University of Maryland

Department of Civil and Environmental Engineering

NEXTOR

Analysis Methods for Inland Waterways

by

Paul Schonfeld

Professor

Dept. of Civil & Environmental Engineering

University of Maryland

College Park, MD 20742

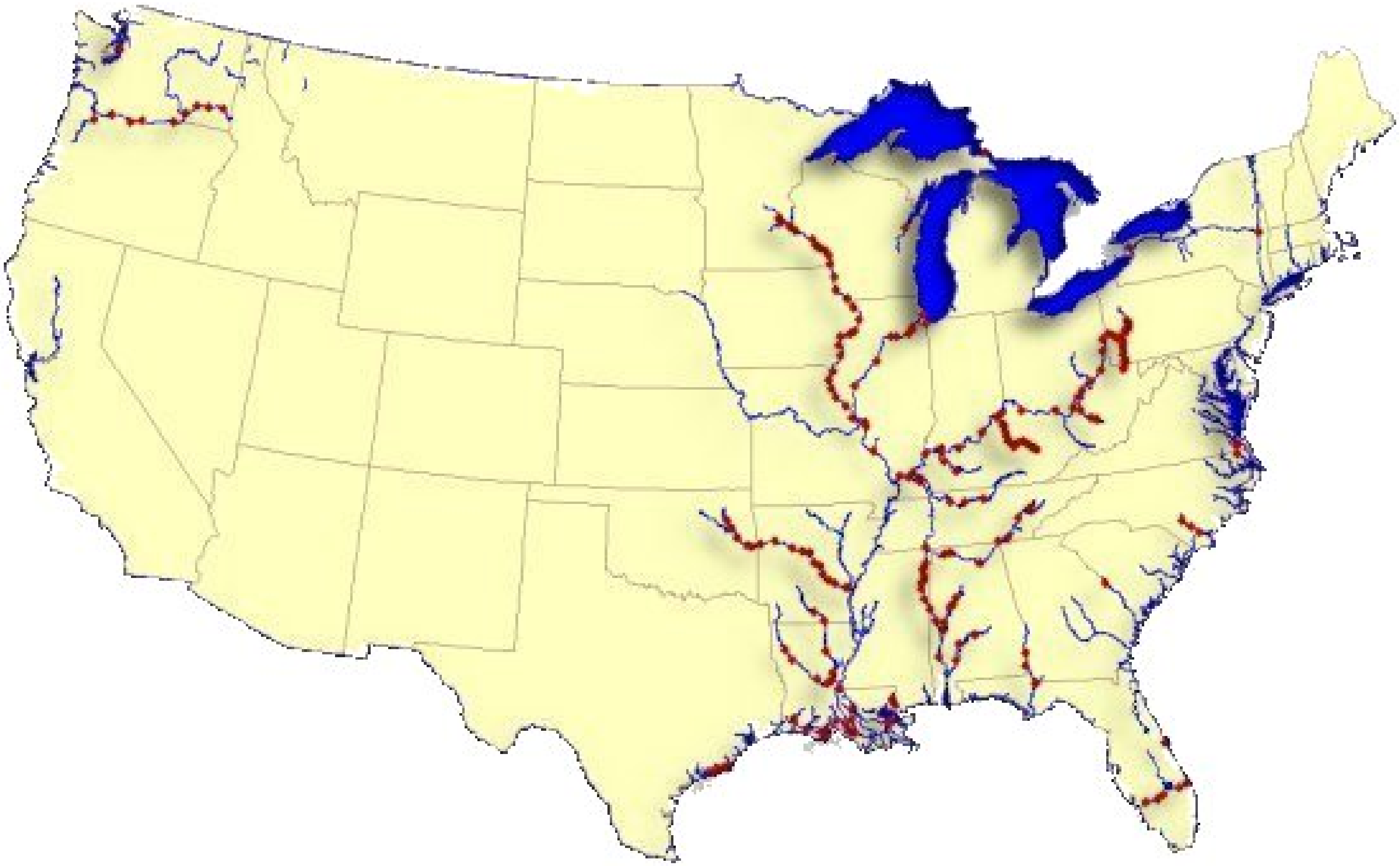
pschon@eng.umd.edu

September 9, 2005

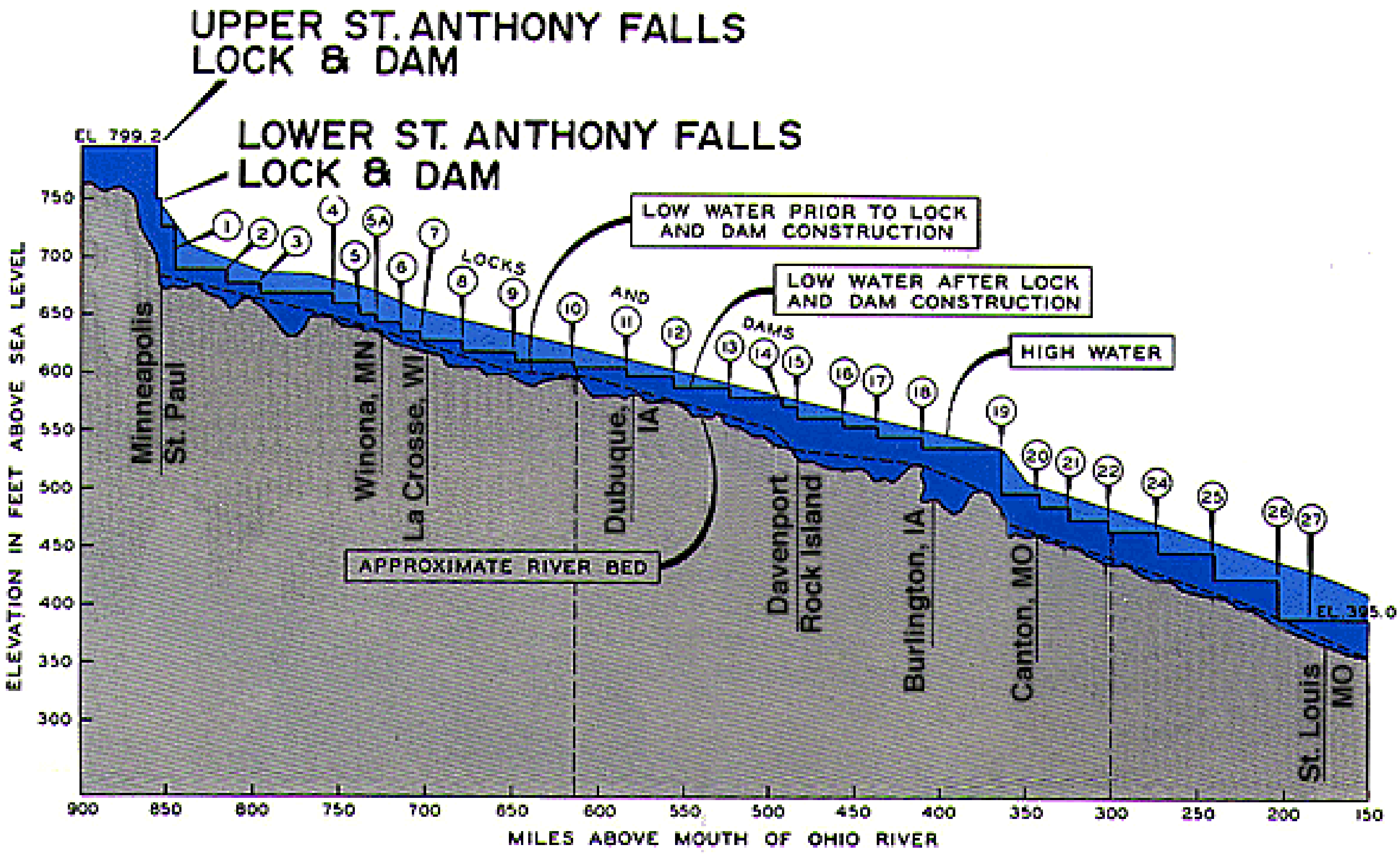
Outline

- Overview
  - Traffic
  - Lock Operations
- Critical Issues
- Comparisons with U.S. Aviation System
- Relevant Methods of Analysis
- Conclusions
- References

Overview



Overview


UPPER ST. ANTHONY FALLS LOCK & DAM
