Paper 123 - Navigable Inland Waterway Transportation Modeling: A Conceptual Framework and Modeling Approach for Consideration of Climate Change Induced Extreme Weather Events

NELSON, K.; CAMP, J.; PHILIP, C.

Vanderbilt University (Department of Civil & Environmental Engineering), Nashville, Tennessee, USA

Email (1st author): katherine.s.nelson@vanderbilt.edu

ABSTRACT: Transportation modeling of navigable inland waterways that examines the economic implications of waterway operational efficiencies on commercial shipping has been studied in detail for several decades. However, with the effects of climate change on extreme weather now gaining more attention, waterway managers are coming to realize that what used to be rare events may occur with increasing regularity, and that these events may begin to impose an increasing burden on commercial shippers and in some cases on entire supply chains, and subsequently society as a whole. In this paper, we describe a new conceptual framework and modeling approach for transportation modeling of navigable inland waterways based on an understanding of the competing demands for waterway services and the predicted increases in extreme weather events.

1 INTRODUCTION

Inland waterway navigation in the U.S. has historically played a major part in the U.S. economy by facilitating shipping of goods and continues to do so today with an estimated economic value of $214 billion in 2012 (Grossardt, Bray, and Burton, 2014). Therefore, it is of little surprise that maintenance of navigable channels and navigation locks is one of the primary missions of the U.S. Army Corps of Engineers (U.S. Army Corps of Engineers, 2009). Inland waterway projects also provide further value through production of hydropower, supplying drinking water for public and commercial uses, flood risk management, maintaining healthy aquatic environments, and providing recreational opportunities to the public. Management of these multiple priorities can be difficult in the best of cases and added stressors such as extreme weather events can make balancing these priorities even more difficult (VV, 2009).

Extreme weather events have caused billions of dollars in direct and indirect damages to the waterway system over the last decade and can lead to long delays in shipping which in turn lead to increased shipping costs which are passed down to consumers (Bloudoff-Indelicato, 2012; Kreis, et. al., 2014). As climate change science continues to indicate that the frequency and severity of extreme weather events is likely to increase, the ability of stakeholders to efficiently manage navigable inland waterways and prepare for and respond to extreme weather events gains increasing importance (IPCC, 2014; VV, 2009; Committee on Adaptation to a Changing Climate, 2015). How these events are handled is likely to have a significant effect on not just commercial waterway activity, but entire supply chains, with implications for social welfare.

2 INLAND WATERWAY TRANSPORTATION MODELS

A good deal of attention has been paid to optimization of tow travel on inland waterway navigation systems. Models that simulate lock improvements, lock congestion, lock queuing procedures, barge-tow configurations, waterway reliability, and tow speed adjustments have all been conducted using various statistical and discrete event simulation techniques (Carroll & Bronzini, 1973; Smith, Sweeney & Campbell, 2007; Smith, Sweeney & Campbell, 2009; Dai and Schonfeld, 1993). While statistical models generally involve developing mathematical relationships between factors affecting the waterway system using aggregate data or theoretical probability distributions and are applicable to the macro-scale waterway system, discrete event simulation techniques model microscopic level detailed system operations as sequences of select events in time which alter the state of the system (Kreis, et. al., 2014; Smith, Sweeney & Campbell, 2009).

One of the earliest detailed waterway transportation simulation models was developed by Carroll and Bronzini in 1973. This simulation consisted of two parts: the first (Towgen) stochastically defines the commodity shipping demand for origin-destination pairs by sampling historical data and generates estimated tow departure times at various locks in a straight-line, multi-lock system by assuming a Poisson distribution; the second (WatSim) processes the outputs of Towgen to generate a list of transactions and travel schedules which can be used to estimate transit and delay times. This model essentially simulates discrete events, such as a tow leaving a lock or a tow arriving at a lock, by sampling from theoretical probability distributions. The objective of this model was to provide a better understanding of operating characteristics of inland waterway navigation systems in order to assess the economic efficiency of improvements to the system (Carroll and Bronzini, 1973).

Building on this work, Dai and Schonfeld (1991) developed a microscopic event-scanning simulation model that explicitly considers variations in lock service times to account for the occurrence of lock stalls, a factor not included in the Towgen-Watsim model, and stochastically generated tow trips based on historical data instead of relying on an assumed probability distribution. Again, this model simulates discrete events including tow departures, tow arrivals and lock stalls, by sampling from distributions based on observed data. The objective of the model was to simulate barge traffic in order to analyze economic effects of waterway congestion and service reliability (e.g., lock stalls) in the context of possible waterway infrastructure improvements (Dai and Schonfeld, 1991).

