Article

Considerations for generating meaningful HRA data: Lessons learned from HuREX data collection

Yochan Kim

Risk & Reliability Research Team, Korea Atomic Energy Research Institute, 111 Daedeok-daero 989 Beon-gil, Yuseong-gu, Daejeon, 34057, Republic of Korea

ARTICLE INFO

Article history:
Received 7 October 2019
Received in revised form
29 January 2020
Accepted 31 January 2020
Available online xxx

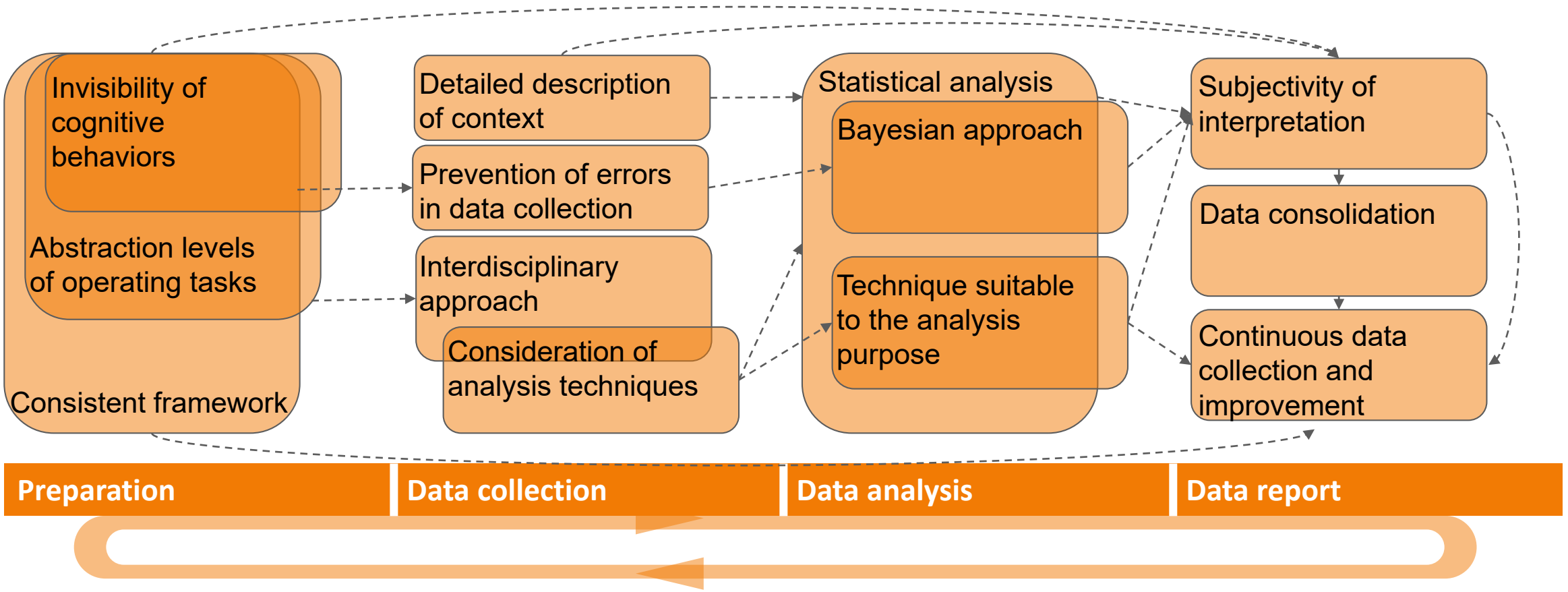
Keywords:
Data analytics
Human reliability analysis
HuREX framework
Lesson learned
Simulation data

ABSTRACT

To enhance the credibility of human reliability analysis, various kinds of data have been recently collected and analyzed. Although it is obvious that the quality of data is critical, the practices or considerations for securing data quality have not been sufficiently discussed. In this work, based on the experience of the recent human reliability data extraction projects, which produced more than fifty thousand data-points, we derive a number of issues to be considered for generating meaningful data. As a result, thirteen considerations are presented here as pertaining to the four different data extraction activities: preparation, collection, analysis, and application. Although the lessons were acquired from a single kind of data collection framework, it is believed that these results will guide researchers to consider important issues in the process of extracting data.

