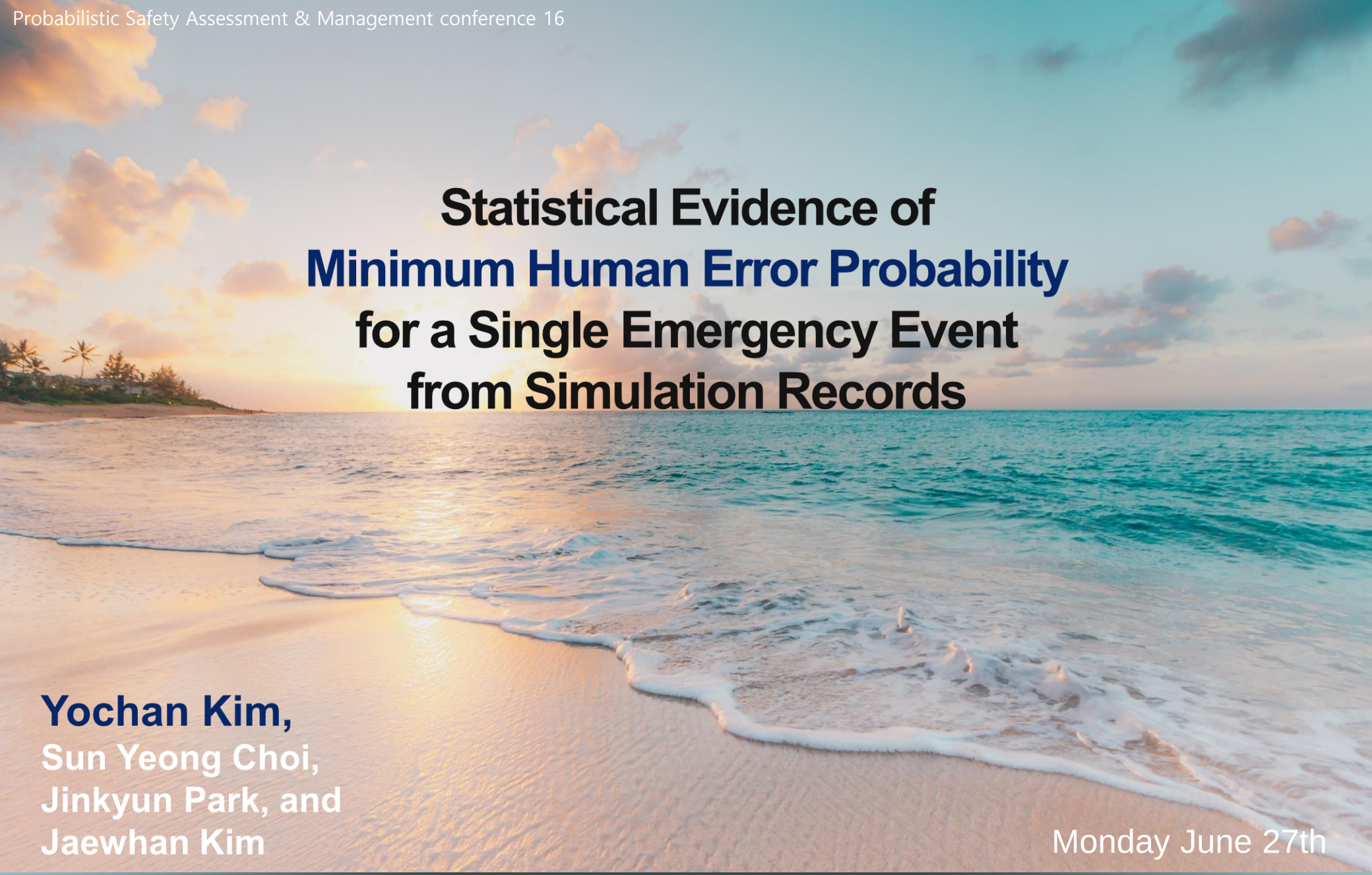

Statistical Evidence of Minimum Human Error Probability for a Single Emergency Event from Simulation Records

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Introduction

- **Human reliability analysis (HRA) method**
  - Estimates the failure probabilities of human events (i.e., human error probabilities – HEP)
  - Is based on simplified cognitive models
  - And various reliability/performance data
- **Uncertainty exist**
  - Model
  - Data
  - Process
- **Low bound of human error probability (HEP)**
  - Conservative belief
  - Even though an event is evaluated as having a negligible probability of failure,
  - The event may have a minimal probability due to some causes of human failure that have not been considered [5].

