Management Systems for Inland Waterway Traffic Control

Upper Mississippi River Locks 20-25

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UMR-IW Navigation System

UM-SL CTS Research Project for the Midwest Transportation Consortium

- In January, 2004 the CTS undertook a project funded by the Midwest Transportation Consortium to:
  - measure the economic benefits and costs of implementing an appointment or scheduling system on a periodically congested segment (Lock 20 through Lock 25) of the Upper Mississippi River;
  - develop a robust simulation tool to measure the effects of a variety of lock scheduling strategies; and
  - prepare the groundwork for operational testing of an appointment or scheduling system.

Scope of the Research is Expanded

- In March, 2004 the Institute for Water Resources of the U.S. Army Corps of Engineers agreed to become a full partner in the ongoing MTC system scheduling study and to fund the development of a prototype of a real time vessel tracking system designed to aid in traffic scheduling.
- Funds were received from the Corps in July 2004.
- The joint MTC-Corps study was completed in October 2005.

Team For UMSL CTS Study

- The research team included:
  - Ray A. Mundy, Ph.D. (PI)
  - James F. Campbell, Ph.D. (PI)
  - Robert M. Nauss, Ph.D.
  - Daniel L. Rust, Ph.D.
  - L. Douglas Smith, Ph.D.
  - Donald C. Sweeney II, Ph.D.
  - graduate and undergraduate student research associates.

Potential Benefits of an Appointment or Scheduling System

- For Shippers and Carriers:
  - More reliable and efficient infrastructure use resulting from shorter queues at locks and dams.
  - More efficient fuel use due to decreased tow idle time and better optimized transit speeds between locks.
- For the Public:
  - A cost-effective solution to periodic lock congestion.
  - Decreased pollution and environmental damage due to more efficient tow operations.

Research Work Plan

- Initial study conferences (Corps, Coast Guard, Towing Companies).
- Refinement of the project scope.
- Development of an array of alternative appointment systems and scheduling rules.
- Data acquisition and statistical analysis.
- Construction of a simulation model.
- Validation of the simulation model.
- Application of the simulation model to evaluate alternatives.
- Final study conference.
- Final report.

Traffic Management Alternatives Identified

1. Existing traffic management: local first come, first served lock queue dispatch policy with exceptions
2. Schedule appointments at locks
   - Using currently available information
   - Using additional information (e.g. vessel tracking)
3. Re-sequence vessels in local lock queues
4. Re-sequence vessels in extended lock queues
   - Using currently available information
   - Using additional information (e.g. vessel tracking)
5. Re-sequence vessels in multiple lock queues
   - Using currently available information
   - Using additional information (e.g. vessel tracking)
6. System-wide traffic management using vessel tracking

Limitations on Evaluating Traffic Management Alternatives

- We were severely constrained in our ability to complete a quantitative economic evaluation of the alternative traffic management measures.
- For example, a lock appointment system is expected to result in reduced fuel usage by tows relative to the existing lock operating policy. Consequently, to measure the economic benefits of reduced transportation costs afforded by reduced fuel usage we required information on fuel use by tows operating in this segment of the UMR.
- No tow company would share that information with us and a search of the literature revealed no published studies regarding fuel savings from better optimized sailing speeds on the UMR.

Limitations on Evaluating Traffic Management Alternatives

- Further, no tow companies publish detailed information regarding revenues from their operations on the UMR-IW and none of the tow operators we contacted would share that information with us.
- As the opportunity to generate additional revenues from the more efficiently utilized transportation assets is the primary source of economic benefits afforded by reduced waiting times at locks with better traffic management policies, we were unable to quantify with precision the economic benefits of the other alternative traffic management policies.

Data and Statistical Analysis

- The IWR supplied OMNI-LPMS data for all Upper Mississippi River and Illinois Waterway lockages for 2000 through 2003.
- We examined, edited and restructured the raw lockage data for our needs.
- We created vessel itineraries from the lockage data.
- We analyzed the lockage data and vessel itineraries in SAS to support the simulation model.

Observed Allocation of Available Tow Time Amongst Selected Activities in the UMR-IW Navigation System 2000-2003

Activity	Hours	Percent of Total Tow Hours on UMR-IW
Total Tow Time Spent Waiting for Lockage at Locks 20-25	164,257	0.7%
Total Tow Time Spent Locking at Locks 20-25	96,112	0.4%
Total Tow Time Spent in Lock 20-25 Segment Not Waiting or Locking	929,797	4.0%
Total Tow Time Spent Waiting for Lockage at UMR-IW Locks Other Than Locks 20-25	358,811	1.6%
Total Tow Time Spent Locking at UMR-IW Locks Other Than Locks 20-25	385,125	1.7%
Total Tow Time Spent in the UMR-IW Outside the Lock 20-25 Segment Not Waiting or Locking	21,853,840	91.6%
Total Time Spent Operating in the UMR-IW	23,044,006	100.0%

An Important Observation from the Data

- While there were periodic delays in locking vessels in this congested area of the river, the delays constituted a very small percentage (0.7%) of the total annual observed vessel operation time in the system.
- Limited potential of increasing the utilization of towboat and barge resources by:
  - using alternative sequencing rules
  - or increasing lock capacity at the five bottleneck locks
  - unless volumes of river traffic increase substantially above existing levels

Statistical Models To Support The Enhanced Simulation Models

- Logistic models for likelihoods of alternative dispositions of each vessel (transition probabilities) after completion of lockage
  - Give likelihoods of transition to alternative configurations and locations of next lockage
- Regression models for the time required to complete the lockage of a vessel
- Regression models for transit times (from the completion of the current lockage to arrival for next lockage) including stop times for vessels that stop en route from their current lockage to the location of their next lockage

