Preventive Resource Allocation of Complex Systems and Apical Dominance

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Outline

- Introduction
- The Model
- Numerical Example

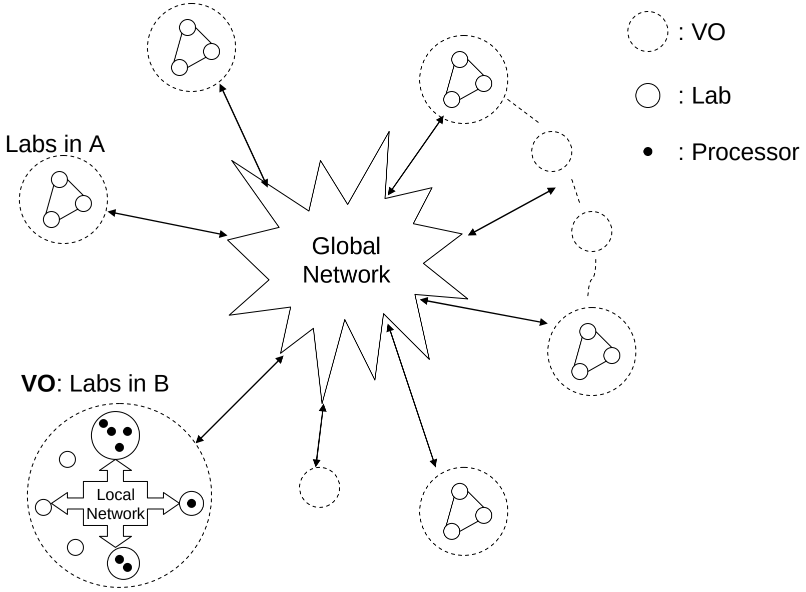
- **A couple of words about some other research topics of us…**

Introduction

- Weak Engineering System
    - Size
    - Complexity
    - Functionality
- Weaker Network System
    - Grid System/P2P System
        - Including Above Factors
        - Accessible to Public

          Grid/P2P systems are large scale network systems; resources and computing nodes are distributed over different sites.
        - Vulnerable to Attacks

          Nodes and links in Grid/P2P systems are vulnerable to mis-operations and intentional attacks.



Improving Reliability by Resource Allocation

- The Problems in Allocating Constrained Resource to the Systems
  - Complex Structure
    - Different component/subsystem might have different reliability importance.
  - Cost Issue
    - Different components/subsystems may have different sensitivity to the amount of resource allocated to;
    - Some components in the system may be even harder or more costly to improve.
  - Attack
    - Potential threat or attach each component or subsystem undergoes.

- Under such circumstance, how to allocate constrained resource to improve reliability of complex systems in a smart way?

- How do trees allocate the resources?
  - Apical Dominance (Botany)
    - A famous phenomenon in the growing process of a plant shows how a plant allocates its resource to the most necessary parts and how this strategy works.

- Link Apical Dominance to Allocation of Constrained Resource
  - The similarities between apical dominance in tree and resource allocation strategy for a engineering system (grid system)

Table 1. Comparison of tree and grid system

Tree	Grid System
apical bud	RMS
high concentrate of auxin	high importance
more water and nutriment	more resource

- Key Problem
  - Determine Auxin for Engineering Systems

The Model

- Important factors for auxin α
  - Importance Measure I_R
    - The effect of failure in individual component or subsystem on overall system reliability
  - Cost Coefficient C_R
    - The efficiency of the resource allocation strategy to increase component reliability
  - Attack Level T_R
    - Potential attacks the system outgoes

- $\alpha = f\left(I_R, C_R, T_R\right)$

Importance Measure

- Structural Importance and Reliability Importance
- Reliability Importance by Birnbaum (1969)

