Risk Based Applications for USACE Navigation Infrastructure

David M. Schaaf, P.E.
LRD Regional Technical Specialist
Louisville District

Robert C. Patev
NAD Regional Technical Specialist
New England District

Outline of Presentation

- Overview of Risk and Reliability
- Utilization within USACE Navigation Projects
- Current Initiative with USACE and LRD
  - Ohio River Mainstem Systems Study
- Risk and Reliability Work for Others
  - Great Lakes & St. Lawrence Seaway (USDOT (SLSDC), SLSMC, Transport Canada)
  - Panama Canal Authority (ACP)

Relationship Between Risk & Reliability

Costs * P_f = Consequences → Risk

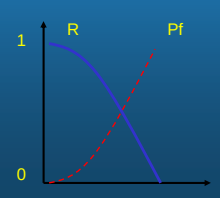
Engineering reliability analysis produces probabilities of failure for components

Cost Examples for USACE Projects
Emergency Repair Costs
Delay Times for Users
Increased O & M Costs and/or Frequency
Damages to Users
Other Damages (Bank Failures, Intakes)
Benefits Foregone

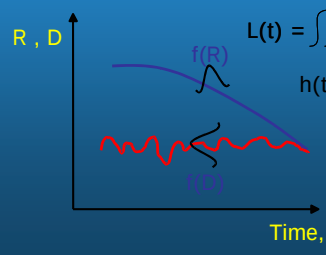
→ Event Tree

Relationship Between Risk & Reliability

- Reliability
  - Converse of probability of failure
    - $R = 1 - P_f$



Time-Dependent Reliabilty

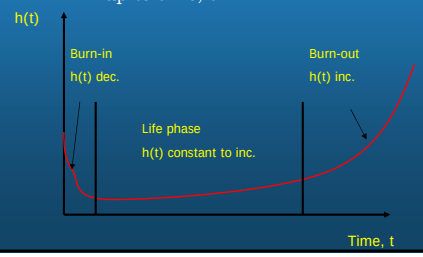


$$L(t) = \iint f(R)*g(t)\, f(D)$$

$$h(t) = -\ln d/dt\,(L(t))$$

One Team—Relevant, Ready, Responsive, Reliable

- Time-dependent reliability
  - Hazard rate, h(t)
    - Conditional probability
      - P_f in time, t + dt, given you have survived up to time, t



One Team—Relevant, Ready, Responsive, Reliable

Why Reliability Analysis? What Are the Benefits of Risk-Based Decision Making?

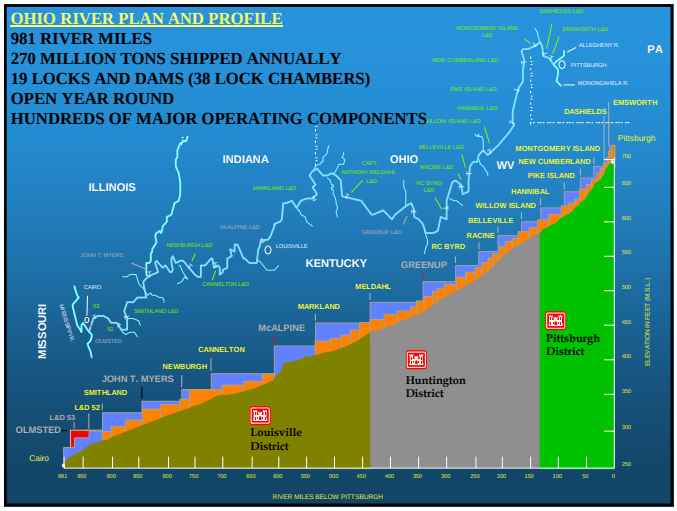
Recognizes and Captures Uncertainty in Engineering and Economic Analyses
- Engineering Uncertainties – Loads, Material Properties, Corrosion, Fatigue
- Economic Uncertainties – Traffic Forecasts, Rate Savings

