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SIMULATION OF THE ILLINOIS WATERWAY LOCKS SYSTEM

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ABSTRACT

A computer simulation model of the locks system on the Illinois Waterway is described. The model was developed using ProModel for Windows and includes boats and barge tows traveling through the locks system and operation of the locks. Entities with attributes are used to simulate the boats and barge tows that enter the system, travel either upstream or downstream through the locks, and then leave the system. Locations are used for the locks and for entry and exiting of the boats and barge tows. The operation of the locks is simulated through the use of variables, resources, and operation logic in the processing module. The handling of both boats and barge tows in the locks greatly complicates the simulation model, since their differences in size is significant. For example, a lockage can easily handle ten or more boats, while a barge tow with fifteen barges can require a double lockage (typically nine barges for the first lockage and six barges and the tow boat for the second lockage). At times both barge tows and boats are included in a single lockage.

1 INTRODUCTION

The Illinois Waterway is part of the waterway system that links the Great Lakes with the Gulf of Mexico. It is the largest and most important water route in Illinois, extending from Lake Michigan at the Chicago and Calumet Harbors to the mouth of the Illinois River where it empties into the Mississippi River at Grafton, Illinois, about 50 miles north of St. Louis. The Illinois Waterway is composed of the Illinois River; the Chicago Sanitary and Ship Canal; the Calumet Sag Channel; and parts of the Calumet, Little Calumet, Chicago, and Des Plaines Rivers. There are nine locks on the Illinois Waterway. The total drop in water elevation from Lake Michigan to Grafton is about 160 feet.

ProModel is a discrete event simulation software package developed primarily for manufacturing and service systems (ProModel Corporation 1992). The Windows version is very easy to use, and its capabilities allow for building simulation models quickly and efficiently. One of the primary features of ProModel for Windows is its animation capabilities. It uses the graphic capabilities of Windows to build both the model and its animation representation interactively. Thus, animation is not an add-on feature. It is an integral part of the model building process. ProModel has been used extensively in various application areas; however, using it to simulate a river locks system is a challenging, unique application.

2 THE ILLINOIS WATERWAY LOCKS SYSTEM

Eight of the locks on the Illinois Waterway are U.S. Government locks operated by the Army Corps of Engineers (U.S. Army Corps of Engineers 1974). They are at the following locations (relative to the mouth of the Illinois River at Grafton): La Grange, Mile 80.2; Peoria, Mile 157.7; Starved Rock, Mile 231.0; Marseilles, Mile 244.6; Dresden Island, Mile 271.5; Brandon Road, Mile 286.0; Lockport, Mile 291.1; and Thomas J. O'Brien, Mile 326.5. The other lock is in Chicago Harbor and is operated by the Metropolitan Sanitary District of Greater Chicago. The Thomas J. O'Brien Lock is the largest of the locks on the Illinois Waterway, with usable dimensions of 110 feet in width by 1000 feet in length. The other seven U.S. Government locks all have usable dimensions of 110 feet in width by 600 feet in length. The lock operated by the Metropolitan Sanitary District of Greater Chicago has usable dimensions of 80 feet in width by 600 feet in length.

The northern part of the Illinois Waterway starts at Lake Michigan, which has an elevation of about 580 feet, and has two branches. The southern branch starts at the mouth of the Calumet River at Calumet Harbor in Lake Michigan on the south side of Chicago, east of 91st Street. From there it consists of the Calumet River for eight miles to where it becomes the Little Calumet River near 141st Street and Torrence Avenue; the Little Calumet River for six miles to where it joins the Calumet Sag Channel at Blue Island; and the Calumet Sag Channel for 16 miles to where it joins the Chicago Sanitary and Ship Canal near Lemont.

The northern branch starts at the mouth of the Chicago River at Lake Michigan in downtown Chicago, essentially at the lock in Chicago Harbor. From there it consists of the Chicago River for two miles to where it branches near Lake Street and Franklin Street in downtown Chicago; the South Branch of the Chicago River for four miles to where it is connected to the Chicago Sanitary and Ship Canal near 31st Street and Ashland Avenue; and the Chicago Sanitary and Ship Canal for 18 miles to where the Calumet Sag Channel joins it near Lemont.