$$I_{R_i} = \frac{\partial R_s}{\partial R_i}$$

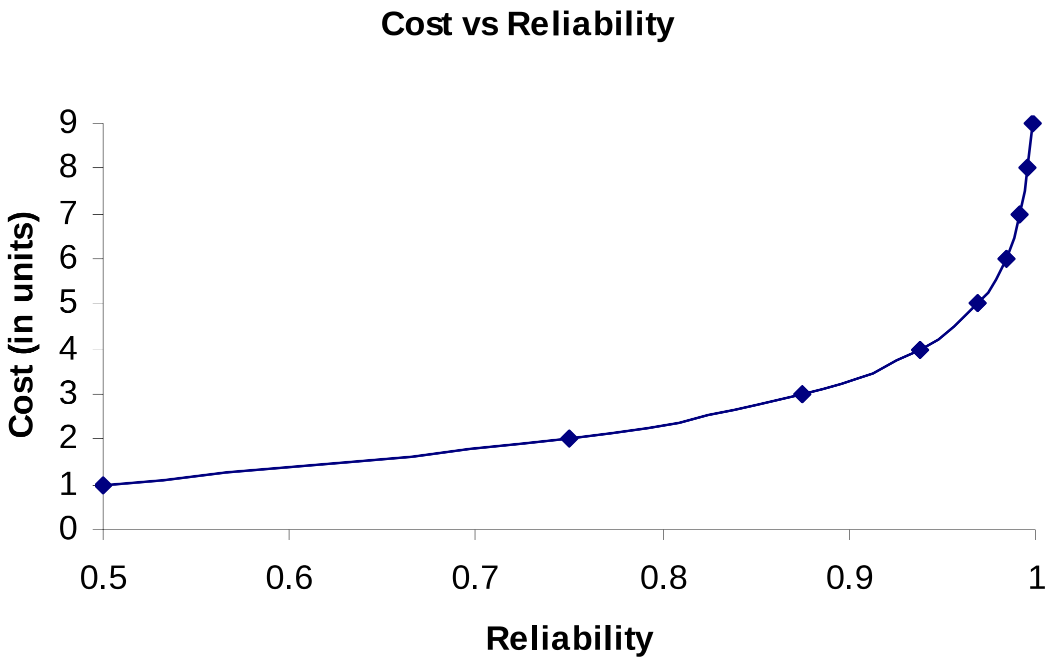
  - R_s is the system reliability
  - R_i is the component reliability
- Other Importance Measure
  - Multistate System
    - Wu (2005)
  - Joint Importance Measure
    - Zio and Podofillini (2006)

Cost

- Components are different cost-sensitive
- Different Allocation Strategies (Xie and Shen 1989)
  - equal improvement
  - replacement by a perfect component
  - active redundancy
- Mettas (2000)

$$c_i\left(R_i; f_i, R_{i,\min}, R_{i,\max}\right) = e^{\left[(1-f_i)\cdot\frac{R_i - R_{i,\min}}{R_{i,\max} - R_i}\right]}$$

  - *Ri,min* is minimum reliability of component/subsystem *i*,
  - *Ri,max* is maximum achievable reliability of component/subsystem *i*,
  - *fi* is feasibility of increasing the reliability of component/subsystem *i*,



- New Index

$$C_{R_i} = \frac{\mathrm{d}c_i}{\mathrm{d}R_i} = (1 - f_i) \cdot \frac{R_{i,\max} - R_{i,\min}}{\left(R_{i,\max} - R_i\right)^2} e^{\left[(1-f_i) \cdot \frac{R_i - R_{i,\min}}{R_{i,\max} - R_i}\right]}$$

Threat and attack

- Grid Computing System/P2P Systems are easily attacked
  - Large Scale
  - Loosely Distributed
  - Accessible to Public

- Attack and Defense
  - Bier (2005)
    - Game theory applied to study attacker and defender's strategy
  - Bier et al. (2007)
    - Max Line method based on a greedy algorithm to assess the vulnerability of complex systems to intentional attacks
  - Levitin (2007)
    - defense strategy in multi-state series-parallel system

Auxin - Composite Measure

- Comparison of auxin and α

Table 2. Comparison of auxin and α

Auxin	α
Location	Reliability importance
Different species	Cost Coefficient
Sunlight	Outside Threat

- (1). more preventive resource should be allocated to the components with higher reliability/structure importance
- (2). resource should be allocated in priority to the component with low cost-coefficient. This ensures that resources are allocated in the most efficient manners.
- (3). the component under more potential threat should be allocated with more resources.

- Our Measure

$$\alpha_i = \frac{I_{R_i}}{C_{R_i}} \cdot T_{R_i}$$

- ***Theorem**: for a coherent system, the resource allocation strategy is optimal if and only if*