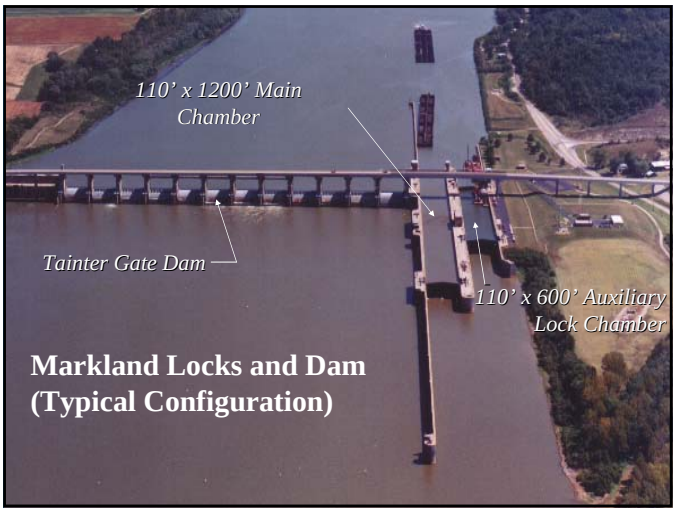
Shows Economic Justification and Risks Associated with Multiple Future Investment Alternatives
- Fix-as-Fails Maintenance, Advance Maintenance, Major Rehabilitation

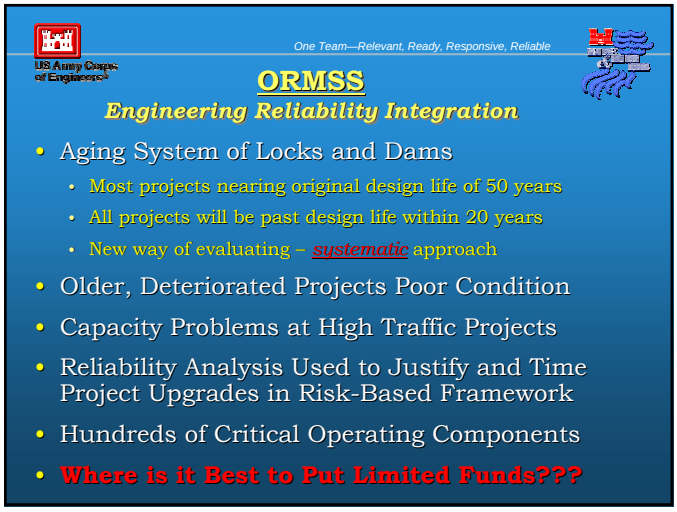
Allows an Unbiased Method to Rate Required Investments Based Upon Risks and Economic Merit
- Where can we best buy down risk for the entire system

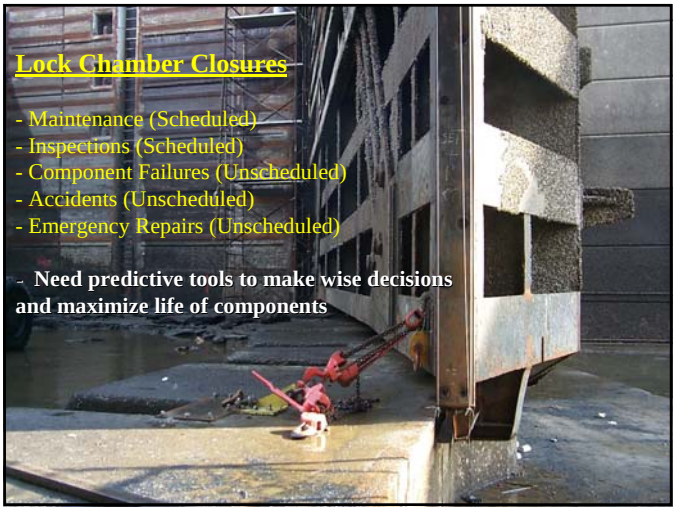
One Team—Relevant, Ready, Responsive, Reliable

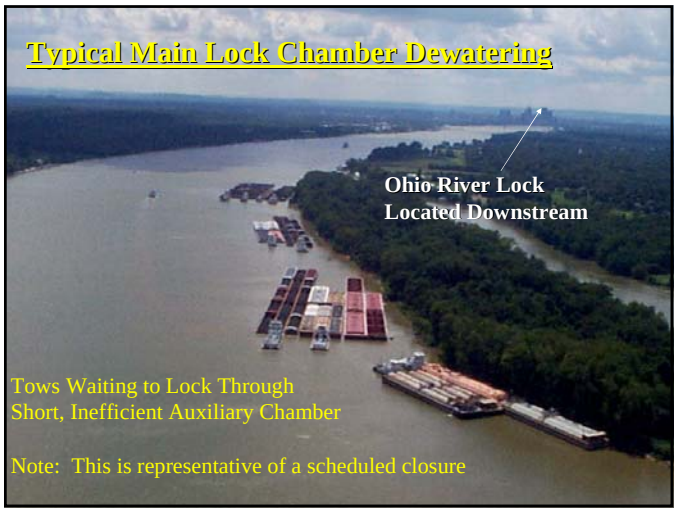
Ohio River Mainstem Systems Study (ORMSS)


