APPLICATION OF ANYLOGIC SIMULATION SOFTWARE TO YARD MODELING

Roger Baugher, Independent Consultant
Webinar Agenda

Provide a high-level look at various yard models
Provide a brief discussion on yard design
Discuss my choice of AnyLogic software for yard modeling
Demonstrate the first two of three yard models to be presented today
Discuss Operations Research efforts to date
Demonstrate the final yard model to be presented today
Discuss possible next steps
Respond to Questions and Comments
My Evolution

Worked in Transportation Department staff at four railroads, but not specifically with yard operations

Applied network flow models and line-of-road dispatch programs for railroad planning, but this provided little insight into yard operations as such models treat yards largely as black boxes

While working in Service Design at BNSF, a problem at a Storage-In-Transit yard in South Texas led me to develop some yard analysis and visualization tools

I soon realized that yard simulation could provide needed functionality for

- Problem solving – What went wrong? Could we have predicted a problem?
- Capital project justification – limited tools today to justify yard improvements
- Training – shorter training opportunities in the field
My Goals for this Webinar

Explore where we stand today
Advocate a role for yard simulation in advancing the understanding and operations of flat yards
Advocate a role for intelligent yard command and control systems
Encourage feedback on ideas presented
Railroads have needed to design yards since railroading began and have relied on manual analysis, a process improved with the arrival of computer spreadsheets.

Tools were developed for Conrail and on other properties for network rationalization
Department of Transportation & Federal Railroad Administration created, providing a source for funds for railroad research
The funding produced a flurry of academic and industry research efforts
Service Planning Model and Automated Blocking Model focused on yards but specifics of internal yard operations were not modeled.

A graphics edition of ABM used by CSX provided insights into blocking improvement.

CN / CSX Terminal Interactive Model (TRIM)

- Loop
  - Computer provided status information and played out commands
  - Large teams of field operating officers and staff specified switching commands
- Process took three times real time – twenty four hours clock time to simulate one eight hour shift
- Not repeatable
### Yard Model Time Line

<table>
<thead>
<tr>
<th>1990’s</th>
<th>MultiRail is widely implemented on North American railroads, again focusing on yards but not modeling specifics of internal yard operations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rail Traffic Controller is widely implemented on North American railroads; it does not directly address yard operations but users can devise ways to improve on the “yard-is-a-black-box” treatment</td>
</tr>
</tbody>
</table>
| 2000’s | Norfolk Southern devises two terminal models  
  - Decatur, IL terminal, including largest flat yard in North America, used AnyLogic  
  - YardSim – hump yard model written in Java  
    - Simulator, Editor, Yard Modeler and Yard Scenario Manager components  
    - 3D animation visualization  
    - Used open source process flow and rule engine to implement operating and scheduling strategy |
2010’s

Optym develops Hump Yard Simulation System for CSX
- Implemented at six hump yards
- Later implemented on Belt Railway and used by University of Illinois for yard operations studies

GE / Wabtec Yard Planner
- Initially focused on hump yards, but working on flat yard version
- Designed to provide end-to-end decision support for yard operations
- Automates workflow through the yard

TEMS introduces Switch-It, an Excel-based simulation, working with CSX
TranSystems Corporation develops Transportation Modeling Studio

- General-purpose railroad terminal simulation
- Built in AnyLogic
- Applied to variety of hump yards, flat yards, intermodal facilities, industrial facilities and ports

I started tinkering with yard visualization and yard simulation
All models are proprietary which often leads to limited use
Custom effort required to integrate with railroad information systems
The models are COMPLICATED because flat yard operations themselves are COMPLICATED – flat yards have widely varying layouts, tasks, staffing levels, deployed technology, etc.
Importantly, yard data systems do not capture the detailed operations in a flat yard, only the inputs and the outputs; much detailed knowledge is in the head of the yard officers, especially the yard masters and yard conductors
Yard designs are very diverse, making creation of a general-purpose model difficult. The one below has three yards with specific functions; it is typical of a hump yard.
Other Sample Yard Layouts

10 track with mainline at the side

10 track with mainline through the middle

10 track trapezoid

10 track stub end
Railroad Yard Simulation

Two major elements

• Simulation software to replicate yard operations
  • Provides outputs and receives inputs
  • Simulates specified yard events

• Command and Control systems to dictate the tasks to be performed
  • Which tasks to perform?
  • When to perform them?
  • In what order to perform them?
Choice of Railroad Simulation Software

To my knowledge, only AnyLogic has modules specifically addressing railroad infrastructure and operations.