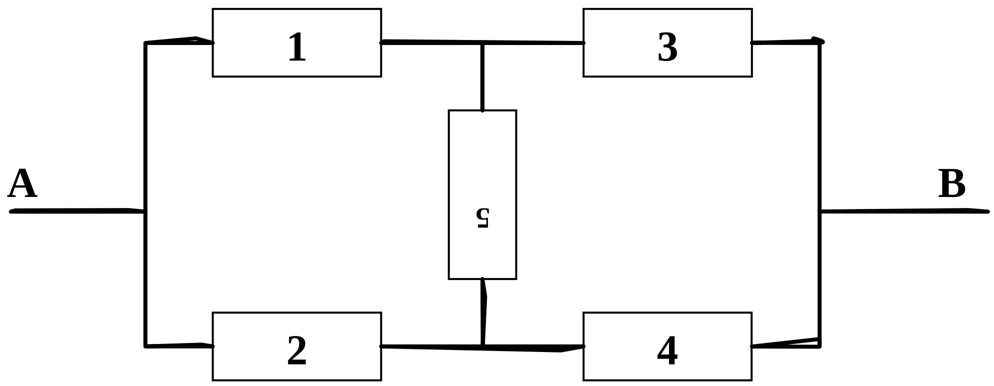
$$\alpha_1 = \alpha_2 = \cdots = \alpha_i = \cdots = \alpha_N$$

- Proof by Solving the Optimization Problem:

$$Max: \quad Cont = I_{R_i} T_{R_i} R_i + I_{R_j} T_{R_j} R_j$$

$$Sub: \quad C_i + C_j \leq C$$

Numerical Example



$$R = R_1R_3 + R_2R_4 + R_1R_4R_5 + R_2R_3R_5 - R_1R_2R_3R_4 - R_1R_2R_3R_5$$
$$- R_1R_2R_4R_5 - R_1R_3R_4R_5 - R_2R_3R_4R_5 + R_1R_2R_3R_4R_5$$

$$I_1 = R_3 + R_4R_5 - R_2R_3R_4 - R_2R_3R_5 - R_2R_4R_5 - R_3R_4R_5 + R_2R_3R_4R_5$$

$$I_2 = R_4 + R_3R_5 - R_1R_3R_4 - R_1R_3R_5 - R_1R_4R_5 - R_3R_4R_5 + R_1R_3R_4R_5$$

$$I_3 = R_1 + R_2R_5 - R_1R_2R_4 - R_1R_2R_5 - R_1R_4R_5 - R_2R_4R_5 + R_1R_2R_4R_5$$

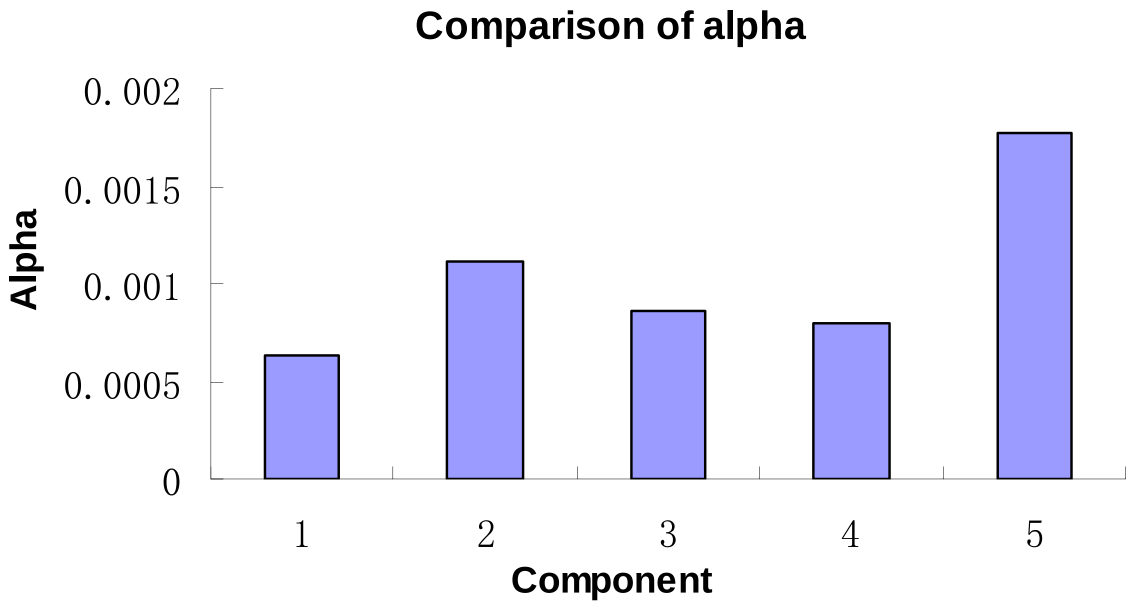
$$I_4 = R_2 + R_1R_5 - R_1R_2R_3 - R_1R_2R_5 - R_1R_3R_5 - R_2R_3R_5 + R_1R_2R_3R_5$$