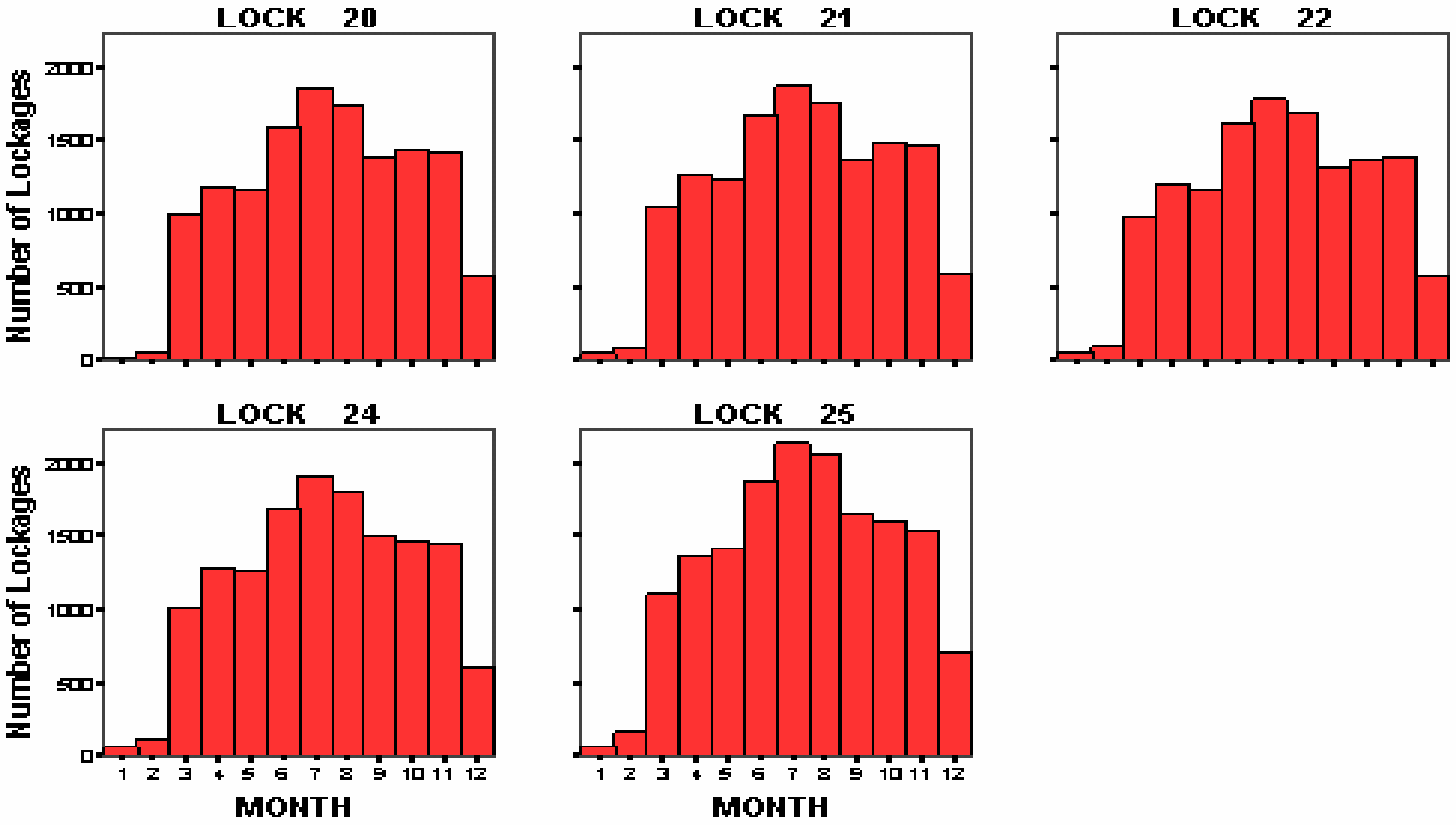
Observed Causes of Lock Queues

- Impaired operating conditions
  - Fog
  - High or low water
  - Fast currents
- Accidents
- Breakdown/malfunction of a lock
- Periods of relatively high demand

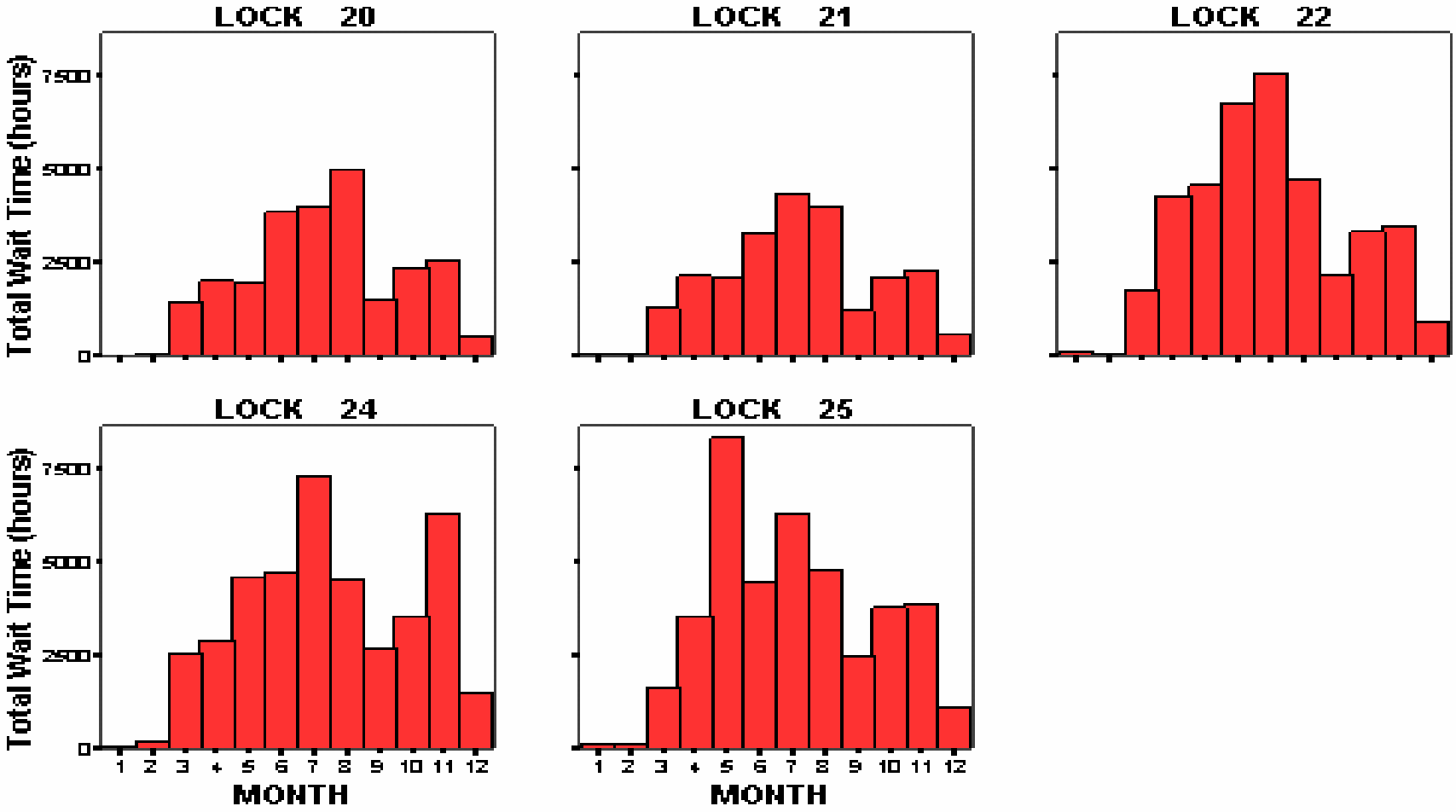
The Need for a Simulation Model

- Why is a system simulation model needed to evaluate alternative traffic management policies on the UMR?
- The UMR system never reaches a steady state.
  - Seasonality of traffic demands, vessel operations, and lock operations
  - Interdependence of individual vessel lockage times at UMR locks
- The scope of the management measures under evaluation and their potential systemic impacts.