(Published online)

13 Considerations for Generating Meaningful HRA Data



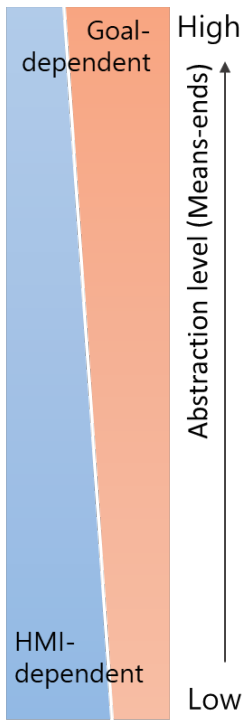
Considerations during Preparation (1)

Consistent framework

- Definitions and assumptions to be explicitly addressed and applied
  - How to define the tasks or human actions to be evaluated (e.g., success or failure) from the obtained raw data;
  - How to classify the types of human behaviors that were evaluated as human errors or successful behaviors;
  - How to determine the meaning of the PSFs or surrogate variables and their levels;
  - How to designate an action changing the plant state that had been influenced by a previous human error, either as a recovery behavior, failed behavior, or successful behavior;
  - How to store the inputted information, such as task performance and PSF variables, into a database

Abstraction levels of operating tasks

- Data collectors should understand the levels of operating tasks (means-ends relations).
  - High level tasks → hard to secure large data
  - Low level tasks → model for HEP interpretation and recovery factors needs



Reactivity Control	RCS Heat Removal
RCS Inventory control	Containment isolation
RCS Pressure Control	Combustible gas control
Core Heat removal	Indirect radioactivity release control
…	
Initiating feed-and-bleed operation	
Delivery of a sufficient SI flow	
Tripping reactor	
Cooling down RCS	
…	
Recognize loss of EW flow to train A	
Secure ECW pump 1A	
Ensure CCP 1A is in service	
Verifies natural circulation	
…	
Checking discrete state - Verifying alarm occurrence	
Checking discrete state - Verifying state of indicator	
Manipulation - Simple (discrete) control	
Notifying/requesting to MCR outside	
…	
Selecting, and identifying to sources of information	
Selecting/adapting/developing the mental model	
Making decision (judgment, strategies, plans)	
Implementing action scripts	
…	

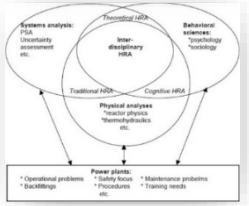
Considerations during Preparation (2)

Invisibility of cognitive behaviors

- Many HRA methods deal with cognitive characteristics of crews.
- Capturing the cognitive characteristics of human operators usually requires deep knowledge and experience of cognitive engineering.
  - E.g., Wrong report in delivering plant information → wrong detection? Wrong speech?
  - Expert judgment? Interview?
- A guideline or training for cognitive engineering is required
- Or, behaviorism-based data (i.e., observable-oriented data) can be collected

Considerations during Collection (1)

Interdisciplinary approach to human error identification and PSF rating



- Multidisciplinary fields
  - Data science
  - Human error identification
  - HRA applications
  - How about HRA data extraction??
- Collaboration during collection is important.
- Important expertise
  - Safety/reliability engineering
  - Cognitive science
  - NPP system dynamics
  - Data analytics
  - Software/database management

Consideration of analysis techniques

- The data should be collected with consideration of analysis technique.
- Example of PSF effect estimation
  - The context information of successful behavior is required.
  - Otherwise, the PSF effects will be over- or under-estimated.
- Example of factor analysis
  - Continuous or ordinal variables are required

Considerations during Collection (2)

Prevention of errors in data collection

- Data is manually generated because of complexities in decision of human errors/ PSF levels
- However, data collector can also make human errors or violations
- Preventive measures
  - Human error identification by data collectors having the least conflict of interest with the results (e.g., The 3rd party data collector)
  - Peer-reviews of the collected data
  - Explicit rules for determining information regarding human errors and contexts
  - Support systems, such as a user interface-based data generation system and a data integrity-verification program

Detailed description of context

- Data science process is iterative.
- Creation of new variables may be required during the data analysis phase.
  - For example, some human error is frequently observed during a particular step.
  - But, the characteristics of the step is not prepared in the data template.
- Detailed contexts including procedures, human-machine interfaces, and communications should be well documented during the collection phase.

Considerations during Analysis (1)

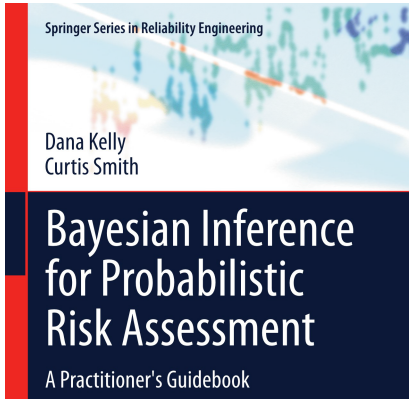
Statistical analysis

- The data does not produce results exactly correspond to our common sense.
  - E.g., execution HEP with training session
    - 1st session: 7.51E-03
    - 2nd session: 1.09E-02
    - 3rd session: 4.43E-02
    - 4th session: 2.61E-02

  - There may be another factor strongly affecting the HEP or uncertainty issue in data.
- We need to statistically infer whether the difference between HEPs is actually due to chance or due to certain factors
- Multivariate analysis is also required to compare effects from different factors

Bayesian approach

- Collected HRA data is not perfect
- It is difficult to secure sufficient amount of data
- Bayesian inference techniques are useful to derive robust insights by combining multiple data sources
  - Preischl and Hellmich, RESS 109, 2013
  - Groth et al., RESS 128, 2014
  - Kim and Park, RESS 189, 2019



