RELIABILITY, AVAILABILITY AND RISK EVALUATION OF SYSTEMS IN VARIABLE OPERATION CONDITIONS

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Why I am here...

- I am Dr Qingpei Hu, a former student of Prof Min Xie, the Singapore PI of a project.
- Dr Joanna Soszynska is a former student of Prof Krzysztof Kolowrocki, the Polish PI of this project
- There is a project review meeting arranged by funding agency, so they had to attend that in Poland.
- I arrived in HK (research fellow at City Univ) a couple of weeks ago, so asked to help present this (as my research is on reliability and related to it).

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 Scope

Propose new and develop existing methods, tools & software capable of supporting intelligent modelling and decision support systems, in controlling and optimising the safety and reliability of complex real industrial systems and processes.

Focus on the use of new safety and reliability analysis techniques to improve and optimise safety and reliability of complex real industrial systems related to their operation processes.

Look into the design of industrial systems and the development and use of new methods and theoretical results that are applicable to designing, safety and reliability evaluations as well as the improvements of real complex industrial systems and processes.

Primary Application in the Maritime Transportation Sector

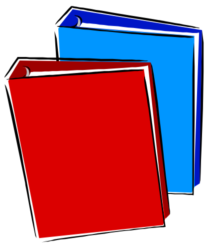
Project Objectives

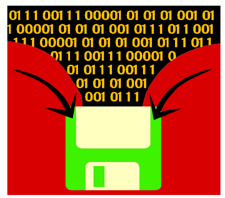
- To conduct a systematic safety and reliability study of complex industrial systems and processes;
- To develop new and innovative models for safety and reliability improvements for complex industrial infrastructure systems;
- To initiate long-term interdisciplinary research resulting in safer, more 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



Potential for future commercialization

The outcome from the developed methods and software can be profitably applied:

- To improve, on the basis of reliability criteria, the maintenance planning applied on the industrial systems and processes
- To define the maintenance planning on the industrial systems and processes in order to improve their competitiveness
- To support the application of a suitable quality assurance program for complex industrial systems and processes
- To perform suitable reliability analyses and risk assessment studies which includes improvements to existing industrial systems and processes
- To allow the adaptation of the industrial activity to the market request and improve it

Announcement

- 2008 Asian Workshop on Advanced Reliability Modeling (AIWARM2008),
- Taichung, Taiwan, 23-25 October, 2008;
- http://aiwarm2008.iem.cyut.edu.tw/
  Submission deadline 31 May

- IEEE International Conference on Industrial Engineering and Engineering Management (IEEM2008)
- Singapore, 8-11 December, 2008;
- www.IEEM2008.org
  Submission deadline 1 June

Contents

1. Introduction

- Transportation systems are complex, with high reliability requirement;
- Multi-state system reliability modeling framework is taken to describe the system;
- Semi-Markov processes are used to model the system operation process;
- Proposal: To link these two approaches into a general joint multi-state reliability model of a system under different operation conditions.

2. MSS Reliability

- **MSS systems definition**
  - **A component based system with degrading components that satisfy the following rules**

- E_{ij}, $i = 1,2,\ldots,k_n$, $j = 1,2,\ldots l_i$ **are components of a system,**

- **all components and a system under consideration have the reliability state set {0,1,...,*z*},** $z \geq 1$,

- the state indexes are ordered, the state 0 is the worst and the state z is the best,

- $T_{ij}(u)$, $i = 1,2,...,k_n$, $j = 1,2,\ldots,l_i$ are independent random variables representing the lifetimes of components E_{ij} in the reliability state subset $\{u,u+1,...,z\}$, while they were in the reliability state z at the moment $t = 0$,

- $T(u)$ is a random variable representing the lifetime of a system in the reliability state subset $\{u,u+1,...,z\}$ while it was in the reliability state z at the moment $t = 0$,

- the system reliability state degrades with time t without repair,

- $E_{ij}(t)$ is a component E_{ij} reliability state at the moment t, $t \geq 0$, given that it was in the reliability state z at the moment $t = 0$,

- $S(t)$ is a system reliability state at the moment t, $t \geq 0$, given that it was in the reliability state z at the moment $t = 0$.