The Chicago Sanitary and Ship Canal project was completed in 1900 and the canal carries Chicago's treated sewage southwest, away from Lake Michigan. Before its completion, Chicago dumped its sewage in Lake Michigan. The lock in Chicago Harbor was built as part of the project, which included reversing the flow of the Chicago River from east to west. It was the first river in the world to flow away from its mouth. The Chicago Sanitary and Ship Canal is 30 miles long, 202 feet wide, and 24 feet deep. Its rate of flow is controlled by sluice gates at Chicago Harbor and at the Thomas J. O'Brien Lock and Controlling Works.

There are two locks on the northern part of the Illinois Waterway, the lock in Chicago Harbor at the beginning of the northern branch and the Thomas J. O'Brien Lock and Controlling Works on the southern branch. The O'Brien Lock is at about the midpoint of the 14-mile stretch of the Calumet and Little Calumet Rivers that connects Calumet Harbor to the Calumet Sag Channel. It is on the Calumet River seven miles from Calumet Harbor. The entrance to the lock by car is on 130th Street, just west of Torrence Avenue on the south side of Chicago. The change in the water level at the Thomas J. O'Brien Lock varies somewhat, as it does at all of the locks, but is approximately four feet.

The location near Lemont where the Calumet Sag Channel joins the Chicago Sanitary and Ship Canal is 303.5 miles by water from the mouth of the Illinois River at Grafton. Of course, the actual distance is much less, since there are many bends in the Illinois and Des Plaines Rivers. From its junction with the Calumet Sag Channel, the Chicago Sanitary and Ship Canal extends 13.5 miles further, joining the Des Plaines River between Joliet and Lockport. There is one lock on this part of the Chicago Sanitary and Ship Canal, the Lockport Lock and Dam, which is one mile east of the junction of the Chicago Sanitary and Ship Canal with the Des Plaines River. The change in elevation at the Lockport Lock and Dam is about 40 feet.

The Des Plaines River is next to the Chicago Sanitary and Ship Canal for 24 miles, from their junction between Joliet and Lockport northeast to Summit. From its junction with the Chicago Sanitary and Ship Canal, the Des Plaines River flows southwest for 17 more miles until it joins with the Kankakee River near Dresden Heights in Will County to form the Illinois River. The Brandon Road Lock and Dam is on this part of the Des Plaines River, four miles southwest of its junction with the Chicago Sanitary and Ship Canal. The entrance to this lock by car is at the intersection of Brandon Road and U.S. Highway 6 near Rockdale, which is just west of Joliet. The change in elevation at the Brandon Road Lock and Dam is about 35 feet.

The Illinois River is 273 miles long and makes up the longest stretch of the Illinois Waterway. There are five locks on the Illinois River. Going downstream, the first one is Dresden Island Lock and Dam, which is near Kankakee Bluffs 1.5 miles from the confluence of the Des Plaines and Kankakee Rivers. The change in elevation at Dresden Island is about 25 feet.

The Marseilles Lock is 27 miles further downstream, while the Marseilles Dam is only 25 miles downstream near downtown Marseilles. The Marseilles Canal is two miles long next to the Illinois River, extending from the dam to the lock. The change in elevation at Marseilles is about 20 feet.

Proceeding downstream the Starved Rock Lock and Dam is 13.5 miles from the Marseilles Lock, eight miles west of Ottawa and five miles east of LaSalle. It has a change in elevation of about 20 feet, and is the easiest of the Illinois River locks to view, since Starved Rock State Park, with its high bluffs, is adjacent to the dam on the south shore. The lock is next to the north shore and has a visitor center.

The Peoria Lock and Dam is 73 miles downstream of the Starved Rock Lock and Dam. It has a change in elevation of about ten feet, but varies greatly. It can be seen from Interstate 494, just south of Peoria, where it crosses the Illinois River.

The La Grange Lock and Dam is 68 miles downstream of the Peoria Lock and Dam and 80 miles upstream of the mouth of the Illinois River at Grafton, about half way between Beardstown and Meredosia. By car it is on some back country roads, pretty much "in the middle of nowhere." The change in elevation is about five feet, but varies greatly.