OHIO RIVER PLAN AND PROFILE
981 RIVER MILES
270 MILLION TONS SHIPPED ANNUALLY
19 LOCKS AND DAMS (38 LOCK CHAMBERS)
OPEN YEAR ROUND
HUNDREDS OF MAJOR OPERATING COMPONENTS
PA
ALLEGHENY R.
PITTSBURGH
MONONGAHELA R.
EMSWORTH
DASHIELDS
Pittsburgh
MONTGOMERY ISLAND
NEW CUMBERLAND
PIKE ISLAND
HANNIBAL
WILLOW ISLAND
BELLEVILLE
RACINE
RC BYRD
GREENUP
MELDAHL
MARKLAND
McALPINE
CANNELTON
NEWBURGH
JOHN T. MYERS
SMITHLAND
L&D 52
L&D 53
OLMSTED
Cairo
ILLINOIS
INDIANA
OHIO
WV
KENTUCKY
MISSOURI
LOUISVILLE
Pittsburgh District
Huntington District
Louisville District
ELEVATION FEET (MSL)
RIVER MILES BELOW PITTSBURGH


110' x 1200' Main Chamber
Tainter Gate Dam
110' x 600' Auxiliary Lock Chamber
Markland Locks and Dam
(Typical Configuration)


One Team—Relevant, Ready, Responsive, Reliable
US Army Corps of Engineers
ORMSS
Engineering Reliability Integration
• Aging System of Locks and Dams
• Most projects nearing original design life of 50 years
• All projects will be past design life within 20 years
• New way of evaluating – systematic approach
• Older, Deteriorated Projects Poor Condition
• Capacity Problems at High Traffic Projects
• Reliability Analysis Used to Justify and Time Project Upgrades in Risk-Based Framework
• Hundreds of Critical Operating Components
• Where is it Best to Put Limited Funds???


Lock Chamber Closures
- Maintenance (Scheduled)
- Inspections (Scheduled)
- Component Failures (Unscheduled)
- Accidents (Unscheduled)
- Emergency Repairs (Unscheduled)
- Need predictive tools to make wise decisions and maximize life of components



US Army Corps of Engineers®

One Team—Relevant, Ready, Responsive, Reliable

Economic Impacts of Main Closures

Event	Duration	Delay $	Repair $	Total $	Peak Delay
Belleville* Jan. 2005	9 days	2.0 M	Not Available	Not Available	349 hours (14 days)
Greenup** Oct. 2003	52 days	13.2 M	1.5 M	14.8 M	93 hours (4 days)
Markland Aug. 2003	15 days	1.2 M	0.8 M	2.0 M	33 hours
McAlpine Sept. 1999	15 days	3.1 M	0.8 M	3.9 M	86 hours (3 ½ days)
McAlpine Aug. 1997	36 days	12.9 M	2.6 M	15.5 M	144 hours (6 days)

* Belleville was unscheduled pool loss due to barge accident. It was truly unscheduled, however, conservatively estimated to cost over $5 million per day to end users while out of service.

** Greenup was partially scheduled. Originally scheduled for 21 days, gate condition required 52 days to make extensive repairs. Additional $30 million in costs to end users also identified.

US Army Corps of Engineers®

One Team—Relevant, Ready, Responsive, Reliable

ORMSS Reliability Integration

Deterioration of Ohio River Miter Gates

What are the problems? How can we better predict them and their potential consequences?