The software got its name because it supports three simulation paradigms:

- Discrete Event
- Agent-Based
- System Dynamics

Multiple paradigms can be used in the same model – consider a model of a PTC system:

- Train movements are treated as discrete events
- Locomotives and wayside devices are treated as agents that communicate based on their relative proximity
AnyLogic’s Rail Library
• Powerful but complex system
• Understands all elements of railroad operations – trains, railcars, tracks, switches, coupling, uncoupling, train movement, routing, conflicts
• Have not encountered any situation that cannot be modeled

AnyLogic has been widely installed at Class Is in the US
Support is excellent – will debug a faulty model and return it
Complex Models Created and Depicted Graphically
Demos of Yard Models

Will demonstrate three models, with each using a different method to specify the sequence of switching events to be executed:

- Manual entries
- Entries from Observation – replay the actions from a rail yard
- Entries from OR and AI algorithms – replay the recommended sequence
Demo of Simulation Based on Manual Entry

Here, the user specifies the sequence of switching instructions and the computer simulates them – similar in concept to CN/CSX TRIM

Steps

• Specify which cars are on which track and the initial location of the switch engine
• Specify the sequence of pull and shove events to be executed
• Keep track of number of moves and time consumed
Demo of Manual Entry Simulation
Lessons Learned

Serve as a simple yard design tool
Improve switching policies and practices
Train / retrain personnel
Quantify relationship between switching sequence and time consumed
Understand how factors like pin pull count and blocking complexity impact yard performance
Demonstrate need for additional track or crew resources
Demo of Simulation Based on Observations

Here, the user, having observed actual yard operations, specifies the sequence of switching instructions and the computer simulates them.

To replay switching sequence:
- Capture rail car position from yard inventory
- Capture actions from video camera at yard throat
- Convert actions to commands
- Simulate commands
- Calibrate model against reality
What to Look For in this Demo

Much to learn from the practices of this very experienced crew

Watch for the crews’ preplanning to anticipate future moves

• Note that tracks are shoved clear to make space for cars to be kicked
• Observe that cut cars are pulled to the clearance point because it
  • Lessens travel distance for subsequent pulls
  • Positions ground crew adjacent to yard ladder for subsequent moves
• Note that spare tracks are used temporarily to hold cars for later movement

Note that nearly all moves involve kicking cars, few cars are shoved to rest
Side-by-Side Visual Comparison
Demo of Simulation Based On Observation
Lessons Learned

Identify factors leading to poor yard operation
• Inefficient switching practices
• Inadequate staffing levels
• Conflicts with inbound and outbound trains
• Yard volumes and block counts
• Maintenance issues

Document need for additional track or crew resources

Usefulness is limited by the inability to easily capture switch movements for input to a simulation
## Calibration Results