Definition 1. Component R-Vector

$$R_{ij}(t,\cdot)=[R_{ij}(t,0),R_{ij}(t,1),\ldots, R_{ij}(t,z)],\ t \in (-\infty, \infty),$$

where

$$R_{ij}(t,u)=P(E_{ij}(t)\geq u|E_{ij}(0) = z)=P(T_{ij}(u) > t),\ t \in (-\infty, \infty),$$

$$u = 0,1,\ldots,z,\ i = 1,2,\ldots,k_n,\ j = 1,2,\ldots,l_i,$$

is the probability that the component E_{ij} is in the reliability state subset $\{u, u+1,\ldots, z\}$ at the moment t, while it was in the reliability state z at the moment $t = 0$, is called the multi-state reliability function of a component E_{ij}.

Definition 2. System R-vector

$$\boldsymbol{R}_n(t,\cdot) = [1, \boldsymbol{R}_n(t,1),...,\boldsymbol{R}_n(t,z)],$$

where

$$\boldsymbol{R}_n(t,u) = P(S(t) \geq u \mid S(0) = z) = P(T(u) > t),$$

for $t \geq 0$, $u = 0,1,...,z$, **is the probability that the system is in the reliability state subset** $\{u, u+1,..., z\}$ **at the moment** t, $t \geq 0$, **while it was in the reliability state** z **at the moment** $t = 0$, **is called the multi-state reliability function of a system.**

Definition 3. Risk-Fucntion

A probability

$$\boldsymbol{r}(t) = P(\mathrm{S}(t) < r \mid S(0) = z) = P(T(r) \le t),\ t \ge 0,$$

that the system is in the subset of states worse than the critical state $r,\ r \in \{1,...,z\}$ **while it was in the reliability state** z **at the moment** $t = 0$ **is called a risk function of the multi-state system.**

$$\boldsymbol{r}(t) = 1 - \boldsymbol{R}_{\boldsymbol{n}}(t, r),\ t \geq 0,$$

and if τ is the moment when the system risk function exceeds a permitted level δ, then

$$\tau = \boldsymbol{r}^{-1}(\delta),$$

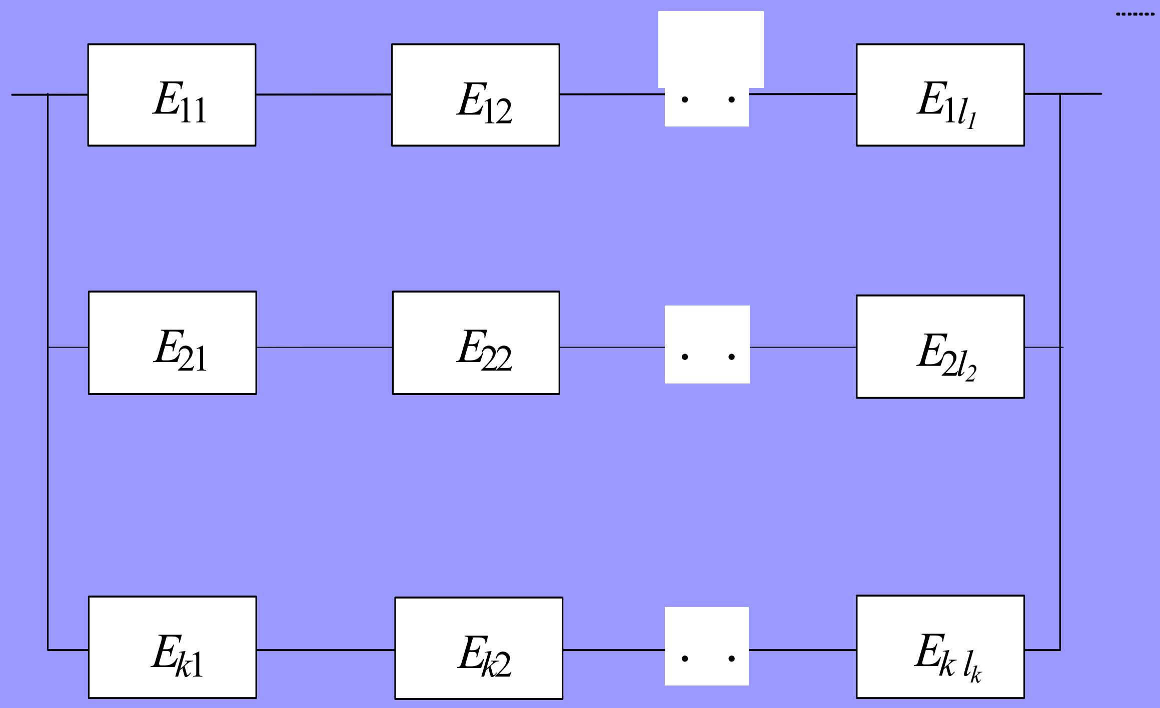
where $\boldsymbol{r}^{-1}(t)$, if it exists, is the inverse function of the risk function $r(t)$.