Additional models as compiled in a 1993 *USACE Compendium on Waterway Transportation Reliability: Lock Congestion and Lock Queues* include probability models of lockage stalls (Kelejian, 1991), event-scanning models of lock interdependence (Chien & Schonfeld, 1992) and tow speed optimization (Dai, Schonfeld, and Antle, 1993), and algorithms and metamodels for optimization of project improvement scheduling, lock delays, and lock service interruptions. These studies were generally focused on consumer demand induced commercial traffic on the waterway system as it relates to lock reliability, economic effects on commercial shipping, and economic efficiency of improvements to the waterway system. The models described do not explicitly consider waterway conditions or other uses of the waterway system (except to acknowledge the presence of recreational vessels in some cases) in their analyses and simulations (Dai and Schonfeld, 1993). Nor do they consider interactions which may occur between the simulated discrete events or the autonomous decision-making behavior of waterway stakeholders.

More recently, researchers at the University of Missouri St. Louis developed discrete event simulations that can be used to evaluate the relative benefits of different navigation system improvements and policies including: various lock queuing procedures, helper boat requirements, and construction of new locks (Campbell Smith & Sweeney, 2009). Like the models described above, the primary factor in these models is waterway traffic, which is generated from observed probability distributions of traffic by month to account for seasonality. The tow arrival events produced are additionally modified to account for traffic differences by day of the week and the time of day. The model described by Smith, Sweeney, and Campbell (2009) considers the implementation of various lock queueing policies based on type of vessel (commercial or recreational) and by tow configuration (single tow, double tow, etc.). The tow configuration type is also based on probability distributions by time of day and effects the number of lockages required. In this model, decisions on what vessel or tow the lock will service first is dependent on the lock queue policy in place [e.g., First-In-First-Out (FIFO)], the lock position, and the properties and arrival times of the queued vessels/tows. While this model effectively considers the effects of waterway policies by including some complex decision-making processes in the model, and accounts for more temporal changes in traffic distributions, it does not account for decisions made based on waterway conditions, interactions that occur between the discrete events considered, and the effects of uses of the waterway system other than commercial shipping and recreational vessel movement. These missing elements may become increasingly important as climate change effects on extreme weather become more apparent.

In a 2014 report, researchers from the University of Kentucky described a predictive Inland Waterways Operational Model (IWOM) for the Ohio River that they developed using statistical analysis. They conducted linear regression analyses of historical data of variables including: river conditions, lock characteristics, and vessel characteristics in order to determine which factors significantly affect lockage times. Their final model accounted for more than two-thirds of the variance in observed lockage times for a ten year period. The relationships in the model were then used in a simulation of the system that visualizes vessel movement on a river segment in a geographical format (Kreis, et. al., 2014). While this study does explicitly consider waterway conditions that may be susceptible to climate change, its heavy use of statistical regression limits the ability of the model (and simulation) to account for complex interactions that occur due to continuous and autonomous decision-making. Additionally, reliance on historical data and statistical methods means that significant variables like river stage, which are key for decision-making in extreme weather events but for which long and accurate records may not be available, are not included in final models of the system (Kreis, et. al., 2014).

While validation of the models described above generally indicates that they do a good job of representing aggregate properties of the system they often fail to explicitly consider the effects of waterway operating conditions and decision-making in extreme weather scenarios. They also simplify tow interactions between locks such that tow-tow and tow-infrastructure interactions on waterway segments between locks and dams are only considered as stochastic elements in probability distributions of travel times, and they fail to consider interactions between navigation and other waterway uses. These complex inter-stakeholder and stakeholder-environmental interactions are expected to display greater importance in extreme weather situations and are therefore are an important element in the evaluation of climate change induced effects on the inland navigable waterway system.