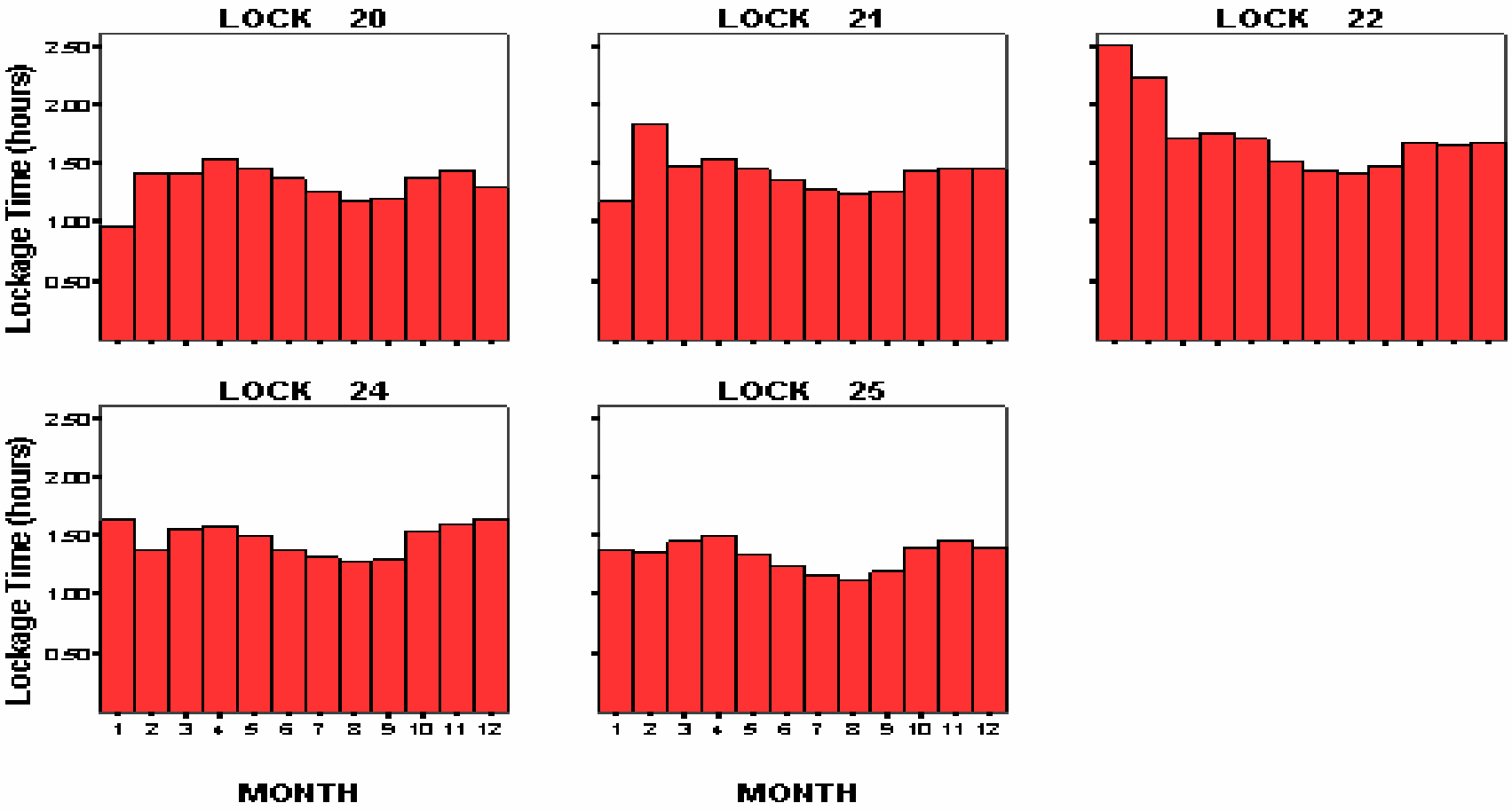
The Seasonality Of Lock Demand
Total Lockages by Month at UMR Locks 20-25, 2000-2003