LOWER ST. ANTHONY FALLS LOCK & DAM
EL 799.2
LOW WATER PRIOR TO LOCK AND DAM CONSTRUCTION
LOW WATER AFTER LOCK AND DAM CONSTRUCTION
HIGH WATER
LOCKS AND DAMS
APPROXIMATE RIVER BED
EL 395.0
Minneapolis St. Paul
Winona, MN
La Crosse, WI
Dubuque, IA
Davenport Rock Island
Burlington, IA
Canton, MO
St. Louis MO
ELEVATION IN FEET ABOVE SEA LEVEL
MILES ABOVE MOUTH OF OHIO RIVER

Overview

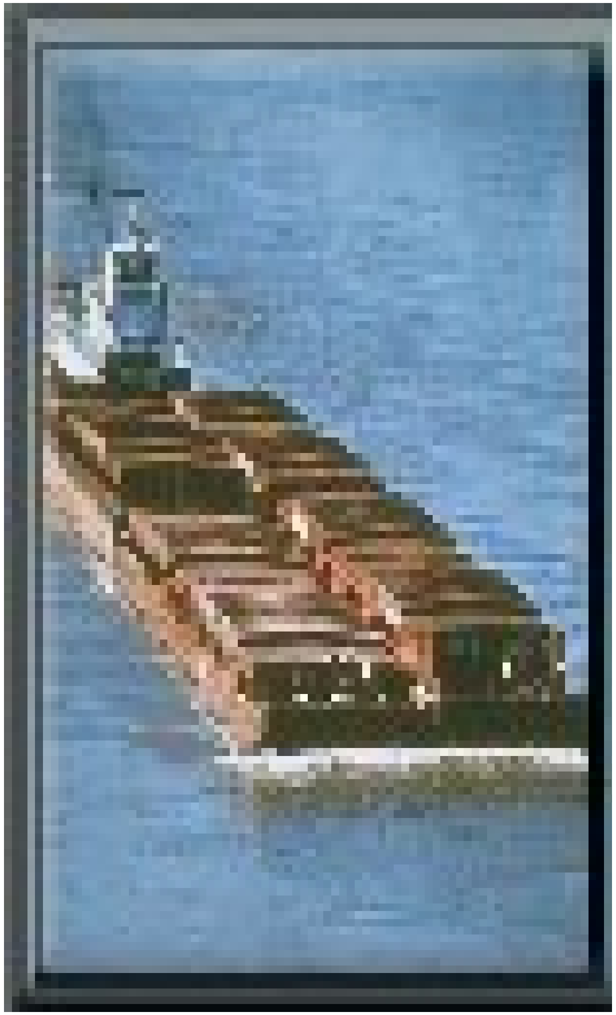
- Approx. 25,000 miles of navigable U.S. waterways
- Approx. 13% of intercity ton miles
- Approx. 4000 towboats
- Approx. 19,000 barges