The use of statistical and discrete event modeling and simulation techniques simplify the problem by removing complexity from the system (by aggregating data or reducing interactions to a set of defined key events). These simplifications reduce the computational requirements of the models and simulations and can be simpler for waterway stakeholders to utilize than more complex models. However, these approaches neglect to consider actions and interactions that can occur continuously and that may contribute to system dynamics, particularly those that relate to decisions made by waterway stakeholders during infrequently observed scenarios such as extreme weather events. As inland waterways are complex systems involving many continuous interactions between different autonomous stakeholders with different priorities (sometimes involving negotiation between parties) and reactions to environmental and infrastructural characteristics, a decision-making based model may help illuminate some of the complexities not captured by statistical models and discrete-event simulations.

3 CONCEPTUAL FRAMEWORK

3.1 *Problem Statement*

In this work, we assume that system level dynamics can, and do, arise out of the myriad complex actions and interactions of individuals and groups in response to each other and their environment. This phenomena of system level patterns coming from the-bottom-up is generally known as “emergence” (Nikolic & Ghorbani, 2011). Using this approach continuous decision-making processes become important, as are other priorities of waterway stakeholders, as these are expected to affect their behavior, particularly in the context of extreme weather events which challenge waterway operators to break out of habitual decision-making patterns and adapt to unusual conditions.

Recognizing that changing behavioral patterns during infrequent extreme weather events is difficult and that delays in adapting to extreme situations typically lead to undesirable results, the Towing industry, U.S. Army Corps of Engineers (USACE), and U.S. Coast Guard (CG) developed sets of guidelines for the navigable inland waterways (U.S. Coast Guard Sector Ohio Valley, 2014). Called Waterways Action Plans (WAPs) these guidelines contain information such as recommended actions (for various river stage or flow trigger points) to assist waterway operators, including tow operators, lock masters, and CG officers, in their decision-making during extreme weather events such as flooding, high flow conditions, ice jams, and drought (U.S. Coast Guard Sector Ohio Valley, 2014). The trigger points in these WAPs do not exist in isolation, but are dependent not only on weather conditions but also on dam operations on the waterway system. USACE dam projects are typically operated in accordance with Water Control Manuals that provide stage, flow, and storage trigger points that address the ability of the projects to meet the demands of several competing water uses including: hydropower production, flood prevention, water supply, navigation, and environmental water quality (Sverdrup Corporation, 1990).

The WAPs are expected to be utilized with greater frequency given the increased frequency and severity of extreme weather events expected to due to climate change. The creation and implementation of the WAPs was a positive step towards addressing waterway management in extreme weather scenarios, however, due to the infrequent nature of the extreme weather events which activate WAP rules and recommendations the value of the WAPs is difficult to assess through observation of the actual waterway system. Additionally, the flexibility contained within the WAPS, which allows for stakeholders to negotiate, utilize their independent decision-making skills and experiential knowledge, and adapt to unforeseen scenarios, limits the ability of many modeling techniques to test the WAPs in virtual environments. In order to understand how the WAPs effect waterway operation in the context of a changing climate and increasing extreme weather events a clear understanding of the decision-making behaviors of various waterway stakeholders under extreme weather conditions is needed. Understanding how decisions are made during extreme weather events from within a WAP framework, what those decisions are, and the consequences of said behaviors, provides a first step toward identifying efficiencies and inefficiencies in waterway operations that may become increasingly important in a changing climate.

3.2 Working Hypothesis

We posit that navigable inland waterway management decisions made in the context of extreme weather events have a significant effect on waterway operational efficiencies and outcomes. The actions and interactions of many individual stakeholders resulting from these continuous decision-making processes are expected to result in emergent system level properties that cannot be fully explained by system-scale models based on aggregated data or by micro-scale models of discrete events. We suggest that these management decisions may be modeled for individual agents (stakeholders) working within the physical system and influenced by boundary conditions and recommended actions in operational guidance documents that relate to extreme weather induced river conditions (e.g., Waterways Action Plans, Water Control Manuals), and that when these modeled individuals are allowed to interact with each other within an “inland waterway-like” virtual environment a realistic approximation of the system response to extreme weather scenarios can be simulated.

3.3 Objective

Our objective is to create a navigable inland waterway simulation that accounts for continuous decision-making processes for individuals and groups managing the waterways and operating on the waterways. The model should serve as a thought-support tool that allows stakeholders to think through situations for which hands-on experience is not an option (e.g., extreme flooding events) via a participatory interface, a tool to support discussions between various stakeholders, and a way for both participants (stakeholders) and observers (researchers) to learn about the waterway system (Barreteau, 2003). In order to meet our objectives, the model should take into account different agent interactions with the environment, agent interactions with other agents of the same type, and interactions between agents of different types, and should be capable of continuous modeling of the entire system at time intervals capable of capturing agents' ability to anticipate and react to situations (see Figure 1) (El hadouaj, Drogoul, and Espié, 2001). As one of the goals of the model is to serve as tool for modeling stakeholder reactions to unusual scenarios, the model should be capable of visualizing, in a simplified form, tow movements on a waterway segment and river conditions, in order to facilitate participatory interactions with actual waterway stakeholders.