The Seasonality of the Wait For Lockage Time UMR Locks 20-25, 2000-2003



The Seasonality of Vessel Lockage Times
UMR Locks 20-25, 2000-2003



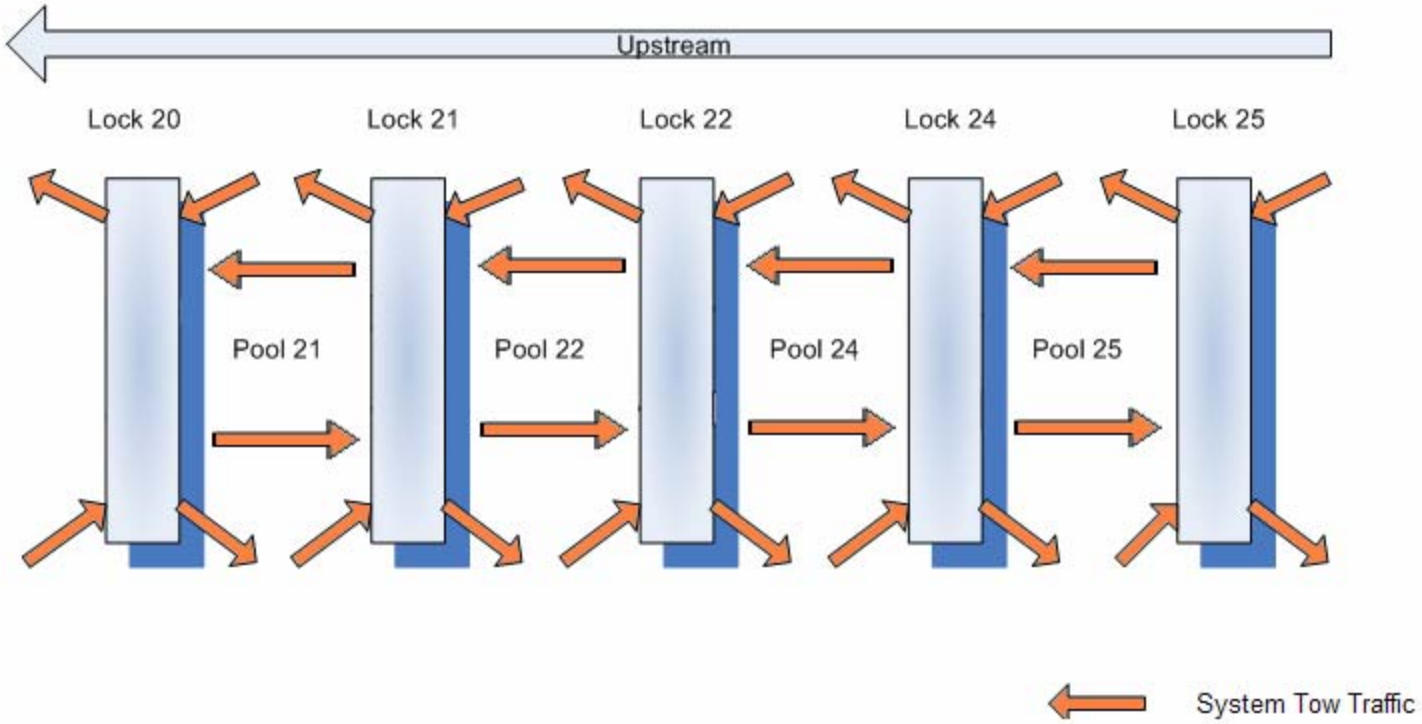
The Simulation Model

- A discrete event simulation model of the segment of the UMR composed on Locks 20 through 25 and connecting pools was constructed using Micro Analysis and Design's Micro Saint Sharp.
- Micro Saint Sharp is a widely used, commercially available software package designed to build discrete event simulation models.
- Any user with a Micro Saint Sharp license may run and alter the simulation model making the model transparent.
- The results may be analyzed in Micro Saint, commercial statistical packages, and spreadsheets.