The elevation of the Mississippi River at Grafton is approximately 420 feet. However, in floods the elevation increases significantly. On the other hand, during droughts the elevation is lower. In recent floods both the Peoria and the La Grange Lock and Dams have been completely under water, with the water level reaching to the second floor of the buildings next to the locks.

3 USE OF THE LOCKS

River locks provide a means for bypassing rapids, dams, and other locations on the river where there are significant changes in elevation. Sometimes canals are associated with locks system, connecting the locks to the river either upstream or downstream of the elevation change, as is the case with the Marseilles Canal. Canals can also provide connections between rivers and other waterways, including both the Calumet Sag Channel and the Chicago Sanitary and Ship Canal. Of course, there can be locks and dams directly on canals, such as the Lockport Lock and Dam on the Chicago Sanitary and Ship Canal.

Whether vessels are traveling upstream or downstream, the procedure for a lockage is essentially the same. Before vessels enter the lock, the elevation of the water inside the lock has to be the same as that where the vessels are located. The water elevation inside the locks is controlled by underwater valves at both the upstream and downstream gates. When the lock gates are opened, vessels can enter the lock. Of course, the lock gates and underwater valves must be closed at the other end of the lock to maintain the proper water level.

The number of vessels that will fit in the lock depends on the usable dimensions of the lock and the size and shape of the vessels. Safety considerations also play a role. As many as twenty or more small boats can easily fit into a large lock. On the other hand, barge tows are often too big to fit into a lock and must be moved through in two parts, which is referred to as a double lockage.

Once the vessels are in the lock, the underwater valves and the lock gates are closed. Then the underwater valves at the other end of the lock are opened, which allows the water elevation in the lock to eventually equalize with that on the other side of the exit gates. The length of time required for this is determined by the size of the valve openings and the total change of elevation required for the water inside the lock. Often the valves are not used wide-open, due to safety considerations with respect to water turbulence, both inside the lock and on the other side of the lock gates when other vessels are waiting there to use the lock. Once the water elevation inside the lock is sufficiently close to that on the other side of the exit gates, the gates are opened. The vessels then exit the lock and proceed on their trip.

Vessels traveling through locks systems are obviously self-propelled. However, often barge tows must be split into two parts to get them through a lock. When this happens, the part with the tow boat is still self-propelled; however, the part that has only barges must be moved by some other external force. This force is provided by electric wenches that are located on shore both upstream and downstream of the lock.

4 BOAT AND BARGE TRAFFIC

Traffic on the Illinois Waterway consists of both boats and barges, which must be moved by tow boats. A barge tow consists of a tow boat and from one to sixteen or more barges, depending on the size of the barges. The barges carry a variety of products, including grain, chemicals, coal, sand and gravel. Barge tows move up and down the waterway at approximately five miles per hour. For lockages there are essentially three types associated with barge tows: 1) a single lockage without having to reconfigure the barge tow; 2) a single lockage with some reconfiguration of the barge tow being required; and 3) a double lockage.

For the first type of lockage, the barge tows have overall dimensions that are less than the usable dimensions of the lock. It is possible that these could consist of nine or more barges and the tow boat, especially at the Thomas J. O'Brien Lock, which is the largest lock in the system. Typically they consist of one or two barges (or three small barges) in single file, or of six barges, three abreast, followed by the tow boat.

For lockages of the second type, the barge tows have an overall length that exceeds the usable length of the lock. They could have as few as three barges, but often have four barges, in single file, followed by the tow boat. Of course, it would be possible to configure the barge tow to fit into the lock (and thus into the first type of lockage); however, they are configured in single file for navigational purposes. These barge tows move through the lock in the following manner: 1) The barge tow is moved into the lock and the front barges are tied to the side of the lock. 2) The barge tow is untied in such a way that the two parts will fit into the lock lengthwise. 3) The back part of the barge tow backs away from the front part, moves to the side and enters the lock next to the front part. 4) The lockage is completed. 5) The front part of the barge tow is pulled out of the lock using one of the electric wenches on shore. 6) The back part of the barge tow moves into position behind the front part. 7) The barge tow is tied back together again. 8) The barge tow continues the trip.