Traffic:

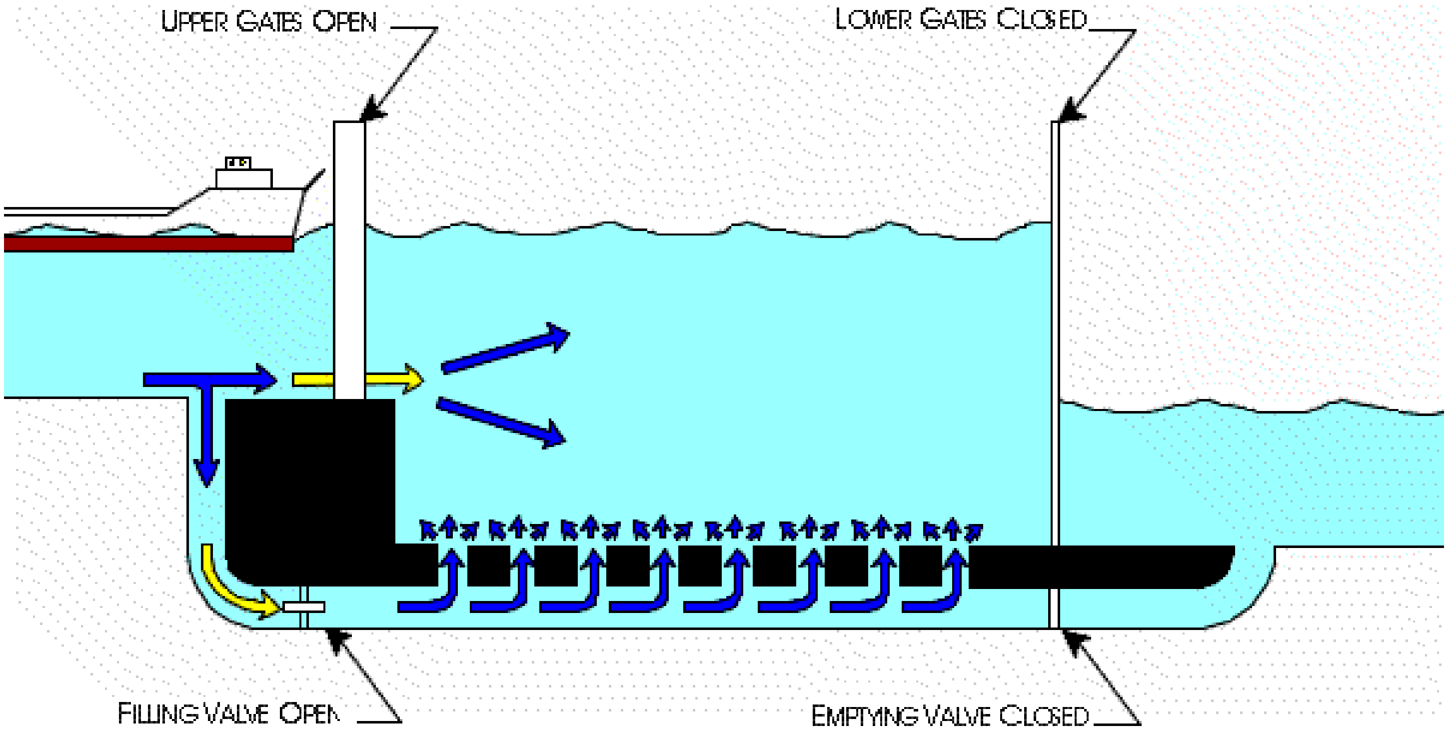
- Commercial tows

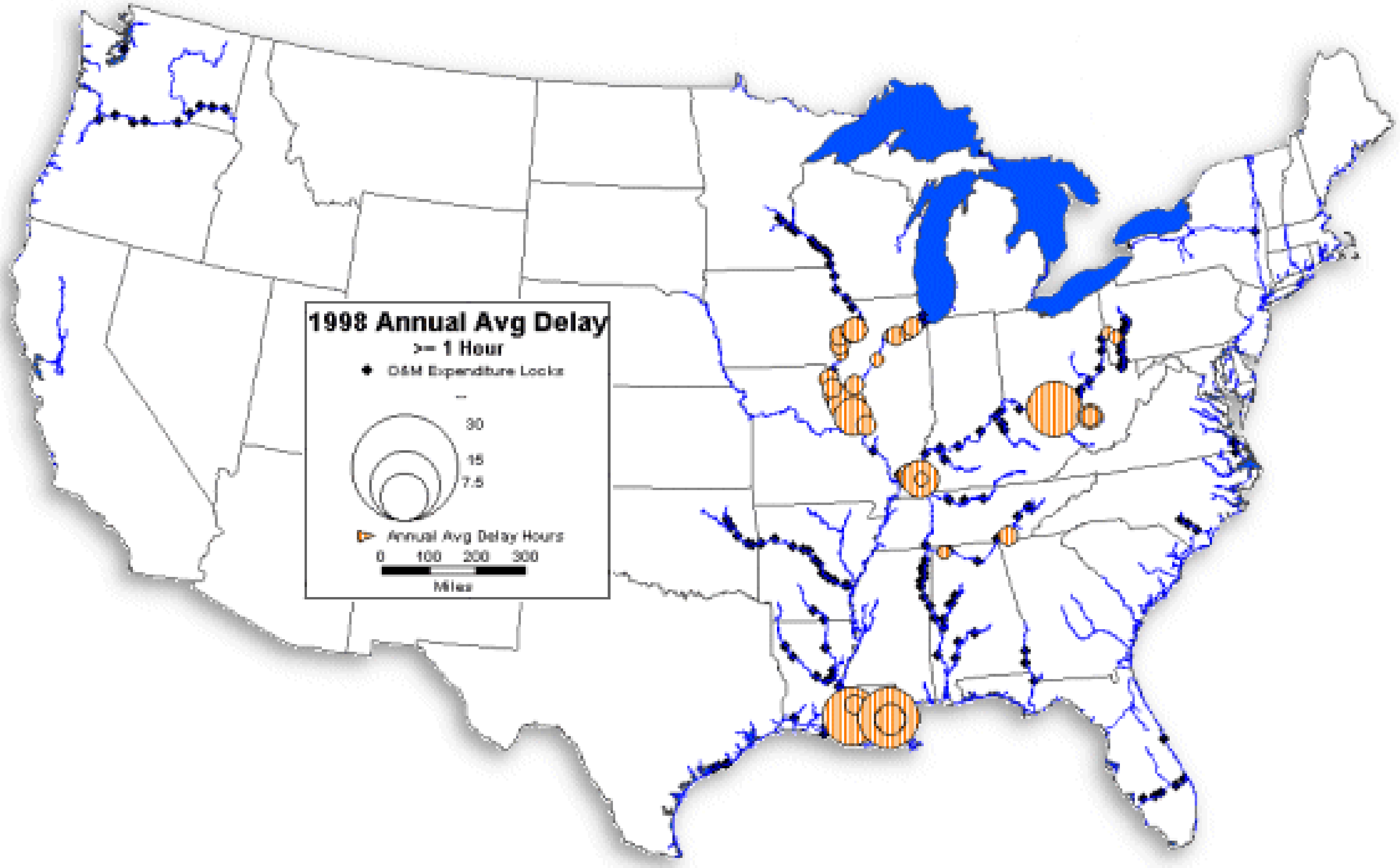
Commercial tows consist of towboats (=powerboats) and unpowered barges (modular, with standardized 195 x 35 ft. dimensions and approx. 1,500 ton capacity), moving at approx. 10 mph