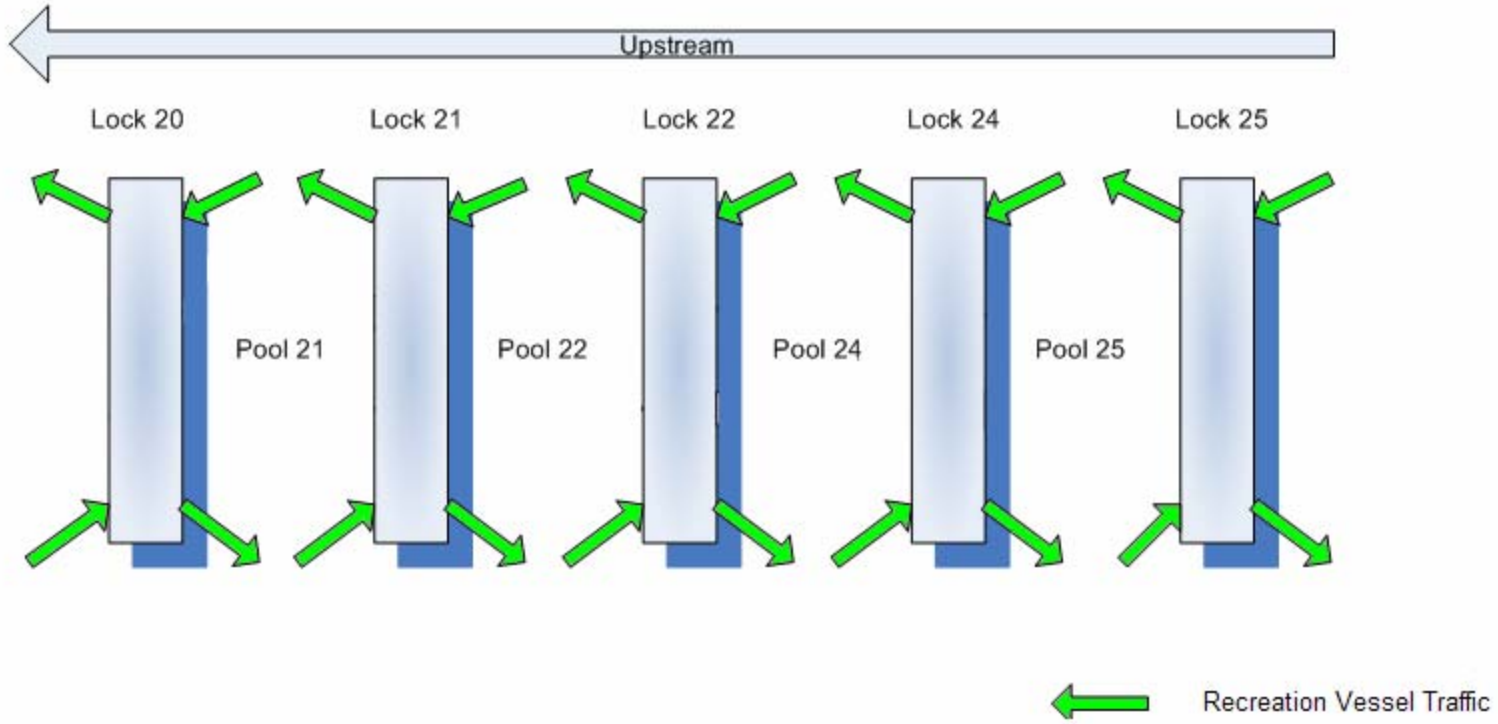
The Simulation Model

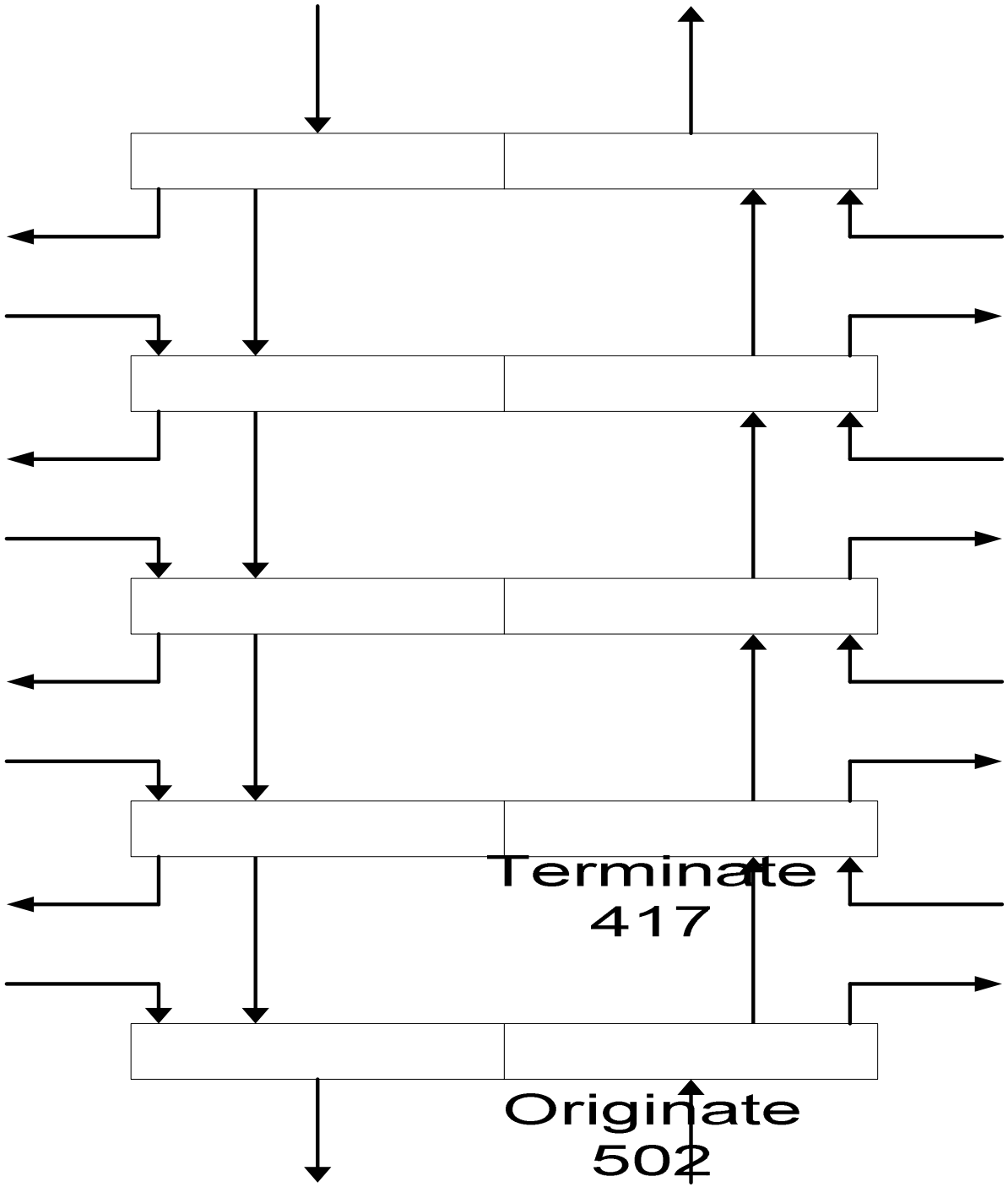
- Vessels (large tows, small tows, and recreation craft) enter the system at one of ten entry points following seasonally estimated, independent inter-arrival time distributions.
- Vessels complete an initial lockage after system entry and then make a seasonally adjusted decision to: (1) continue to the next lock in their direction of travel; (2) stop; or (3) re-configure their flotilla. If vessels stop or re-configure their flotilla, they are terminated after completing their lockage and then later regenerated and reconfigured in the pool in which they terminated.
- All recreation craft are terminated after a single lockage.

Simulation Model Schematic Diagram - Tow Traffic



Simulation Model Schematic Diagram - Recreation Vessel Traffic




Terminate
417
Originate
502

The Simulation Model

- Vessel lockage times depend on the vessel configuration, the direction of travel, the month of occurrence, and the state of the lock when the lockage occurs.
- Pool transit times depend on the vessel configuration, the direction of travel, and the month of occurrence.
- Periods of lock closure or impaired performance are modeled as independent occurrences with independent durations.

Two Important Lockage Types

- Single Lockage: A commercial tow lockage where the entire tow (towboat and barges) is processed through the lock in a single lock chamber operation without any reconfiguration of the tow.
- Double Lockage: A commercial tow lockage where the entire tow (towboat and barges) is processed through the lock in two successive lock chamber operations with the tow broken into two separate “cuts” during the lockages and then reconfigured into a single unit at the conclusion of the lockage of the second cut.

Three Lock Operation Types

- Fly Lockage: A lockage operation in which the lock is unoccupied when the vessel arrives at the lock and the vessel is the next vessel processed at the lock.
- Turnback Lockage: A lockage operation in which the lock is occupied when the vessel arrives at the lock, the arriving vessel must then wait for service in the lock queue, and when the vessel finally begins its lockage, the immediate prior vessel completing lockage is traveling in the same direction as the vessel beginning its lockage.
- Exchange Lockage: A lockage operation in which the lock is occupied when the vessel arrives at the lock, the arriving vessel must then wait for service in the lock queue, and when the vessel finally begins its lockage, the immediate prior vessel completing lockage is traveling in the opposite direction as the vessel beginning lockage.

Example Lockage Time Distribution Statistics

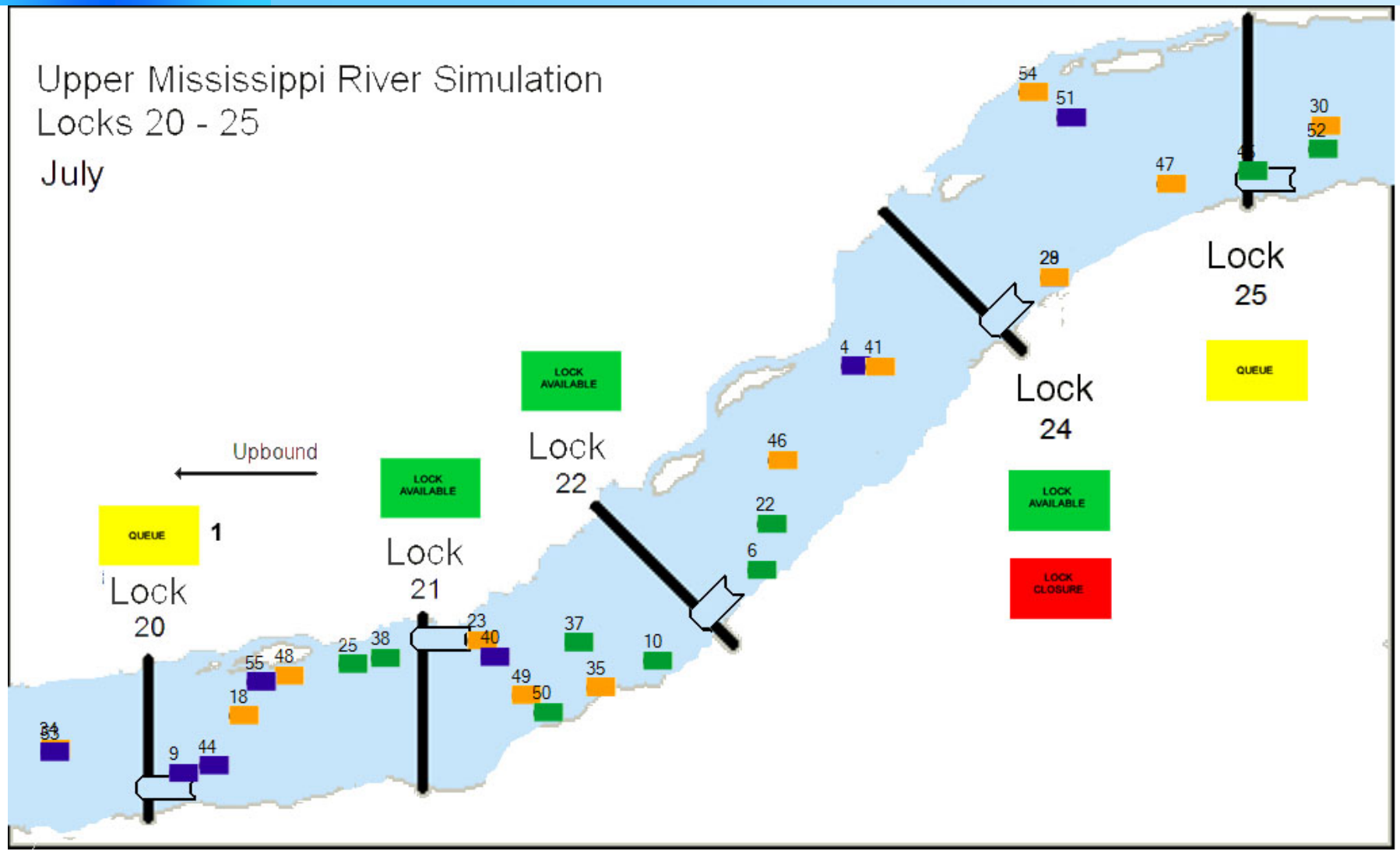
Lock	Lockage Type	Operations Type	Mean Lock Time (hours)	Number	Std Dev (hours)
20 Dn	Double	EXCHANGE	1.89	1691	0.76
		FLY	2.00	1207	0.57
		TURNBACK	1.82	1460	0.45
	Single	EXCHANGE	0.46	414	0.29
		FLY	0.50	496	0.54
		TURNBACK	0.40	403	0.17