Literatures

- **MERMOS method [4]**
  - Assumes that the low bound will be between 1.0E-04 and 1.0E-05
- **EPRI guidance [5]**
  - Low bound: 1.0E-04, 1.0E-05, or 1.0E-06 (according to contextual factors)
  - Assumes the values based on typical hardware failure probabilities
- **SPAR-H step-by-step guideline [6]**
  - Low bound: 1.0E-5
  - Determined based on the cardiac death rate and the joint HEP lower bound proposed in good practices
- **The objective evidence for the minimum HEP is still insufficient**
- **➔ Goal of this study**
  - To generate an objective evidence supporting the minimum HEP

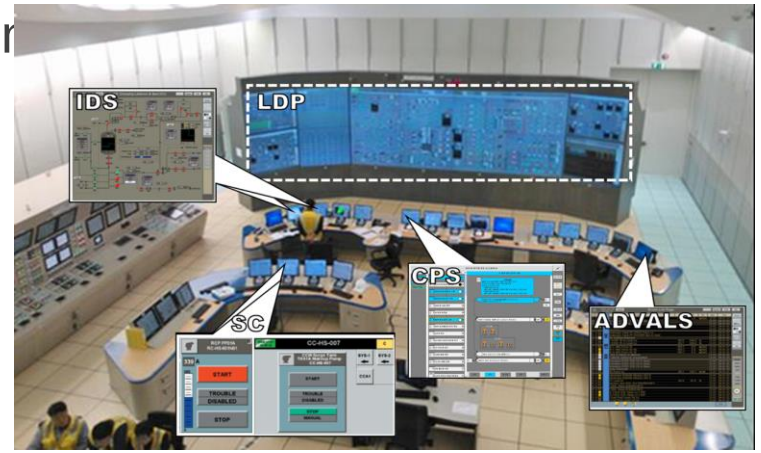
Possible Approaches

- **(1) To prove that most human events occur with a probability greater than a certain value**
  - Resource-intensive
  - Difficulties in assessing uncertainties residing in all the HEP calculations
- **(2) To develop the basis by predicting the failure probability due to causes not covered by general HRA methods.**
  - Example: cardiac death rate for men in their 40s and 50s [6]
    - Cardiac death rate: 1.0E-06 per hour → Low bound of HEP: 1.0E-05
    - Conservative basis (multiple operators works in a crew)
- **▪➔As one of second approach, this study estimates the occurrence frequency of a type of human error that has not been analyzed much so far**
  - The frequency of component operation not prescribed in the procedure during the process of performing tasks according to the procedure

Component Operation Outside the Procedure (COOP)

Simulation Observation in 2017~2019

- The human behaviors in the simulations were analyzed based on the HuREX (Human REliability data Extraction) framework
- Operators sometimes operated components that are not described in the procedures even when they follow given procedures for the plant situations
- E.g., habits formed through training
  - Checking the state of a device
  - Performing a task in a procedure to be entered
- But, there were times when the componer functions of the plant
  - A sort of error of commission
  - Aggravating the plant safety [8]



Analysis Assumption

- **First, the erroneous component operation outside the procedure (COOP) can be forecasted by finite contextual conditions.**
  - Not a specific accident process mechanism or an operator's personal psychological issues.
- **Second, the erroneous COOP is linked to the failure of human events.**
  - In reality, a non-procedural component manipulation may or may not aggravate the plant situation than a failure of a human event
- **Third, the failure probability of COOP can be represented by a specific statistical distribution.**
- **Lastly, the COOP can be recovered and its recovery probability follows the THERP dependency rules.**
  - Scarce data for the recoveries

Summary of Simulation Records

- **Total observations**
  - 107 emergency simulations
  - Total observation: 2362 min

Scenario	Simulation runs	Average observation time (min)
LOCA from pilot-operated safety relief valve	8	19.338
DVI LOCA	9	19.589
Interfacing system LOCA (letdown valve)	8	26.373
LOCA from RCP seal	8	17.369
SBO	6	23.617
SGTR	7	24.214
Feed and bleed operation in LOAF	10	27.345
SGTR with CPS failure	11	24.156
Interfacing system LOCA (low-temperature overpressure protection valve)	12	24.238
SGTR with failure of N-16 radiation indicator	11	26.647
LOCA with SIn failure	9	14.172
SGTR with SIn failure	8	14.89

- **Two erroneous COOPs (safety functions were affected)**
  - Improperly stopping a safety-injection pump during safety injection
  - Improperly opening the atmospheric release valve connected to the damaged steam generator
- **Two causes of the COOPs**
  - Inexperience of the crew in commercial operations
  - Existence of a goal-conflict in a scenario

Statistical Analysis (1)

Poisson regression analysis

- Response variable (μ): the number of erroneous COOPs
- Independent variable (x_i) – subjectively selected:
  - Inexperience of the crew
  - Existence of a goal-conflict
- Offset variable (t): observation time per simulation
- Model equation
  - $\log(\mu) = \log(t) + \beta_0 + \beta_1 x_1 + \cdots + \beta_i x_i + \cdots + \beta_n x_n$
    - Similar to a normal linear regression
  - Exponentiated equation
  - $\mu/t = e^{\beta_0} \cdot e^{\beta_1 x_1} \cdot \ldots \cdot e^{\beta_n x_n}$

the COOP occurrence rate per unit time

Statistical Analysis (2)