- Recreational boats
- Other

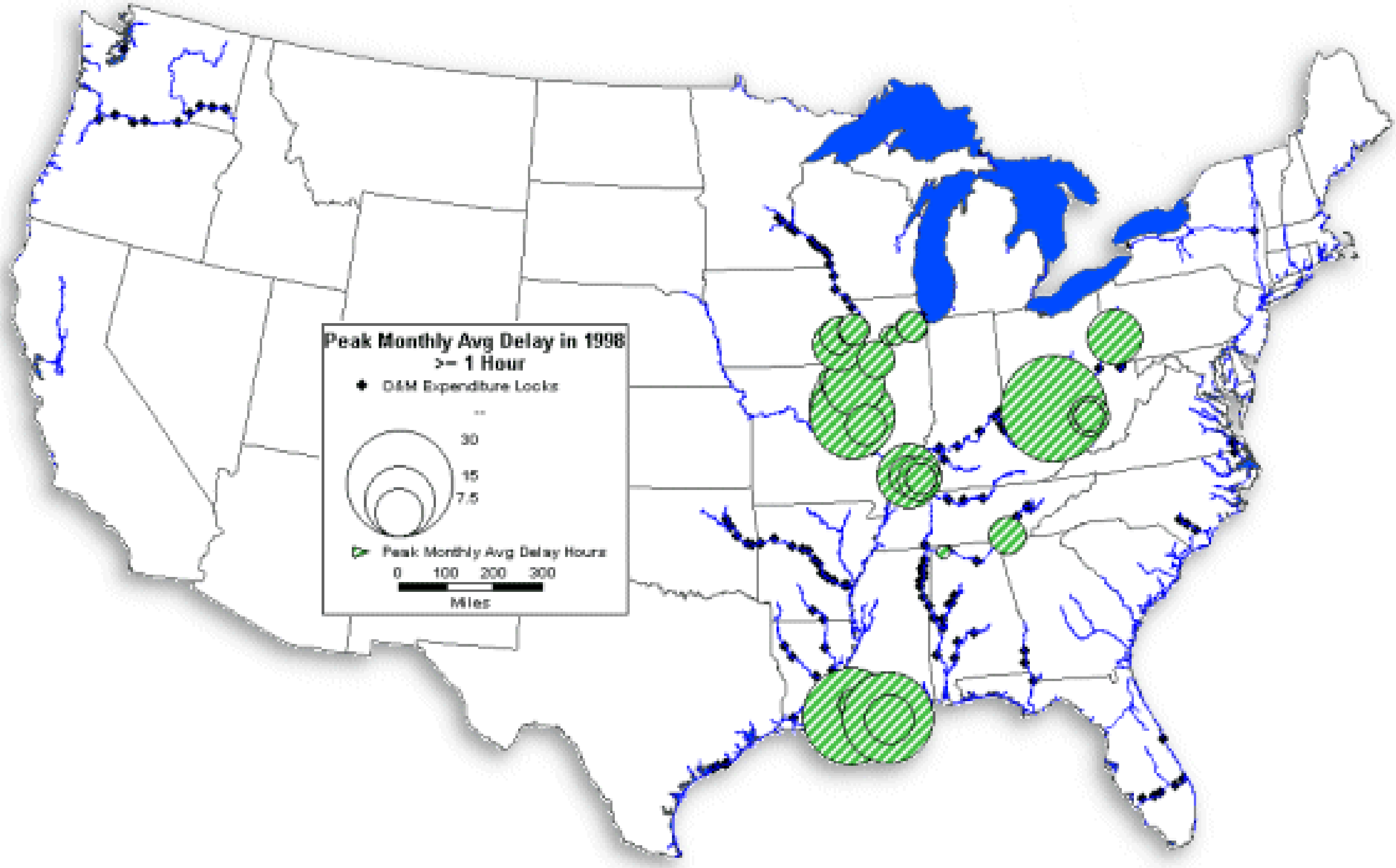


Lock Operations

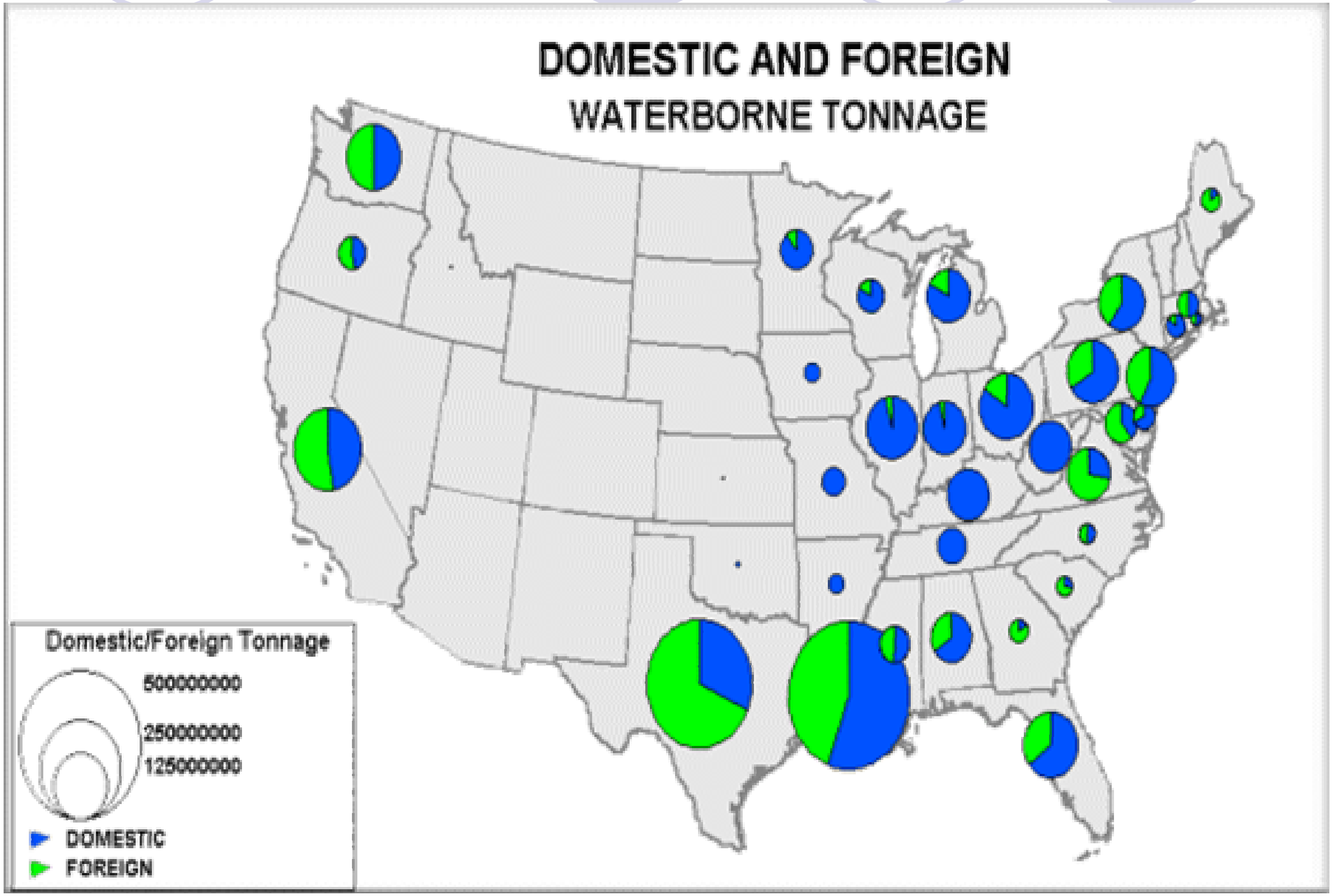




Source: UDC Publications and U.S. Waterway Data (2004)



Source: UDC Publications and U.S. Waterway Data (2004)