$$I_5 = R_1R_4 + R_2R_3 - R_1R_2R_3 - R_1R_2R_4 - R_1R_3R_4 - R_2R_3R_4 + R_1R_2R_3R_4$$

Table 3. Calculation of Alpha

	1	2	3	4	5
Attack	0.8	0.88	0.85	0.9	0.85
Cost	12	11	13	10	10
Rmax	0.95	0.99	0.9	0.99	0.95
Rmin	0.5	0.4	0.3	0.5	0.4
Feasibility	0.3	0.2	0.4	0.3	0.2
Reliability	0.8511	0.8424	0.7862	0.8758	0.8082
Importance	0.3052	0.3009	0.3666	0.2334	0.4563
CostCoefficient	386.42	238.33	361.72	262.84	218.77
Alpha	**0.0006320**	**0.001111**	**0.000861**	**0.000799**	**0.001773**

- Next Component to Improve is the 5th!



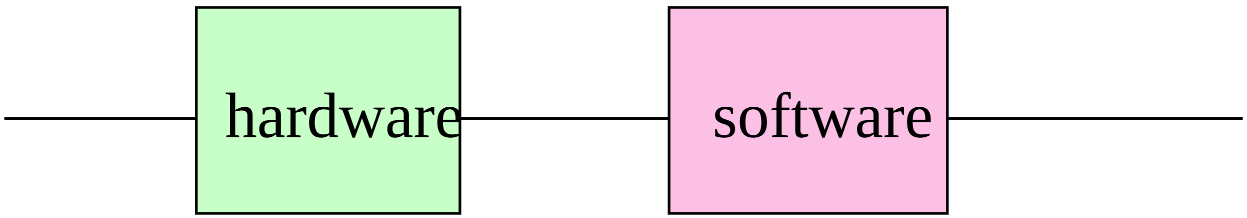
INTRODUCTION TO SOFTWARE SYSTEM RELIABILITY

PROBLEMS, MODELS AND ANALYSIS

Reliability of Software System

- Complex systems contain both software and hardware
- Software is different from hardware in many aspects
- Hardware failures are “easier” to deal with
  - Longer history and many researchers
- Software problems are usually solved only by the developer

Reliability of Combined System

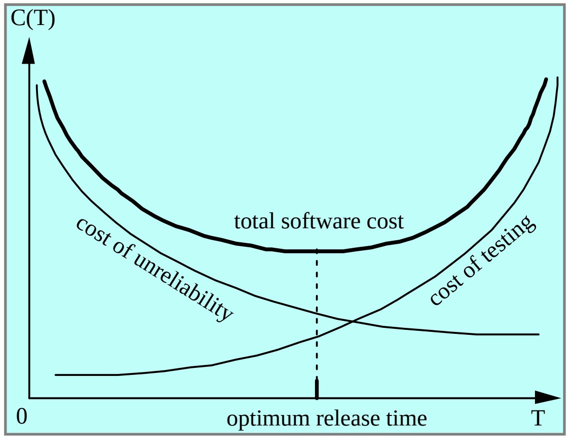


- Assuming both are needed for the system to work
- Failure of one should not affect the other
- The failure causes should be able to be isolated
- Software may not be more reliable than hardware
- Important to consider serious failures