Cracking Near Quoin Block

Cracking Through Thrust Plate

US Army Corps of Engineers®

One Team—Relevant, Ready, Responsive, Reliable

List of Engineering Reliability Models

Time Dependent Predictive Models for ORMSS

STRUCTURAL MODELS

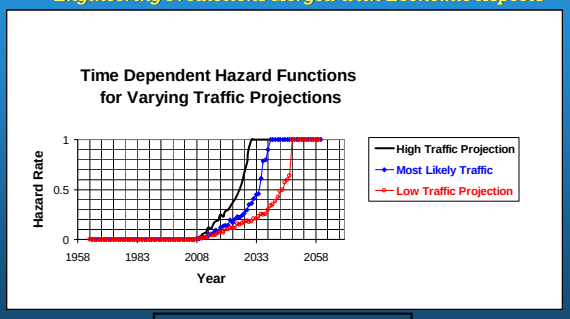
HF Miter Gates
VF Miter Gates
Anchored Monoliths
Anchored Sills
HF Culvert Valves
VF Culvert Valves

MECHANICAL/ELECTRICAL

MG Machinery
CV Machinery
Lock Hydraulic
Lock Electrical

ORMSS Reliability Integration

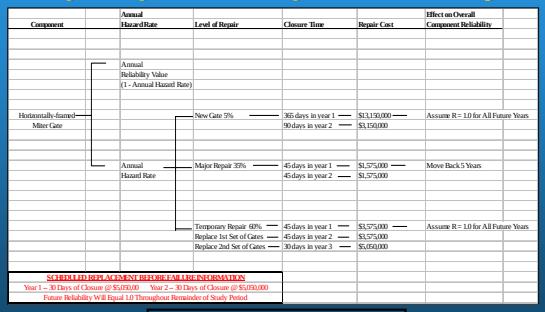
Engineering Predictions Merged with Economic Aspects



Time dependent probabilities of failure for various repair schemes and traffic projections

ORMSS Reliability Integration

Engineering Predictions Merged with Economic Aspects



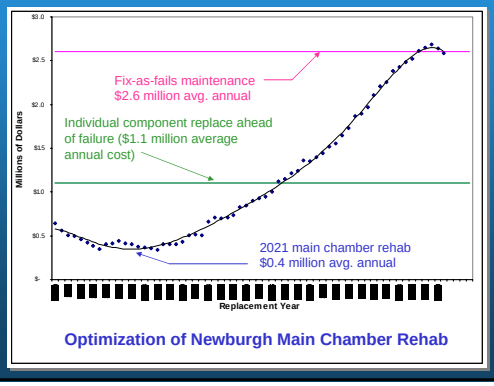
Consequence event tree given the limit state is exceeded in the reliability analysis

Main Chamber Miter Gate Reliability Results

Scenario	Avg. Annual Cost
Fix-As-Fails	$8,746,700
Advance Maintenance	$3,728,400
Replace in 2006	$1,603,100
Replace in 2007	$1,566,500
Replace in 2009	$1,531,600
Replace in 2009	$1,509,200
Replace in 2010	$1,491,800
Replace in 2011	$1,494,600
Replace in 2012	$2,195,100
Replace in 2015	$6,275,100

OPTIMUM TIME TO REPLACE

ORNIM Output for Newburgh Main Chamber Major Rehabilitation



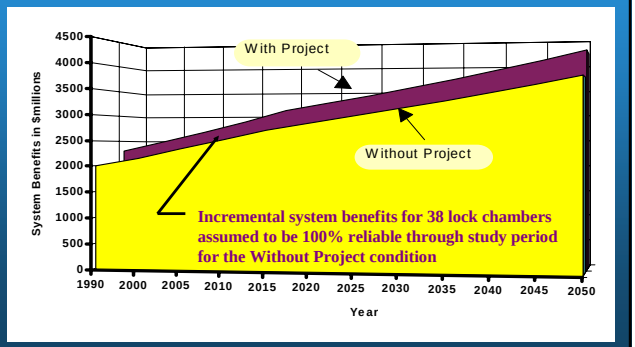
Optimization of Newburgh Main Chamber Rehab

Optimal Replacement Timing

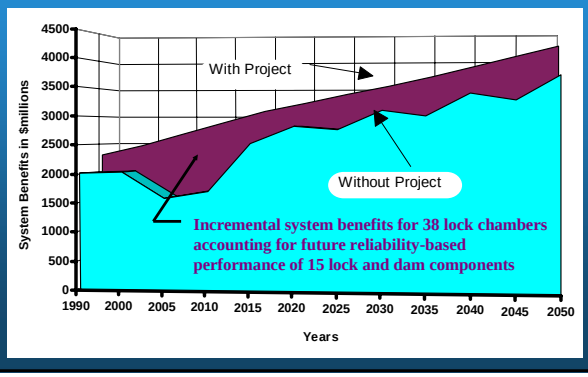
J.T. Myers Main Chamber

Feature	Clear Skies	Modified Clr Skies	NAAQS	Utility	Utility High
Miter Gates	2030	2029	2028	2029	2028
Culvert Valves	2021	2019	2019	2019	2019
Miter Gate Machinery	2020	2019	2018	2020	2020
Hydraulic System	2018	2017	2017	2018	2018
Electrical Controls	2015	2014	2014	2015	2015

How Does Including Reliability Performance of Aging, Deteriorated Components Affect End Results of the Economic Analysis?