- **Variable combination selection**
  - All combinations of independent variables were tested
    - Seven combinations of the two Individual variables and the interaction variable
      - Inexperience of the crew
      - Existence of a goal-conflict
      - Inexperience of the crew + Existence of a goal-conflict
      - Interaction of inexperience and goal-conflict
      - Inexperience of the crew + interaction of inexperience and goal-conflict
      - Existence of a goal-conflict + interaction of inexperience and goal-conflict
      - Inexperience of the crew + Existence of a goal-conflict + Interaction of inexperience and goal-conflict
  - Test measure
    - Bayesian information criterion (BIC)
    - Likelihood ratio test

Result

- **The finally selected variables**
  - Include an interaction of the two variables
    - Inexperience of the crew
    - Existence of a goal-conflict
  - The p-value of the ratio test: 0.049
  - The BIC score: 2.56E+01
- **Coefficients**

$$\mu/t = e^{\beta_0} \cdot e^{\beta_1 x_1}$$

Variable	Regression coefficient (β_0)	Exp(coefficient) ($e^{\beta 1}$)
(intercept)	–7.73	4.40E-04
[inexperience of the crew: true] and [existence of a goal-conflict: true]	3.25	2.59E+01

- **The nominal rate of erroneous COOPs: 4.40E-04/min**
  - The occurrence rate can increase about 26 times (1.14E-02/min)
    - When the crew has insufficient experience with commercial operations
    - **And**, when the accident includes a conflict between multiple operation conditions

COOP Rates Considering Recoveries (1)

- **The nominal rate of erroneous COOPs: 4.40E-04/min**
- **Possible recoveries**
  - Self/peer-review (within 2 min after an COOP)
    - One of two COOPs was recovered. → 0.5
    - High dependency is expected.
  - Safety-function monitoring by the shift technical advisor (STA) (every 15 min)
    - When the time margin is less than 15 min: 0.5 (high dependency)
    - When it is between 15 and 30 min: 0.14 (medium dependency)
    - When it is more than 30 min: 0.05 (low dependency)
  - Overall check during the crew shift change (normally, 8h following reactor trip)
    - Zero dependence (independence)
    - Empirical error rates of this recovery action from APR1400 HuREX data [EPRI report 2021]
      - Detection error rate (synthetical evaluation) = 3.10E-03
      - Manipulation error rate (dynamic manipulation) = 3.13E-02
    - Expected recovery probability = 3.44E-02

(THERP dependency rule)

Dependence level	Conditional Prob.
Complete	1
High	0.5
Medium	0.14
Low	0.05
Zero	HEP

COOP Rates Considering Recoveries (2)

Expected COOP rates considering recoveries

Time margin	Dependence level (conditional probability)			COOP rates
	Self/peer	Safety-function monitoring	Crew shift change	
< 5 min	Complete (1.0)	Complete (1.0)	Complete (1.0)	4.40E-04/min
5–15 min	High (0.5)	High (0.5)	Complete (1.0)	1.10E-04/min
15–30 min	High (0.5)	Medium (0.14)	Complete (1.0)	3.08E-05/min
30 min – 8 h	High (0.5)	Low (0.05)	Complete (1.0)	1.10E-05/min
> 8 h	High (0.5)	Low (0.05)	Zero (3.44E-02)	**3.78E-07/min**

Application to the minimum HEP

- **The COOP rate is an occurrence probability per operation time**
- **What is the operation time significant to the COOP?**
  - In the simulations, COOPs occurred only during significant operator actions for coping with the accident situation
  - No COOP unrelated to the required tasks, such as slipping, were found.
  - The time for following important procedural steps and execution related to a given human failure event
- **The minimum HEP is calculated by multiplication of**
  - The COOP rate (e.g., 3.78E-07/min for over 8 h time margin)
  - The significant performance time related to a given human failure event
- **General assumption**
  - A simple task: 30 min of performance time → e.g., 1.13E-05
  - A complex task: 60 min of performance time → e.g., 2.27E-05
- **If the human failure event is very new and challenging,**
  - It can be predicted by multiplying 1.13E-05 or 2.27E-05 and 26

(2.95E-04 or 5.89E-04)

Coefficient of
the interaction variable

Discussion and Conclusion

- **An objective basis for the minimum HEP was proposed**
  - The empirical data regarding COOPs was statistically analyzed.
  - Some possible recoveries and performance time were assumed.
  - The range of the low bound was estimated along with time margin and performance time.
- **Limitations**
  - The collected simulator data were too sparse.
    - Variables were selected by expert judgment.
    - The statistical significance of the model is still weak to draw a convincing conclusion.
  - Rare recovery data
    - The THERP dependency rules has no empirical basis.
  - Strong assumption: “A COOP directly contributes to a failure of a human event.”


THANK YOU