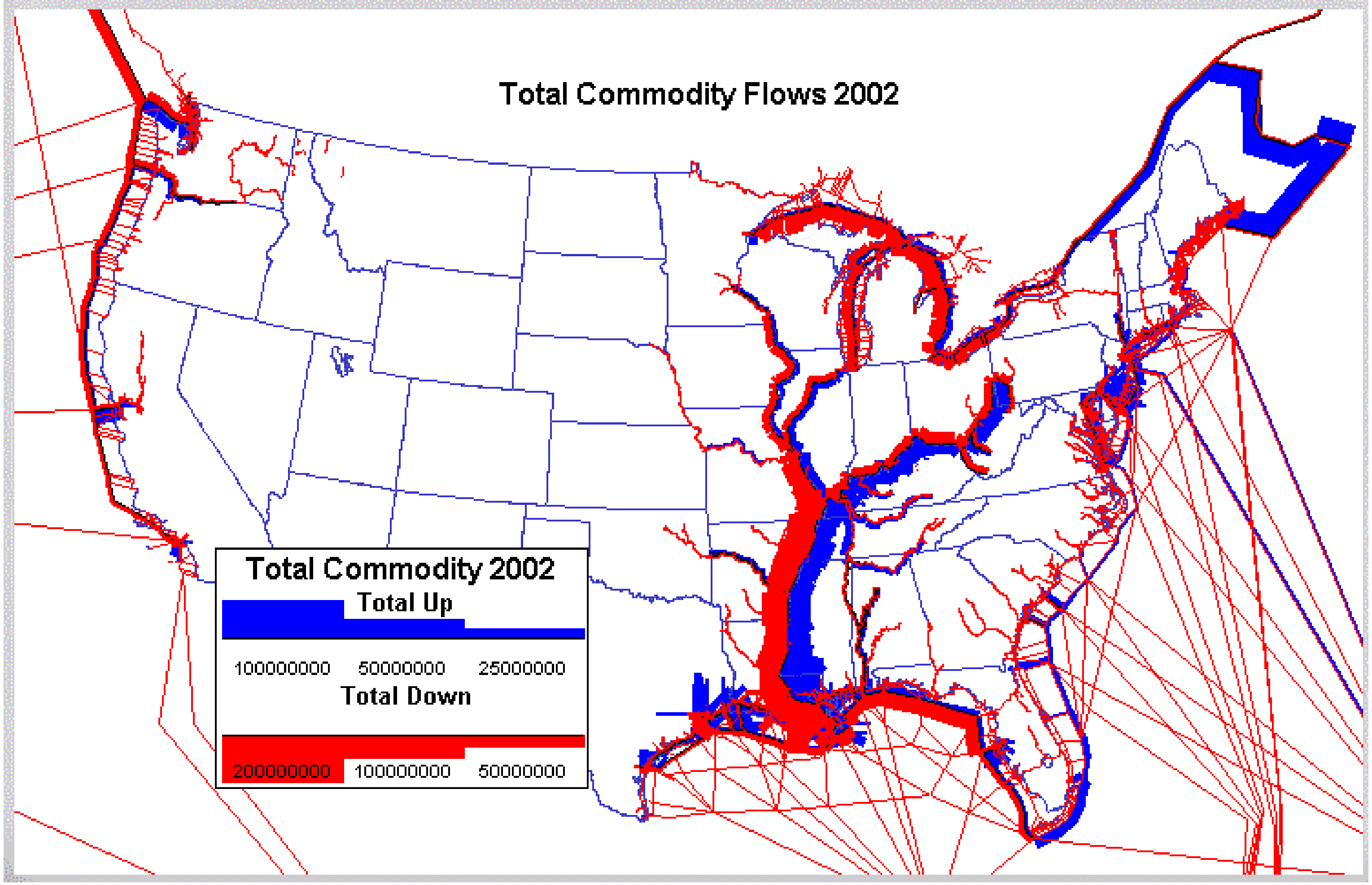


Source: UDC Publications and U.S. Waterway Data (2004)

University of Maryland

Department of Civil and Environmental Engineering

NEXTOR



Source: UDC Publications and U.S. Waterway Data (2004)

System Capacity and Service Levels Limited by:

- Lock chamber dimensions
- Parallel chambers per lock
- Lockage times
- Channel characteristics
- Seasonal icing or low water
- Scheduled lock closures
- Unscheduled lock closures

Critical Issues

- Aging infrastructure with very high replacement costs
- Vulnerability to service interruptions due to lock closures, icing, low water, etc.
- Seasonality of demand and supply
- Environmental impacts
- Taxes and subsidies
- Intermodal competition

Comparisons with U.S. Aviation System (1)

1. Federal Agency (U.S. Army Corps of Engineers rather than FAA) builds and operates the infrastructure, except for the terminal facilities.
2. Competing commercial fleet operators and owners of small private vehicles must be served efficiently and fairly
3. Insufficient capacity results in congestion and queuing delays
4. The hard infrastructure (locks, airfields) may be difficult to maintain, repair or expand without interrupting service
5. Severe funding problems

Comparisons with U.S. Aviation System (2)

6. Political influences on resource allocation
7. More decentralized planning and operation for waterways
8. "Real-time" is slower on waterways
9. Waterway network is more interruptible by single failures
10. Possible control policies for runways and lock chambers have interesting similarities (grouping, sequencing, chamber assignment, direction changes, reserved slots)
11. Similar interference effects among parallel runways and lock chambers

Relevant Methods of Analysis

- Demand forecasting
- Analysis of operations
- Network simulation
- Control of lock operations
- Condition assessment
- Reliability analysis
- Investment planning and scheduling
- Maintenance planning and scheduling

Network Simulation

- WAM 1973
- Dai & Schonfeld 1991, 1998
- Ting & Schonfeld 1996, 1998
- Wang & Schonfeld 2002, 2005
- Navsym
- ORNIM
- Simopt
- Locksim
- UMR
- NaSS

Expectations in New Waterway Simulation Models

1. Validity
2. Generality
3. Automatic extraction and preprocessing of input data
4. User interfaces with visualization and animation
5. Multi-modal equilibrium demand
6. Hierarchical analysis
7. Detailed analysis of lock operations
8. Component-level reliability
9. Complex operating policies
10. Interactions among locks
11. Applications
12. Performance measures
13. Computation efficiency suitable for optimization

Relevant Methods of Analysis

- Demand forecasting
- Analysis of operations
- Network simulation
- Control of lock operations
- Condition assessment
- Reliability analysis
- Investment planning and scheduling
- Maintenance planning and scheduling

Control of Lock Operations (1)

1. Assignment of tows to multiple chambers
2. Alternating platoons of variable size (M-up and N-down)
3. Priorities and mixing rules for commercial and recreational traffic
4. Fairness objectives and constraints
5. Tow cutting and reassembly considerations
6. Chamber packing
7. Chamber packing with tow cutting

Control of Lock Operations (2)

8. Integrated control of adjacent locks
9. Appointment and reservation systems
10. Priorities based on relative service times, time values for tows and their contents, and relative lateness
11. Auxiliary (“helper”) towboats at congested locks
12. Combined control policies
13. Dynamic control policies

Relevant Methods of Analysis

- Demand forecasting
- Analysis of operations
- Network simulation
- Control of lock operations
- Condition assessment
- Reliability analysis
- Investment planning and scheduling
- Maintenance planning and scheduling

Investment Planning and Scheduling for Interdependent Projects

- Project design
- Evaluation
- Selection
- Sequencing
- Scheduling

Investment Planning and Scheduling

- If budget constraints over time are binding, project sequencing determines project implementation times.
- Still, identifying the best sequence of projects can be a large combinatorial problem with numerous local optima.
- Methods used for project evaluation are largely separable from those used for project selection & scheduling.
- Microscopic simulation is a very expensive way to repeatedly evaluate the objective function during an optimization process, but is becoming practical for waterway networks.

Previous Work (1)

- For evaluation of interdependent projects we tried:
  - Queuing metamodels (Dai & Schonfeld, 1998)
  - Artificial Neural Networks (Wei & Schonfeld, 1993, 1994)
  - ANN-based queuing networks (Zhu et al, 1999)
  - Microscopic simulation (Ting & Schonfeld, 1998, Tao & Schonfeld, 2004, Wang & Schonfeld, 2005)

Previous Work (2)

- For optimizing project selection and scheduling we experimented with:
  - Swapping algorithms (Martinelli & Schonfeld, 1993)
  - Branch and Bound (Wei & Schonfeld, 1993)
  - SPSA (Ting & Schonfeld, 1998)
  - Simulated annealing
  - Genetic algorithms (Jong & Schonfeld, 2001, Wang & Schonfeld, 2005)
  - Island models (Tao & Schonfeld, 2004)

Conclusions

- The U.S. inland waterway system seems less complex in most respects than the air transportation system. Thus, it seems easier to analyze and optimize at a larger scale and, simultaneously, at a finer level of detail.

- Because "real-time" is slower in inland waterways, more complex control policies, based on deeper search and longer anticipation, are feasible.