Lock	Lockage Type	Operations Type	Mean Lock Time (hours)	Number	Std Dev (hours)
20 Up	Double	EXCHANGE	1.93	1594	0.41
		FLY	1.91	1109	0.59
		TURNBACK	1.60	1459	0.45
	Single	EXCHANGE	0.48	570	0.50
		FLY	0.51	601	0.54
		TURNBACK	0.38	383	0.15

The Simulation Model

- Alternative traffic management policies were formulated as integer programming optimizations and incorporated into selectable lock queue dispatch policies.
- Monthly and annual measures of system output and performance such as the categorized tow-miles produced, categorized utilized tow hours, categorized lockage times and utilizations, categorized lock delay times, and categorized pool transit times were recorded for the alternative traffic management policies.

Simulation Model Screen Capture



Comparison of 100 Runs of the Simulation Model with the 2000-2003 Omni Data – Existing Traffic Management Policy

Results of 100 Annual Simulations Compared with 2000 - 2003 OMNI Data

	Lock 20	Lock 21	Lock 22	Lock 24	Lock 25	Totals	Per-cent
Observed Lockages per Year	3,341	3,461	3,295	3,537	3,911	17,545	
Mean Simulated Lockages per Year	3,313	3,452	3,277	3,471	3,902	17,415	99.3%
Observed Wait Time per Year (hours)	6,250	5,786	9,864	10,150	10,067	42,117	
Mean Simulated Wait Time (hours)	5,763	5,462	9,004	10,185	10,528	40,942	97.2%
Observed Lock Usage per Year (hours)	4,620	4,868	5,367	5,262	5,273	25,390	
Mean Simulated Lock Usage (hours)	4,477	4,748	5,264	5,134	5,181	24,804	97.7%

Results of 100 Simulations with Existing Traffic Management

	N	Minimum (hours)	Maximum (hours)	Mean (hours)	Std. Deviation (hours)
Wait Time - All Vessels All Locks	100	32,531.47	55,099.77	40,942.23	4,682.06
Total Tow Time	100	171,696.58	199,140.45	182,834.99	5,657.53
Tow Time - Large Tows	100	109,396.61	132,129.86	118,937.60	4,861.36
Tow Time - Small Tows	100	60,031.55	67,468.85	63,897.39	1,581.48
Tow Wait Lock 20	100	4,178.51	8,149.14	5,508.74	749.87
Tow Wait Lock 21	100	3,822.53	7,014.62	5,150.77	634.79
Tow Wait Lock 22	100	5,801.72	11,920.32	8,662.97	1,408.49
Tow Wait Lock 24	100	6,170.31	19,965.69	9,787.61	2,221.42
Tow Wait Lock 25	100	6,664.81	13,924.74	9,965.10	1,566.70

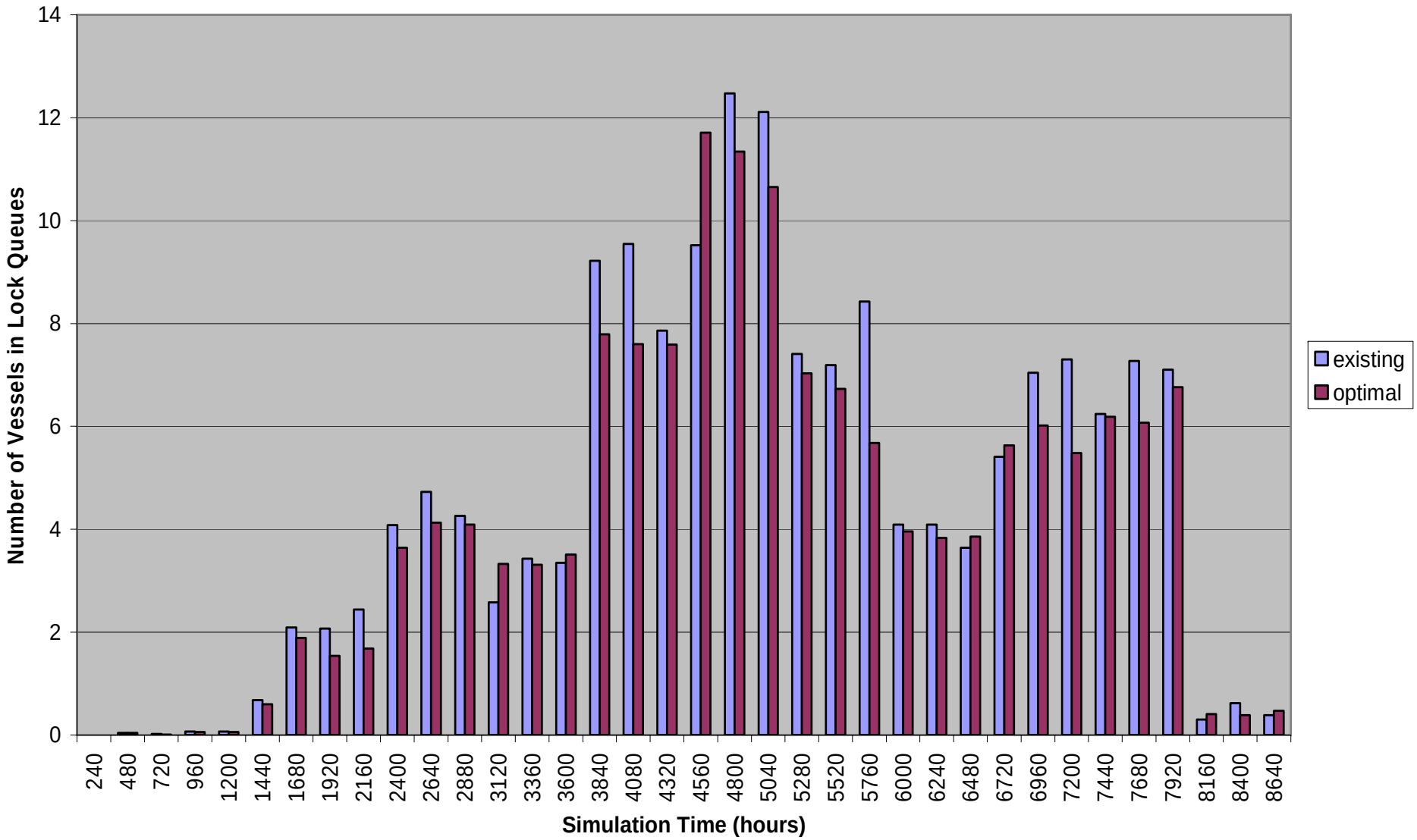
Results of 100 Simulations with a Locally Optimal Queue Re-Sequencing Policy (Fastest Expected Tow First)