3. MSSPS Reliability

Definition 4.

A multi-state system is called series-parallel if its lifetime $T(u)$ **in the state subset** $\{u, u+1, \ldots, z\}$ **is given by**

$$T(u) = \max_{1 \le i \le k_n} \{\min_{1 \le j \le l_i} \{T_{ij}(u)\}\}, \; u = 1, 2, \ldots, z.$$



Series-Parallel System

$$\boldsymbol{R}_{k;l_1,l_2,\dots,l_k}(t,\cdot) = [1, \boldsymbol{R}_{k;l_1,l_2,\dots,l_k}(t,1),\dots,\boldsymbol{R}_{k;l_1,l_2,\dots,l_k}(t,z)],$$

where

$$\boldsymbol{R}_{k;l_1,l_2,\dots,l_k}(t,u) = P(S(t) \geq u \mid S(0) = z) = P(T(u) > t),$$

for $t \geq 0$, $u = 0,1,\dots,z$, is the probability that the system is in the reliability state subset $\{u, u+1,\dots, z\}$ at the moment t, $t \geq 0$, while it was in the reliability state z at the moment $t = 0$, is called the multi-state reliability function of a system

–Mean lifetime of the system in the state subset $\{u, u+1, \dots, z\}$,

$$M(u) = E[T(u)] = \int_0^\infty \boldsymbol{R}_{k;l_1,l_2,\dots,l_k}(t,u)dt, \; u = 1,2,\dots,z,$$

–Standard deviation of the system lifetime in the state subset $\{u, u+1, \dots, z\}$

$$\sigma(u) = \sqrt{D[T(u)]} = \sqrt{N(u) - [M(u)]^2}, \; u = 1,2,\dots,z,$$

–Mean lifetime of the system in the state u

$$\overline{M}(u) = \int_0^\infty p(t,u)dt, \quad u = 1,2,\dots,z,$$

4. MSSPS in Operations

We assume that the system during its operation process has v different operation states. Thus we can define $Z(t)$ as the system operation process with discrete states from the set

$$Z = \{z_1, z_2, \ldots, z_v\}.$$

In practice a convenient assumption is that $Z(t)$ is a semi-markov process with its conditional sojourn times θ_{bl} at the operation state z_b when its next operation state is z_l , $b, l = 1,2,...,v,\ b \neq l.$

- **the vector of probabilities of the initial operation states** $[p_b(0)]_{1x\nu}$,

- **the matrix of the probabilities of its transitions between the states** $[p_{bl}]_{\nu x\nu}$,

- **the matrix of the conditional distribution functions** $[H_{bl}(t)]_{\nu x\nu}$ **of the sojourn times** $\theta_{bl}, b \neq l$,

Under these assumptions, the following characteristics can be found:

- The mean values M_{bl} of the conditional sojourn times θ_{bl},

- The unconditional distribution functions $H_b(t)$ of the sojourn times θ_b of the process $Z(t)$ at the states z_b,

- **The mean values M_b of the unconditional sojourn times θ_b,**

- **The limit values p_b of the transient probabilities at the states.**

We assume that the changes of the process $Z(t)$ states have an influence on the system components E_{ij} reliability and on the system reliability structure as well.

The mean values and variances of the series-parallel system lifetimes in the reliability state subset $\{u, u+1, \ldots, z\}$ are

$$M(u) \cong \sum_{b=1}^{v} p_b M_b(u), u = 1,2,\ldots,z,$$

$$D[T^{(b)}(u)] = 2\int_0^\infty t[\boldsymbol{R}_{k_n l_n}(t,u)]^{(b)} dt - [M_b(u)]^2$$

$$\overline{M}(u) = M(u) - M(u+1), u = 1,2,\ldots,z-1,$$

$$\overline{M}(z) = M(z).$$

5. Applications

- Please refer to the paper…

6. Conclusions

The paper proposes an approach to the solution of practically very important problem of linking the systems' reliability and their operation processes.
Application of the proposed method is illustrated in the reliability, risk and selected availability characteristics evaluation of one of the subsystems of the port grain transportation system.

THANK YOU FOR YOUR

ATTENTION