Release Time Determination - cost minimization

- Time to minimize total cost
  - need a cost model

$$c(T) = c_1 m(T) + c_2\left[m(\infty)-m(T)\right] + c_3 T.$$



☞ c_1 = expected cost of removing a fault in testing

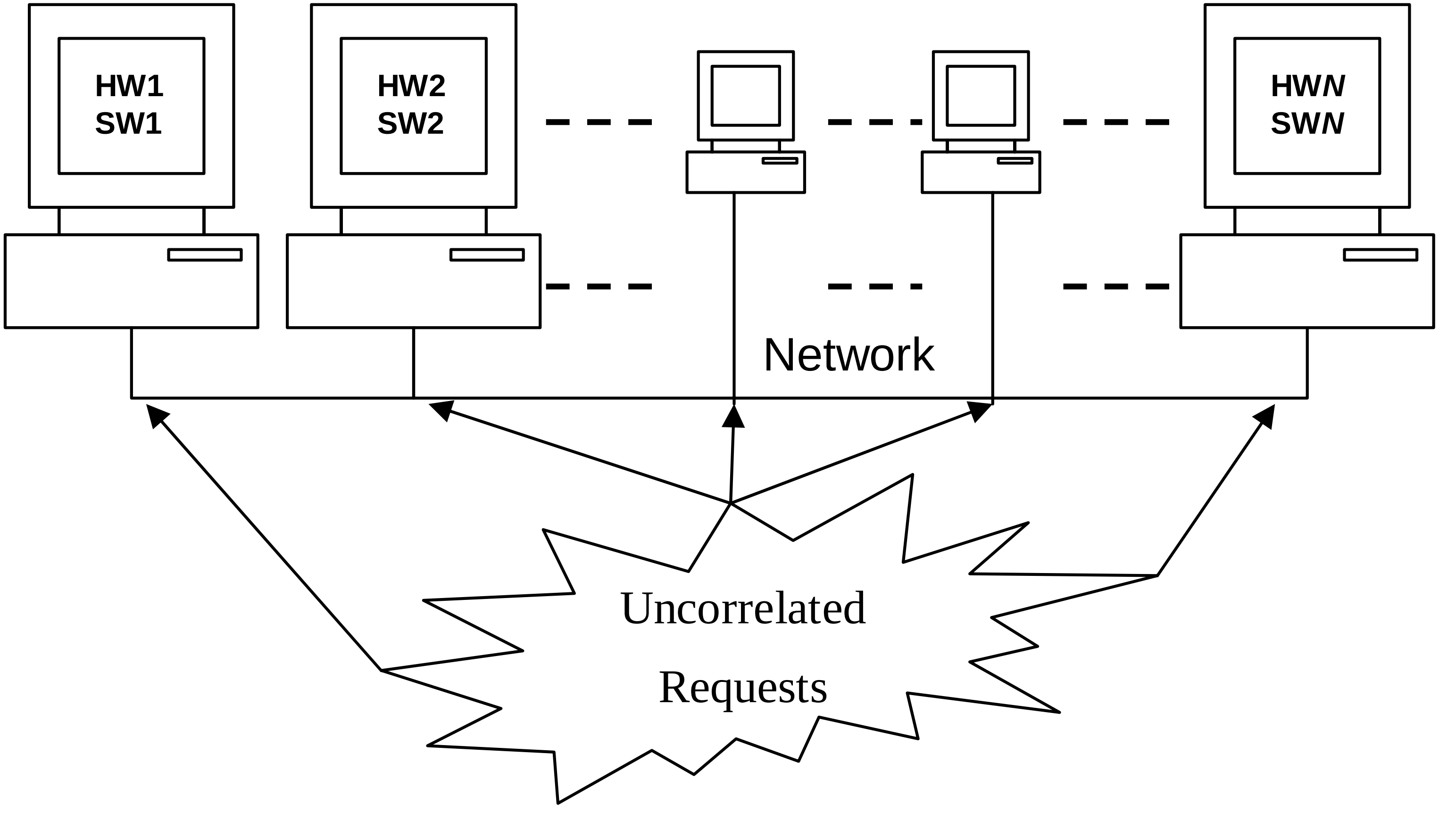
☞ c_2 = expected cost of removing a fault in field

☞ c_3 = expected cost per unit time of software testing including the cost of testing, the cost due to a delay in releasing the software, etc.