	N	Minimum (hours)	Maximum (hours)	Mean (hours)	Std. Deviation (hours)
Wait Time - All Vessels All Locks	100	31,062.22	53,470.08	36,634.54	3,783.58
Total Tow Time	100	170,606.51	196,562.82	178,466.11	4,422.38
Tow Time - Large Tows	100	111,702.22	139,504.35	121,592.09	4,626.93
Tow Time - Small Tows	100	52,803.52	59,410.97	56,874.02	1,025.80
Tow Wait Lock 20	100	3,815.54	8,211.37	5,230.26	825.97
Tow Wait Lock 21	100	3,659.05	6,232.74	4,758.34	461.81
Tow Wait Lock 22	100	5,766.83	12,605.38	7,991.90	1,246.89
Tow Wait Lock 24	100	6,009.74	13,661.27	8,746.56	1,527.49
Tow Wait Lock 25	100	6,250.73	11,928.92	8,037.93	1,079.87

Changes Resulting from a Locally Optimal Queue Re-Sequencing Policy (Fastest First)

	N	Minimum (hours)	Maximum (hours)	Mean (hours)	Std. Deviation (hours)
Wait Time - All Vessels All Locks	100	-1,469.25	-1,629.69	-4,307.69	-898.48
Total Tow Time	100	-1,090.07	-2,577.63	-4,368.88	-1,235.15
Tow Time - Large Tows	100	2,305.61	7,374.49	2,654.49	-234.43
Tow Time - Small Tows	100	-7,228.03	-8,057.88	-7,023.37	-555.68
Tow Wait Lock 20	100	-362.97	62.23	-278.48	76.10
Tow Wait Lock 21	100	-163.48	-781.88	-392.43	-172.98
Tow Wait Lock 22	100	-34.89	685.06	-671.07	-161.60
Tow Wait Lock 24	100	-160.57	-6,304.42	-1,041.05	-693.93
Tow Wait Lock 25	100	-414.08	-1,995.82	-1,927.17	-486.83

Comparison of a Resequencing and the Existing Lock Queue Policy
Mean Total Number of Vessels in Lock Queues
Locks 20-25



Vessel Re-Sequencing Discussion

- Mean average annual reduction of approximately 4,369 total tow hours required to complete the same set of vessel itineraries. (The average annual value of the increased production is approximately $750,000 at 2002 price levels which represents an approximate 0.1% increase in the average annual value of output of tows operating on the UMR-IW.)
- This reduction represents approximately a 2.4% decrease in equipment time needed to complete the same set of movements through these five locks.
- Some vessel types “win” and other vessel types “lose”.
- The variability of system performance is also reduced.

Qualitative Economic Evaluation of Alternatives at Current Traffic Levels

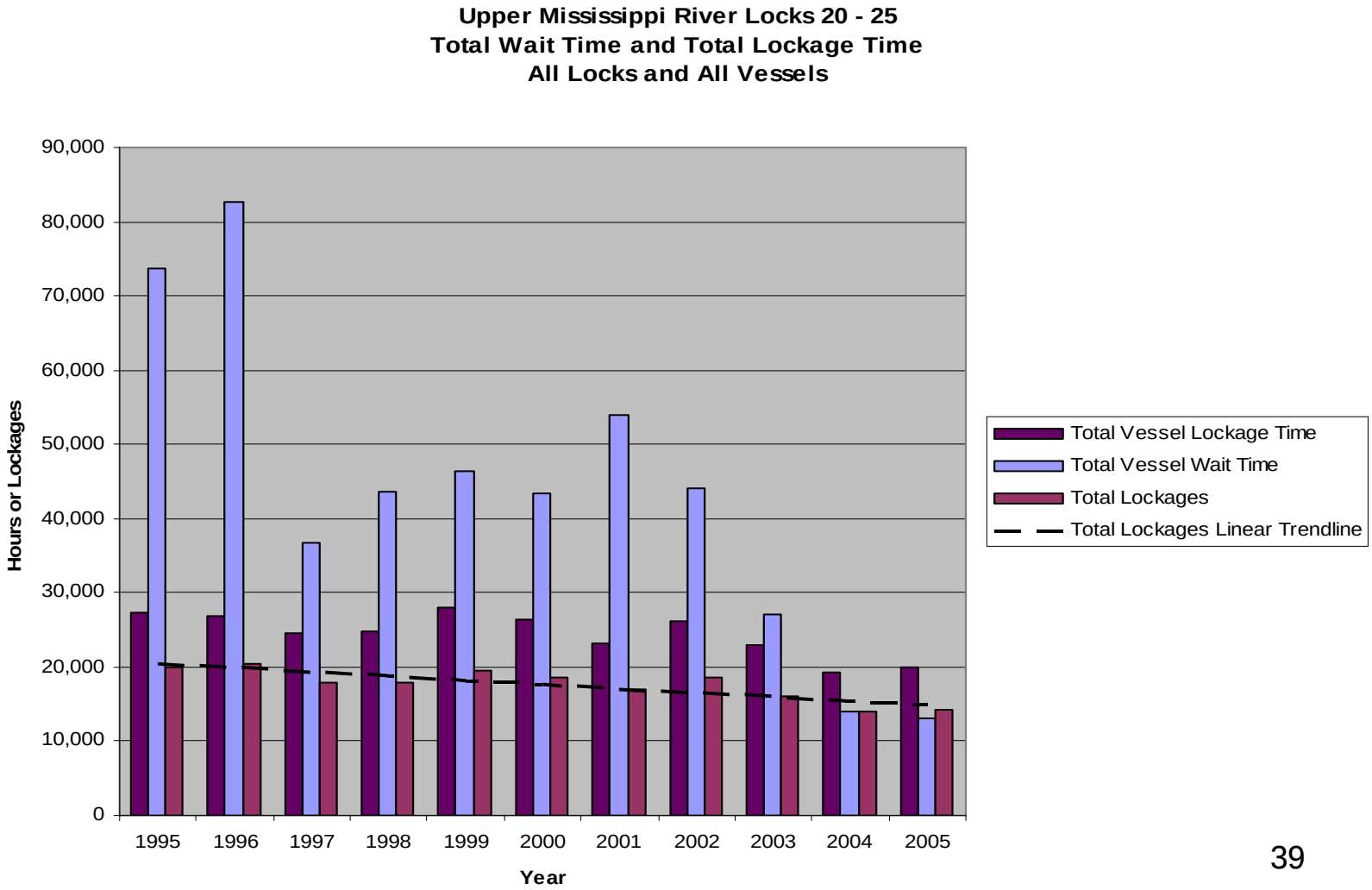
Alternative	Benefits	Costs
1. Existing conditions: first come, first served with exceptions.	none	none
2. Schedule appointments at locks:		
▪ Using existing available information.	very small	very small
▪ Using real time vessel tracking.	very small	small +
3. Re-sequence vessels in local lock queues.	small	very small
4. Re-sequence vessels in extended lock queues:		
▪ Using existing available information.	small	very small
▪ Using real time vessel tracking.	small	small +
5. Re-sequence vessels in multiple lock queues:		
▪ Using existing available information.	small	small
▪ Using real time vessel tracking.	small	small ++
6. System-wide traffic management using real time vessel tracking.	small	very large