4 METHODOLOGICAL APPROACH

In order to meet our objectives, a modeling approach that is different from those described above, is necessary. Agent based modeling is a form of modeling that utilizes a micro-scale decision making approach. In agent based models the stakeholders, or agents, are modeled as individuals that follow specified behavioral patterns of action and interaction. Multiple agents are placed within the modeling system and the interaction of these agents with the model environment and with each other over time creates emergent system patterns (Nikolic & Ghorbani, 2011). This approach uses a micro-scale model of the most basic building blocks of the system model, agents, which are characterized by their reactions to environmental stimuli and interactions with other agents (Nikolic & Ghorbani, 2011). An assumed behavioral model for each agent type is created and agents are then allowed to interact with each other and their environment to form system patterns. Agent based modeling reduces complexity by eliminating the need to have a complete understanding of all the system level interactions, feedback loops, lags, and other relationships between system variables that are present in complex human-natural systems (An, 2012; Nikolic & Ghorbani, 2011). The complexity of the system model then depends upon the degree of complexity programmed into agents' behavioral models. One advantage of this approach is that it is possible to then understand the relative

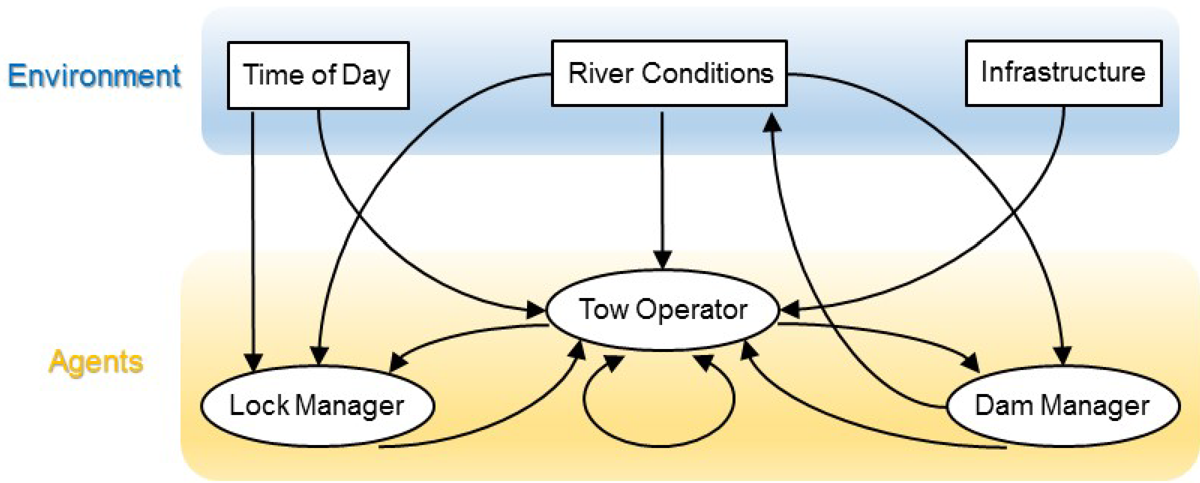

Figure 1: Agent and environmental variable interaction diagram (simplified).

importance in certain types of behaviors or decisions by simply turning off those relationships in the agent model (Nikolic & Ghorbani, 2011).

This modeling approach is also useful for conducting participatory simulations in which actual stakeholders (or general members of the public) can interact with the model via a graphical user interface that allows for behaviors (that would typically be hard programmed in the model) to be modified by the participant to reflect their individual perspective (Guyot & Honiden, 2006).