Difference When Including Engineering Reliability Analysis!!!



USACE Risk & Reliability Work for Others

Great Lakes and St. Lawrence Seaway Study

Panama Canal Authority Study

Great Lakes & St. Lawrence Seaway Study

- ✓ Collaborative effort between U.S. and Canadian governments to evaluate long-term needs for entire GLSLS system
- ✓ 42-month study jointly done with multi-national teams initiated in May 2003
- ✓ Utilization of risk-based analysis and engineering reliability models to optimize investment plans for major infrastructure upgrades
- ✓ Budgetary Issues

  President's FY06 Budget = $300k
  House Mark-up = $2.4 million
  Senate Mark-up = $300k
  Capability and Need to Complete in FY06 = $3.3 million

Great Lakes & St. Lawrence Seaway Study

- Pre-Screening
  - Over 160 components ranked
    - Locks
    - Dams
    - Bridges (railroad, highway)
  - Criticality Ranking
    - Redundancy
    - Current condition
    - Likelihood of future problems
    - Relative cost to upgrade/replace
    - Impact to navigation
    - Other impacts

Great Lakes & St. Lawrence Seaway Study

COMPONENT DESCRIPTION	Category	GLSLS Project	RANKING	RESULTS
Mass Concrete/Lock Wall Monoliths (Lower Locks)	LW	Maisonneuve	1.40	Reliability Model
Bridge No. 6 (Bascule) - Structural	BS	Welland	1.60	Reliability Model
Lock Wall Monoliths / Mass Concrete (Eisenhower)	LW	USDOT	1.70	Expert Elicitation
Upper Approach Walls	AW	Soo - Poe	1.90	Reliability Model
Lower Miter Gates - Single Gates	GMS	USDOT	1.90	Reliability Model
Upper Miter Gates - Single Gates	GMS	Soo - Poe	1.90	Reliability Model
Head Race Crib Dike at Hydropower Plant	D	Soo - Dam	1.90	Reliability Model
Lift bridges - Structural (Bridge 2,3,7a & 7b, 9 & 10	BS	Maisonneuve	1.95	Reliability Model
International Seaway Bridge - South Span	BS	USDOT	2.05	Reliability Model
Lift bridges - Machinery (Bridge 2,3 7a, 7b, 9 & 10)	BM	Maisonneuve	2.10	Expert Elicitation
Moveable Bridges - Structural (Bascule)	BS	Welland	2.10	Reliability Model
Bascule Bridges (2) - Structural	BS	Maisonneuve	2.10	Reliability Model
Moveable Bridges - Structural (Lift)	BS	Welland	2.15	Reliability Model
Lock Wall Monoliths / Mass Concrete (Snell)	LW	USDOT	2.15	Expert Elicitation
Swing Bridge	BS	Maisonneuve	2.15	Reliability Model
Entrance Walls - Timber Tie Up	AW	Welland	2.15	Expert Elicitation
Tunnel Structure at Eisenhower Lock	T	USDOT	2.20	Expert Elicitation
Original Lock Walls - Single Locks	LW	Welland	2.30	Expert Elicitation

Great Lakes & St. Lawrence Seaway Study

- Reliability Modeling
  - 20 components
    - Time-dependent models
      - Concrete structures
      - Steel structures
    - Expert Elicitation
      - Concrete deterioration
      - Tunnels
      - Timber tie-up walls

Panama Canal Authority (ACP) Infrastructure Risk & Reliability Assessment

- ✓ Multi-phased approach to develop analytical reliability models for existing infrastructure of ACP
- ✓ Includes evaluating existing maintenance, need for rehabilitation, seismic events, hydropower operations, and terrorism measures
- ✓ Will provide ACP will analytical means to make investment decisions
- ✓ Team to be led by Louisville District with other LRD and USACE support as required
- ✓ Briefing between key USACE and ACP staff planned for fall 2006 to initiate effort

US Army Corps of Engineers®
One Team—Relevant, Ready, Responsive, Reliable

Thank You

Questions???