Considerations during Analysis (2)

Technique suitable to the analysis purpose

- It is required to consider how to use the analysis result in HRA applications
- HRA application prefers intuitive models
  - Decision trees
  - Simple Bayesian networks
  - Multiplier tables
- The large-scale neural networks may not be easy for the HRA practitioners to interpret
  - Additional technique aiding interpretation of practitioners is required
- From the personal experience, the followings are attractive
  - Structural equation modeling
  - (Logistic) regression
  - Decision tree learning

Considerations during Application (1)

Subjectivity of interpretation

- The interpretation often requires the subjective opinions of data analysts
  - If a PSF variable is significant, it is desirable to discuss cognitive feature of it.
  - If two PSF variables are closely correlated, meanings of those variables are important
- Recommendations
  - Data analyzers should collaborate with data collectors or carefully review the description of the relevant situations
  - More data should be collected with more variables

Data consolidation

- General insights requires various data sources
  - No HRA data can be asserted as perfect
  - APR1400 data is very local
  - Operating culture and system design matters
- Data comparison and consolidation is important
- It is recommended to record
  - The basic assumptions of each data collection
  - The characteristics of the operational environment
    - E.g., long-term operation data in HuREX

Considerations during Application (2)

Continuous data collection and system improvement

- Data extraction is very useful for identifying system improvements
  - Findings from operator hesitations, conversations, and non-verbal communications
- Procedure and interface can be improved by the data analysis
- Repeated analysis is desirable

Evaluation of HuREX project against the considerations (1)

Considerations	HuREX project
Consistent framework	· The criteria discriminating success and failure were developed based on the definition of an unsafe act. The criteria were consistently applied by educating the data collectors with several workshops. · The task and error taxonomies were developed taking into account the procedure sentences, cognitive models, existing error types, and simulator characteristics [24]. The classifications were implemented into the database management systems. · Spreadsheet-based databases were developed and managed. · For clarifying subtle issues in the identification or classification of human errors and recovery actions, additional rules were established.
Abstraction levels of operating tasks	· The procedure sentence-based primitive tasks were defined (the second level tasks from the bottom in the hierarchy of Figure 3). This task level is more concrete than the general HFE in HRA practice; hence, the model to link the results of the projects with the HRA applications should be developed.
Invisibility of cognitive behaviors	· The tasks distinguishable from audio-video records and procedure sentences were used.
Interdisciplinary approach to human error identification and PSF rating	· HRA experts, statisticians, cognitive scientist, software/database developer participated in this project. · The plant operators and training instructors were regularly interviewed for explaining plant dynamics.
Consideration of analysis techniques	· The data that can be used for average HEPs or recovery failure probabilities were mainly obtained (e.g., occurrences of success and failure cases) · To estimate PSF effects, the contextual information for both successes and failures were additionally generated.
Prevention of errors in data collection	· The human reliability data was generated by the 3rd party researchers. · Database containing properties of procedure sentences were developed and used. · Spreadsheet-based data (i.e., IGTs) were obtained and managed. · Softwares to aid observe multiple videos simultaneously and to generate IGT data along with procedure sentences were developed and employed. · Software to check synthetic errors were developed and employed. · Monthly workshops were held for peer-reviewing the data collection.

Evaluation of HuREX project against the considerations (2)

Considerations	HuREX project
Detailed description of context	· The procedure sentences, significant conversations, and consequences related to human errors were documented.
Statistical analysis	· Several statistical criteria such as p-value, confidence interval (for maximum likelihood estimation), credible interval (for Bayesian analysis), and Bayesian information criterion were used to test the hypotheses or quantify the parametric uncertainty.
Bayesian approach	· Bayesian inference based on Jeffrey's prior was applied to the estimation of HEPs. · The PSF multipliers were also predicted by a Bayesian inference [19].
Technique suitable to the analysis purpose	· Logistics regression models that allow estimates that can represent the multiplicative HRA models were used.
Subjectivity of interpretation	· The data analyzer and data collector collaborated with to understand the statistical results.
Data consolidation	· The estimates for PSF multipliers were combined with the multipliers in existing HRA methods [19]. · The HEPs from this project were compared with those obtained from the Micro tasks [41]. · The statistical results were compared with the results of the second extraction project.
Continuous data collection and system improvement	· This project provides the motivation for the second extraction project. · Some improvements regarding procedure expressions were reported to the operating company.

Future Works

- The modeling method to use the estimates from HuREX in HRA applications is under development
  - EMBRACE (EMpirical data-Based crew Reliability Assessment and Cognitive Error analysis)
- Comparison HEPs in CBDTM and HuREX data
- Estimating PSF effects from HuREX data
  - Other data mining techniques
  - Combining the HuREX data with prior knowledge

Together...Shaping the Future of Electricity