5 MODEL DEVELOPMENT

To test our working hypothesis, we are developing a multi-agent based model using boundary conditions and basic actions in the WAP and Water Control Manuals for the Cumberland River System as a starting point. The Cumberland River is a major tributary of the Ohio River located in the Southern United States (see Figure 2). The river has over 300 miles of navigable waterway and 4 navigation locks which are operated by the USACE (Sverdrup Corporation, 1990). Over 20 million tons of commodities were shipped on the Cumberland River in 2004, with the top commodities being coal and crude materials such as sand and gravel (Hanson Professional Services, 2007). The Cumberland River basin, which includes the Cumberland River and several tributaries, is also home to nine hydropower plants as well as several flood control projects (Nashville District, 2015; Sverdrup Corporation, 1990).

The region does not experience many ice jams, but has experienced both extreme high water and extreme low water events in the past 10 years. The Cumberland River system provides an ideal case study due to the relative simplicity of the layout of the main stem and the availability of extreme high water and extreme low water scenario data. Additionally, the system includes other major waterway uses such as hydropower and flood control that interact with navigation priorities (Sverdrup Corporation, 1990).

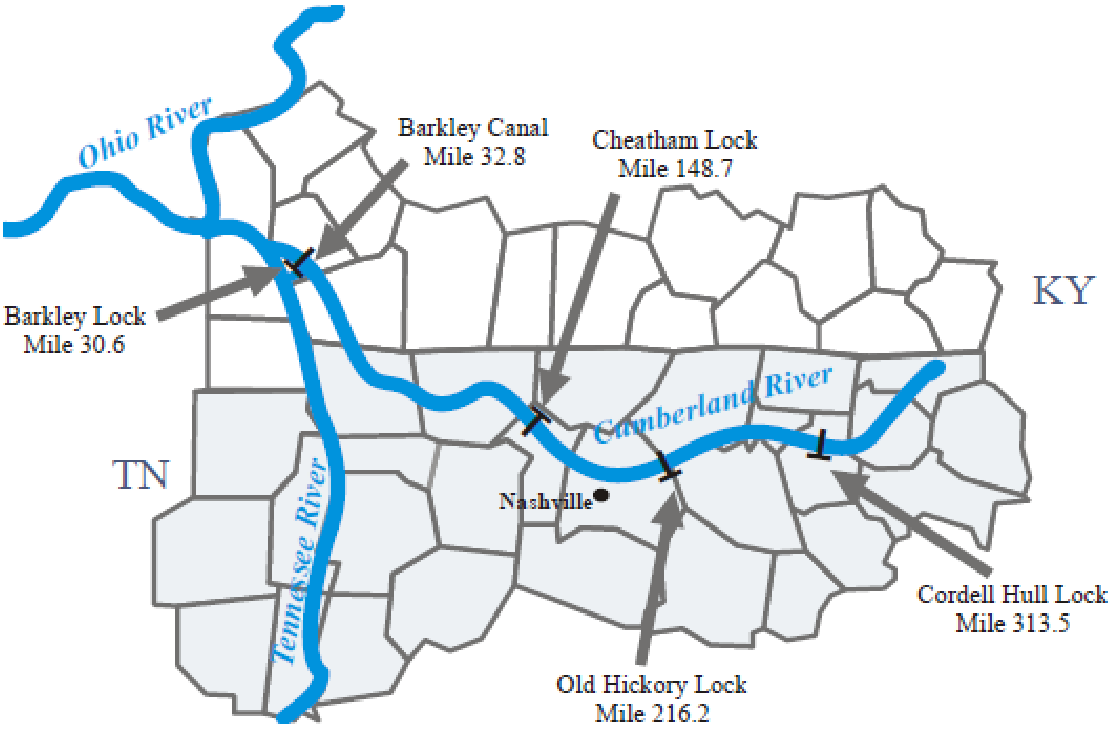

Figure 2: Schematic of the Cumberland River system (Exhibit 2-1 from the 2007 Tennessee Waterway Assessment Study prepared for the Nashville District of the U.S. Army Corps of Engineers and the Tennessee Department of Transportation by Hanson Professional Services, Inc.).

By using a case study river system and framing our model around the WAP for the system we can test the effects of the WAP by comparing simulated behavior to observed behaviors. A positive control of complete conformity to WAP recommendations can be tested by creating a set of hard rules that will be followed using the basic actions and boundary conditions in the WAP. A negative control (i.e. absence of extreme weather specific decision making) can be implemented by removing all boundary conditions and basic actions from the WAP and leave only basic physical operation parameters. These control scenarios can be tested against observed reality and against a range of operational parameter (tow speed, vessel passing allowances, etc.) configurations (see Table 1 for more details on possible behaviors).