- **In most areas of interest the analytic state-of-the-art seems more advanced in aviation than in inland waterways. However, some methods developed for waterways seem promising for aviation applications, including:**
  - **Selection and scheduling of capital improvements**
  - **Maintenance planning and scheduling**
  - **Introduction of new technologies and operating policies**
  - **Scheduling of runway operations**
  - **Optimization based on simulation**
  - **Optimization based on ANN approximations of queuing networks**

University of Maryland

Department of Civil and Environmental Engineering

NEXTOR

References

- Dai, D.M. and Schonfeld, P., "Simulation of Waterway Transportation Reliability," Transp. Res. Record 1313, 1991, pp. 98-105.
- Wei, C.H., Dai, M.D.M. and Schonfeld, P., "Computational Characteristics of a Numerical Model for Series of Waterway Queues," Transp. Res. Record 1333, 1992, pp. 45-54.
- Martinelli, D. and Schonfeld, P. "Prioritizing and Scheduling Interdependent Lock Improvement Projects," Compendium on Waterway Transportation Reliability, Inst of Water Resources Report 93-R-9, Fort Belvoir, April 1993.
- Martinelli, D., Dai, M.D.M., Schonfeld, P. and Antle, G., "A Methodology for Planning Interdependent Waterway Improvements," Transp. Res. Record 1383, June 1993, pp. 49-57.
- Ramanathan, V. and Schonfeld, P., "Approximate Delays Caused by Lock Service Interruptions," Transp. Res. Record 1430, Jan. 1994, pp. 41-49.
- Wei, C.H. and Schonfeld, P., "Multiperiod Network Improvement Model," Transp. Res. Record 1443, Oct. 1994, pp. 110-118.
- Kim.M. and Schonfeld, P., "Neural Network Estimation of Lock Service Times," Transp. Res. Record 1497, July 1995, pp. 36-43.
- Martinelli, D. and Schonfeld, P., "Approximating Delays at Interdependent Locks," J. of Waterway, Port, Coastal and Ocean Eng., ASCE, Vol. 121, No. 6, Nov. 1995, pp.300-307.
- Ting, C.J. and Schonfeld, P., "Effects of Tow Sequencing on Lock Capacities and Service Times," J. of Waterway, Port, Coastal and Ocean Eng., ASCE, Vol. 122, No. 1, Jan./Feb. 1996, pp. 16-26., Y
- Dai, D.M. and Schonfeld, P., "Metamodels for Estimating Delays through Series of Waterway Queues," Transp. Res. Part B, Vol. 32, No. 1, Jan. 1998, pp. 1-19.
- Ting, C. J. and Schonfeld, P., "Optimization through Simulation of Waterway Transportation Investments," Transp. Res. Record 1620, 1998, pp. 11-16.

- Ting, C. J. and Schonfeld, P., "Integrated Control for Series of Waterway Locks, " J. of Waterway, Port, Coastal and Ocean Eng., ASCE, Vol. 124, No. 4, July/Aug. 1998, pp. 199-206.
- Ting, C. J. and Schonfeld, P., "Effects of Speed Control on Tow Travel Costs," J. of Wateway, Port, Coastal and Ocean Eng., ASCE, Vol. 125, No. 4. July/Aug. 1999, pp. 203-206.
- Jong, J. C. and Schonfeld, P., "Cost Functions for Optimizing Highway Alignments," Transp. Res. Record 1659, Aug. 1999, pp. 58-67.
- Zhu, L, Schonfeld, P., Kim, Y. M. Flood, I. and Ting C. J., "Waterway Network Analysis with Artificial Neural Networks," Artificial Intelligence for Eng. Design, Analysis and Manufacturing, Vol. 13, 1999, pp. 365-375.
- Jong, J. C. and Schonfeld, P., “A Genetic Algorithm for Selecting and Scheduling Interdependent Projects,” J. of Waterway, Port, Coastal and Ocean Eng., ASCE, Vol. 127 No. 1, Jan./Feb. 2001, pp. 45-52
- Ting, C.J. and Schonfeld P., “Control Alternatives at a Waterway Lock,” J. of Waterway, Port, Coastal and Ocean Eng., Vol. 127, Nov. 2, March/April 2001, pp. 89-96.
- Ting, C. J. and Schonfeld, P., "Efficiency Versus Fairness in Priority Control: A Waterway Lock Case, " J. of Waterway, Port, Coastal and Ocean Eng., ASCE, Vol. 127, No. 2, March/April 2001, pp. 82-88.
- Wang, SL. And Schonfeld, P., “Development of Generalized Waterway Simulation Model,” Annual TRB Meeting, Jan. 2002 (02-2194 on Conference CD_ROM).
- Tao, X. and Schonfeld, P., “A Simulation Method for Selecting and Scheduling Waterway Projects,” Annual TRB Meeting, Jan. 2004 (04-2899 on CD-ROM).
- Tao, X., and Schonfeld, P., “A Lagrangian Relaxation Algorithm for Selecting Interdependent Projects under Cost Uncertainty,” Annual TRB Meeting, Jan. 2005 (05-0565).
- Wang, S.L. and Schonfeld, P., “Scheduling Interdependent Waterway Projects through Simulation and Genetic Optimization,” J. of Waterway, Port, Coastal and Ocean Eng., ASCE, Vol.131, No. 3, May/June 2005, pp. 89-97.

THANK YOU !