Findings

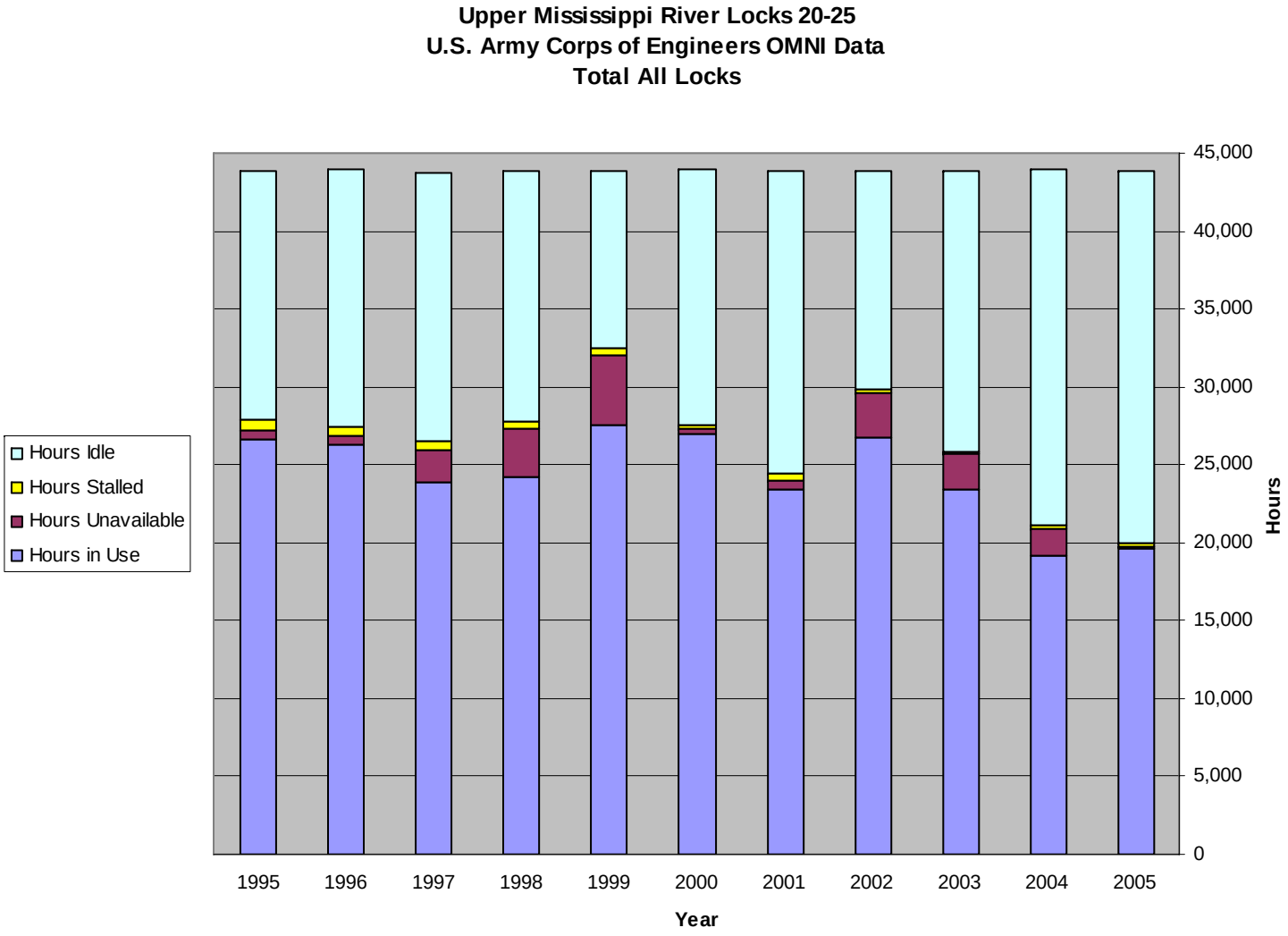
- Economic benefits of new traffic management policies are likely to be small at current traffic levels.
- The economic benefits accrue differentially across system users with some users disadvantaged.
- The costs range from very small for implementing management policies using existing data to very large for policies utilizing sophisticated real-time vessel tracking.
- Disruption of existing markets ranges from small to large.

Summary of Annual Data 1995-2005

UMR Locks 20-25



Summary of Data 1995-2005
The Temporal Distribution of Activities
UMR Locks 20-25



American Commercial Lines Inc.

- "We believe that existing capacity will continue to be retired from the barging sector. According to Informa, from 1998 to 2004, the industry fleet size was reduced by 2,036 barges, or an 8.8% reduction, to its 2004 year end level of 21,056. This level represents the lowest number of barges in operation within our industry since 1992."
  - SEC Form 10-Q, American Commercial Lines Inc., November 10, 2005, page 26.

Recommendation

- At current or foreseeable traffic levels, new traffic management policies such as appointment and scheduling systems are not recommended because of the small economic benefits they would create relative to the potential disruptions they would create in existing markets.