Double lockages are required for barge tows that are so big that they cannot fit into the lock for a single lockage. Usually they consist of nine or more barges, three abreast, followed by the tow boat. These barge tows require two lockages and they move through the lock in the following manner: 1) The barge tow is moved into the lock and the front barges are tied to the side of the lock. 2) The barge tow is untied in such a way that each of the two parts will fit into the lock. 3) The back part of the barge tow backs out of the lock. 4) The lockage for the front part is completed. 5) The front part of the barge tow is pulled out of the lock using an electric wench. 6) The water level in the lock is returned to the initial level (essentially an empty lockage, which does not count). 7) The back part of the barge tow moves into position into the lock. 8) The lockage is completed for the back part of the barge tow. 9) The back part of the barge tow moves into position behind the front part. 10) The barge tow is tied back together again. 11) The barge tow continues the trip.

Commercial boats are typically much smaller than barge tows. In addition, the Illinois Waterway is used extensively for recreation, which results in numerous small boats using the system. The recreational boating season is primarily during the summer months, especially on weekends and holidays. Several small boats can be moved through a lock on a single lockage. In addition, a few small boats will often fit into the lock with a barge tow, or part of a barge tow. This is often done, at the discretion of the lockmaster, subject to safety considerations. In cases where a double lockage is required for the barge tow, boats can be included in the second lockage.

5 DESCRIPTION OF THE MODEL

The model, which was developed using ProModel for Windows, simulates the operation of the Illinois Waterway in terms of the boats and barge tows traveling through the locks system and operation of the locks. Entities and locations were the starting points for developing the model. Entities in the model represent the boats and barge tows that enter the system, travel either upstream or downstream through the locks, and then leave the system. Locations within the model include the locks, locations where barge tows and boats enter and/or leave the system, and queues for barge tows and boats where they wait to use the locks. Operation of the locks is simulated through the use of variables, resources, and operation logic in the processing module. The northern branch of the northern part of the Illinois Waterway, which extends from the mouth of the Chicago River at Lake Michigan to the junction of the Chicago Sanitary and Ship Canal and the Calumet Sag Channel near Lemont, is not included in the model. In addition, there are a great many barge tows and boats that use the Illinois Waterway without going through a lock. These barge tows and boats are not included in the simulation, since its primary focus is on the locks.

There are only two entities in the model, one for boats and one for barge tows. They have five attributes as follows: 1) direction in which the boat or barge tow is traveling (1 = downstream, 2 = upstream); 2) speed of the boat or barge tow in miles per hour; 3) size of the boat or barge tow for use in determining how many will fit into the lock for a lockage; 4) additional duration required for the lockage due to the size of the boat or barge tow; and 5) final destination for the boat or barge tow (from 1 for the La Grange Lock at the southern part to 8 for the Thomas J. O'Brien Lock in the northern part).

There are 44 locations in the model, as shown in Figure 1. Of these 44 locations, 24 are directly associated with the locks, eight locations for the eight locks and 16 locations for queues for the boats and barge tows that are waiting for the locks. Two queues, which look like ladders in Figure 1, are needed for each lock to handle the vessels going upstream and the vessels going downstream. Six locations are used to identify the rivers and canals for the animation aspects of the models: Illinois River, Des Plaines River, Little Calumet