To achieve more realism in the model, we will use participatory simulation methods to create experimentally derived decision-making models for individual agents working within the physical system under the influence of the WAPs (as guidance instead of hard rules). This will be accomplished by creating a control interface for variables subject to change under the basic actions in the WAP and the Water Control Manuals that can be manipulated by participants, and conducting a participatory simulation with representatives of the various system agents. Records of participant decisions can be used to create models of agent decision-making behavior that can be used to modify the basic actions taken in the WAPs at boundary conditions.

Table 1: Descriptions of system agents, inter-agent and agent-environment interactions, and possible actions.

Agent	React to/ Interacts with	Possible Actions (intended and unintended)
Tow Operators: Responsible for moving barge freight on the waterway, traverse the waterway segments, make navigation decisions (some individually and some through negotiation) regarding physical movements of the tows	Time of Day + Other Tows + Infrastructure + (stationary, but not necessarily permanent, Bridges, Locks & Dams, and restricted traffic zones) River Conditions + (physical constraints such as width, depth and length and weather related flow, stage, and dissolved oxygen levels)	Adjust Speed Up or Down * Stop/Wait * Pass * Casualty
Lock Manager: Responsible for operating the lock for passage of vessels from one waterway segment to the next, stationary, make decisions (individual and sometimes negotiated) on lockage availability and requirements	Time of Day + River Conditions + Tows	Lock Closure * Restrict Lockage * Set Lockage Time
Dam Manager: Responsible for maintaining flows and project water levels, stationary, make decisions (mostly individual and rarely negotiated) on dam flow releases	River Conditions - Tows	Adjust Outflow * Alter Project Stage

+ Action levels associated with these are defined in the Waterways Action Plans
- Action levels associated with this are defined in the Water Control Manuals
* These actions can be manipulated in the participatory simulation

This approach will allow us to simulate activity on the waterway system for extreme weather scenarios and estimate the extent to which extreme weather events hamper activity on the waterway system, the extent to which the WAPs address and minimize the effects of extreme weather on waterway operation, and the extent to which individual agent decisions during extreme weather events influence the efficiency and inefficiency of waterway operations.

6 CONCLUSION

While much work has been conducted on understanding navigable inland waterway dynamics and produced valuable models and simulations, very little is known about how increased frequency and severity of extreme weather events may affect the efficiency of inland waterway operations. The complex dynamics of multiple stakeholder decision-making and negotiation during extreme weather events and the infrequent nature of extreme weather events mean that any understanding of these scenarios using more standard statistical and discrete event models is likely to be heavily limited. By using a different methodological approach, agent-based modeling, to represent decision-making behaviors of individuals and framing our navigable inland waterway model using Waterways Action Plans and Water Control Manuals an explicitly extreme weather-centric, multi-use waterway approach becomes possible.

The model under development will not only serve as a tool for assessing the utility of WAPs, identifying inefficiencies in waterway operations, and supporting thought-experiments for extreme weather scenarios, but may also allow for assessment of commercial shipping related economic impacts of extreme weather scenarios. If one imagines the waterway system as one piece of a broader, multi-modal, economic system the results of this model can serve as a starting point for estimating supply chain impacts of extreme weather scenarios that affect waterway navigation.

REFERENCES

An, Li 2012. Modeling human decisions in coupled human and natural systems: Review of agent-based models, *Ecological Modelling*, 229, 25–36

Barreteau, O. 2003. The joint use of role-playing games and models regarding negotiation processes: characterization of associations. *Journal of Artificial Societies and Social Simulation*, vol. 6, no. 2

Bloudoff-Indelicato, M. 2012, July 27. TRANSPORTATION: Drought hurts shipping industry, raises prices, *Environment & Energy Publishing*, Retrieved July 14, 2015, from http://www.eenews.net/stories/1059967948

Campbell, J. F., Smith, L. D., & Sweeney, D. C. 2009. A Robust Strategy for Managing Congestion at Locks on the Upper Mississippi River, *Proceedings of the 42nd Hawaii International Conference on System Sciences 2009*, pp. 1–10

Carroll, J. L., & Bronzini, M. S. 1973. Waterway transportation simulation models: Development and application, *Water Resources Research*, 9(1), 51-63

Chien, S. I., & Schonfeld, P. M. 1992. Effects of Lock Interdependence on Tow Delays, *AD-A271 647*, 21