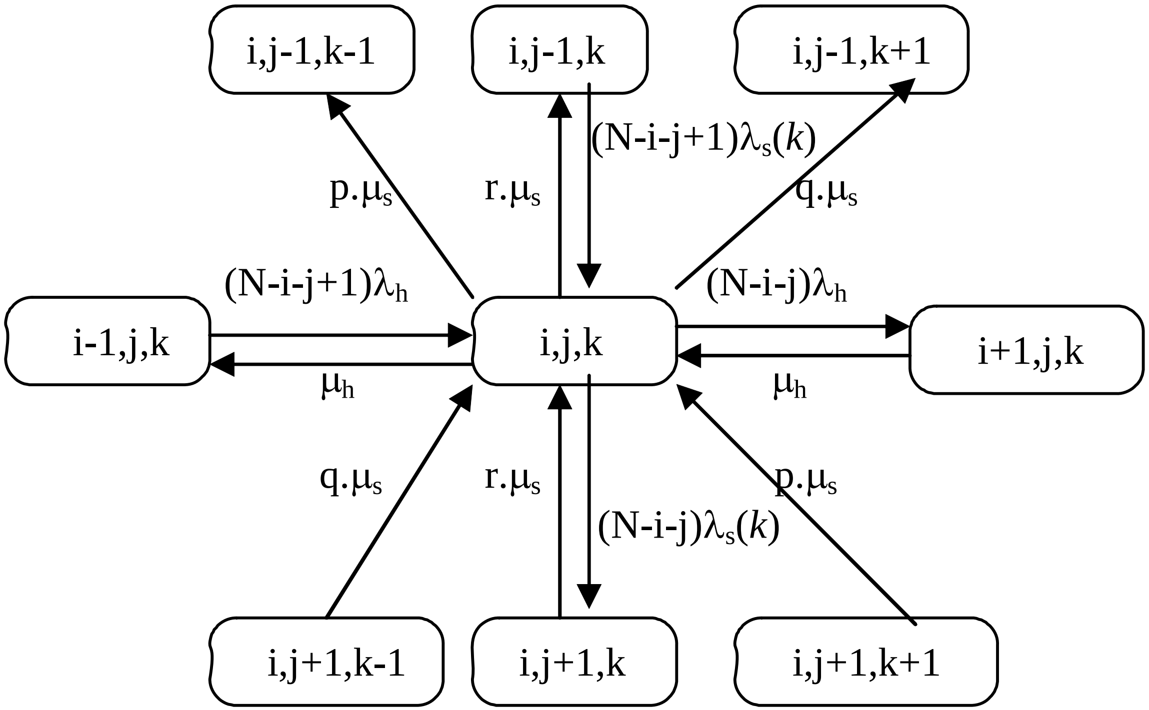
The Need for Efficient Testing-resource Allocation

- Software testing is extremely time-consuming and costly
- Available testing-resource is limited
- Complex systems are usually composed of several modules
- It is important to allocate the limited testing-resource among modules efficiently

Combined Software & Hardware



Imperfect Debugging (combined software-hardware system)



Markov model – transition rate

Some of my books

- **Xie, M. (1991).** *Software Reliability Modelling***. World Scientific Publisher, Singapore.**
- **Xu, R.Z.; Xie, M. and Zheng, R.J. (1994).** *Software Reliability Models and their Applications***. Tsinghua University Press, Beijing.**
- **Hayakawa, Y.; Irony, T. and Xie, M. (2001).** *Systems and Bayesian Reliability***. (Eds), World Scientific Publisher, Singapore.**
- **Xie, M., Dai, Y.S. and Poh, K.L. (2004).** *Computing Systems Reliability***. Kluwer Academic Publishers, Boston.**

SAFETY AND RELIABILITY OF COMPLEX INDUSTRIAL SYSTEMS AND PROCESSES

Project co-ordinators: Krzysztof Kolowrocki (Poland, GMU)
Xie Min (Singapore, NUS)

A collaboration between Singapore and Poland

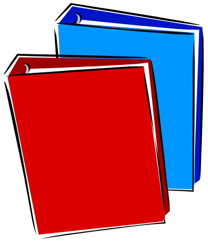
Project Objectives

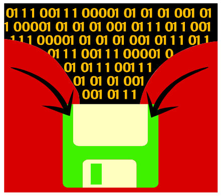
- To conduct a systematic safety and reliability study of complex industrial systems and processes;
- To develop new and innovative models for safety and reliability improvements for complex industrial infrastructure systems;
- To initiate long-term interdisciplinary research resulting in safer, more effective and more competitive industrial activities;
- To produce a package of practical tools capable of investigating, improving and optimising industrial systems and processes;
- To implement techniques for the design of safety and reliability decision support systems for maritime transportation sectors;
- To provide education and training courses, in addressing the lack of knowledge and technology within the current industry;

Collaboration with GMU, NUS, IHPC + International Maritime Partners

Deliverables

- General model for complex industrial systems operations and processes that relates to their environment and infrastructure
- Systematic report of methods for safety and reliability that includes an evaluation of current complex industrial systems
- Statistical report of current complex systems to evaluate unknown parameters of models using data mining techniques
- Web-based program package and its description
- User-friendly guidebooks for practitioners, which includes methods, procedures, descriptions, and applications, etc
- An Integrated Safety and Reliability Decision Support System for Maritime and Coastal Transport model





Announcement

- 2008 Asian Workshop on Advanced Reliability Modeling (AIWARM2008),
- Taichung, Taiwan, 23-25 October, 2008;
- http://aiwarm2008.iem.cyut.edu.tw/

- IEEE International Conference on Industrial Engineering and Engineering Management (IEEM2008)
- Singapore, 8-11 December, 2008;
- www.IEEM2008.org

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