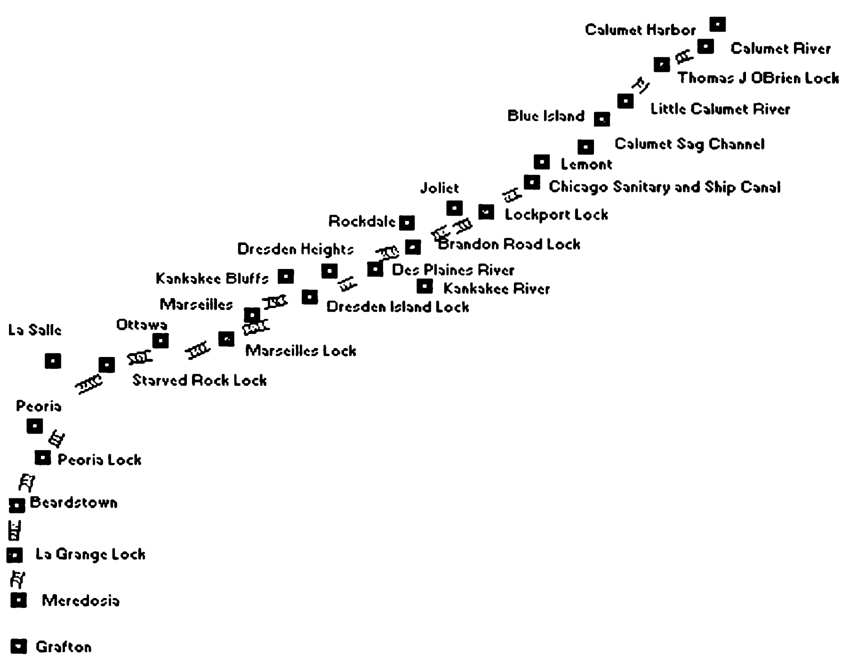

Figure 1. Locations in the ProModel Simulation Model of the Illinois Waterway Locks System

River, Calumet River, Chicago Sanitary and Ship Canal, and Calumet Sag Channel. The other 14 locations are also used for animation to identify locations that are part of or near the Illinois Waterway: Calumet Harbor, Blue Island, Lemont, Joliet, Rockdale, Dresden Heights, Kankakee Bluffs, Marseilles, Ottawa, LaSalle, Peoria, Beardstown, Meredosia, and Grafton. Squares are shown in Figure 1 for all locations that are not queues. When the simulation model is run, the squares and "ladders" disappear, and the animation depicts the boats and barge tows moving up and down the Illinios Waterway, waiting for the locks, moving through the locks, and proceeding to their final destination. It should be noted that Figure 1 is not to scale. For example, the distance from Grafton to the Peoria Lock is 158 miles, while the distance from the Starved Rock Lock to the Lockport Lock is only 60 miles.

Of the twenty locations in the model that are used to identify locations for animation, nine are also used to handle arrivals of the entities that represent boats and barge tows. These include Calumet Harbor and Grafton, the two end points of the Illinois Waterway, as well as one location between each pair of adjacent locks. There are 18 sets of arrivals in the model, for each of the two entities arriving at each of the nine arrival locations. For each set of arrivals several aspects are included: the time of the first arrival, the total number of arrivals in the model run, the interarrival frequency, and logic for calculating values for all of the attributes for the entity. The exponential probability distribution is used interarrival times. thus assuming a Poisson process for arrivals.

Operation of the locks and routing of the barge tows and boats from location to location is one of the most involved aspects of the model. This part of the model is carried out through the use of resources, global variables, priorities, and operation logic in the processing section of ProModel. For each lock four resources are required, for boats and barge tows traveling upstream and traveling downstream. These resources are used to move the boats and barge tows from the corresponding location queue to the location for the lock. The operation logic for the boats and barge tows at the lock locations also uses these resources, in order to prevent them from moving any boats or barge tows into the lock location during a lockage that is already in progress. Seven global variables are used in this logic for each lock for the following aspects: 1) the total amount of time required for the lockage; 2) the number of boats involved in the lockage; 3) the direction the barge tow and/or boats are traveling for the lockage; 4) an indicator variable for whether or not a barge tow is involved in the lockage; 5) an indicator variable for whether or not the lock is in use or is reserved for a lockage; 6) a counter to keep track of the boats going upstream as they enter and leave the lock; and 7) a counter to keep track of the boats going downstream as they enter and leave the lock. Barge tows have priority over boats for lockages, so their resources are freed first when a lockage ends. Thus, if any barge tows are waiting in the queues, one will enter the lock before any boats are allowed to enter. If there is room for boats in the lockage along with the barge tow, they enter the lock following the barge tow. If no barge tow is involved in the lockage, all of the boats that are waiting and are going in the direction of the lockage will be included, up to the capacity of the lock, which is assumed to be 33 boats for the Thomas J. O'Brien Lock and 20 boats for the other locks. Resources are also freed in a manner that results in alternating between lockages going upstream and lockages going downstream, when boats going in both directions are present. However, barge tows still take priority over boats, even if consecutive barge tows are going in the same direction.

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AUTHOR BIOGRAPHY

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