Committee on Adaptation to a Changing Climate 2015. Adapting Infrastructure and Civil Engineering Practice to a Changing Climate (J. R. Olsen, Ed.), Reston, VA, *American Society of Civil Engineers*, Retrieved from http://ascelibrary.org/doi/book/10.1061/9780784479193

Dai, M. D., & Schonfeld, P. 1991. Simulation of waterway transportation reliability, *Transportation Research Record No. 1313, Freight Transportation: Truck, Rail, Water, and Hazardous Materials*, p. 98-105

Dai, M. D., & Schonfeld, P. 1993. Compendium on Waterway Transportation Reliability: Lock Congestion and Lock Queues (No. IWR-93-R-9), *Army Engineer Institute for Water Resources*, Alexandria, VA

Dai, M. D., Schonfeld, P., & Antle, G. A. 1993. Effects of Lock Congestion and Reliability on Optimal Waterway Travel Times, *Transportation Research Record*, Paper No. 930596

El hadouaj, S., Drogoul, A., and Espié, S. 2001. How to Combine Reactivity and Anticipation: The Case of Conflicts Resolution in a Simulated Road Traffic, *Multi-agent-based simulation: second international workshop, MABS 2000, Boston, MA,* *USA, July: Revised and Additional Papers*, Springer.

Grossardt, T., Bray, L., Burton, M. 2014. Inland navigation in the United States an evaluation of economic impacts and the potential effects of infrastructure investment, *National Waterways Foundation Research Report*, Retrieved July 14, 2015, from http://www.nationalwaterwaysfoundation.org/Research.html

Guyot, P., & Honiden, S. 2006. Agent-based participatory simulations: Merging multi-agent systems and role-playing games, *Journal of Artificial Societies and Social Simulation*, 9(4). Retrieved from http://jasss.soc.surrey.ac.uk/9/4/8.html

Hanson Professional Services, Inc. 2007. Tennessee Waterway Assessment Study, *Nashville District of the U.S. Army Corps of Engineers and the Tennessee Department of Transportation*

IPCC, 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)], *IPCC, Geneva, Switzerland*, 151 pp.

Kelejian, H. H. 1991. Probability Model of Lockage Stalls and Interferences. *Transportation Research Record No. 1313, Freight Transportation: Truck, Rail, Water, and Hazardous Materials*, p. 991-97

Kreis, D., Sturgill, R. E., Howell, B. K., Van Dyke, C. W., & Voss, D. S. 2014. Inland Waterway Operational Model & Simulation Along the Ohio River, *Paper 1458, Kentucky Transportation Center Research Report*

Nashville District, About the Nashville District, *U.S. Army Corps of Engineers*, Retrieved July 14, 2015, from http://www.lrn.usace.army.mil/About.aspx

Nikolic, I., & Ghorbani, A. 2011. A method for developing agent-based models of socio-technical systems, *In Networking, Sensing and Control (ICNSC), 2011 IEEE International Conference on* (pp. 44–49)

Smith, L. D., Sweeney, I. I., & Campbell, J. F. 2007. A simulation model to evaluate decision rules for lock operations on the Upper Mississippi River, *Proceedings of the 40th Hawaii International Conference on System Sciences 2007*, pp. 56–56

Smith, L. D., Sweeney, D. C., & Campbell, J. F. 2009. Simulation of alternative approaches to relieving congestion at locks in a river transportation system, *Journal of the Operational Research Society*, 60(4), 519–533, http://doi.org/10.1057/palgrave.jors.2602587

Sverdrup Corporation 1990. Cumberland River Basin Master Water Control Reference Manual, *Nashville District of the U.S. Army Corps of Engineers*

U.S. Army Corps of Engineers 2009. Inland waterway navigation value to the nation, *U.S. Army Engineer Institute for Water Resources Brochure*, Retrieved July 14, 2015, from http://www.corpsresults.us/navigation/navigation.cfm

U.S. Coast Guard Sector Ohio Valley 2014. Waterways Action Plan, *U.S. Coast Guard Eighth District Western Rivers*, Retrieved July 14, 2015, from http://www.uscg.mil/d8/westernrivers/

VV, A. 2009. Waterborne transport, ports and waterways: a review of climate change drivers, impacts, responses and mitigation, *Final Report of the EnviCom-Task Group, 3, World Association for Waterborne Transport Infrastructure*