<table>
<thead>
<tr>
<th>Move</th>
<th>Start Event</th>
<th>Intermediate Event</th>
<th>End Event</th>
<th>Video Time (minutes)</th>
<th>Simulation Time (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pull from 203</td>
<td></td>
<td>Shove to 204</td>
<td>1.63</td>
<td>1.62</td>
</tr>
<tr>
<td>2</td>
<td>Pull from 204</td>
<td></td>
<td>Shove to 205</td>
<td>1.58</td>
<td>1.00</td>
</tr>
<tr>
<td>3</td>
<td>Pull from 205</td>
<td></td>
<td>Shove to 204</td>
<td>5.42</td>
<td>2.99</td>
</tr>
<tr>
<td>4</td>
<td>Shove 9 deep in 204</td>
<td></td>
<td></td>
<td>2.82</td>
<td>4.45</td>
</tr>
<tr>
<td>5</td>
<td>Pull from 204</td>
<td></td>
<td>Shove to 207</td>
<td>1.93</td>
<td>1.78</td>
</tr>
<tr>
<td>6</td>
<td>Shove 5 deep in 207</td>
<td></td>
<td></td>
<td>1.10</td>
<td>0.91</td>
</tr>
<tr>
<td>7</td>
<td>Pull from 207</td>
<td></td>
<td>Shove to 210</td>
<td>2.00</td>
<td>1.45</td>
</tr>
<tr>
<td>8</td>
<td>Pull 210 before uncoupling</td>
<td></td>
<td></td>
<td>4.12</td>
<td>2.86</td>
</tr>
<tr>
<td>9</td>
<td>Pull from 210</td>
<td>Kick to 207</td>
<td>Shove to 210</td>
<td>1.95</td>
<td>3.38</td>
</tr>
<tr>
<td>10</td>
<td>Shove clear in 210</td>
<td></td>
<td></td>
<td>1.57</td>
<td>1.68</td>
</tr>
<tr>
<td>11</td>
<td>Pull from 210</td>
<td>Kick to 207</td>
<td>Shove to 210</td>
<td>2.17</td>
<td>3.25</td>
</tr>
<tr>
<td>12</td>
<td>Shove clear in 210</td>
<td></td>
<td></td>
<td>1.35</td>
<td>1.41</td>
</tr>
<tr>
<td>13</td>
<td>Pull from 210</td>
<td>Kick to 207</td>
<td>Shove to 203</td>
<td>1.67</td>
<td>3.36</td>
</tr>
<tr>
<td>14</td>
<td>Shove clear in 210</td>
<td></td>
<td></td>
<td>1.48</td>
<td>1.26</td>
</tr>
<tr>
<td>15</td>
<td>Pull from 210</td>
<td></td>
<td></td>
<td>1.97</td>
<td>1.79</td>
</tr>
<tr>
<td>16</td>
<td>Pull 203 before uncoupling</td>
<td></td>
<td></td>
<td>3.18</td>
<td>2.63</td>
</tr>
<tr>
<td>17</td>
<td>Pull from 203</td>
<td>Kick to 204</td>
<td>Shove to 203</td>
<td>2.68</td>
<td>1.18</td>
</tr>
<tr>
<td>18</td>
<td>Pull 203 before uncoupling</td>
<td></td>
<td></td>
<td>2.45</td>
<td>2.27</td>
</tr>
<tr>
<td>19</td>
<td>Shove clear in 203</td>
<td></td>
<td></td>
<td>3.82</td>
<td>4.49</td>
</tr>
<tr>
<td>20</td>
<td>Pull from 203</td>
<td></td>
<td>Shove to 207</td>
<td>1.50</td>
<td>1.36</td>
</tr>
<tr>
<td>21</td>
<td>Pull from 207</td>
<td></td>
<td>Shove to 204</td>
<td>2.68</td>
<td>2.90</td>
</tr>
</tbody>
</table>

**TOTALS**

|                  | **49.07** | **48.02** |
Revisiting Command and Control Systems

Three ways to specify the sequence of switching events to be executed

• Manual entries
• Entries from Observation – replay the actions from a rail yard
• Entries from OR and AI algorithms – replay the recommended sequence

We’ve visited the first two, now let’s examine the third
If I were asked what algorithms have been discussed for yard operations, I would mention the following:

- Inbound train sequencing
- Hump sequencing
- Block to track assignment
- Pull-down and train assembly

This list overlooks a key yard process typically assigned to yardmasters and yard conductors – specifying and executing the sequence of switch moves needed to sort cars from inbound trains to build outbound trains.
Potential for Research and Development

To my knowledge, little attention has been focused on analyzing or optimizing switch movement sequencing for flat yards.

This occurs at a time of:

• rapid retirement of experienced personnel
• their replacement with new employees without the necessary skills and lacking the traditional training in the field working under experienced yardmasters and conductors.
Cedar AI

Several years ago, three former members of Amazon Web Services formed Cedar AI to apply their skills to analyzing and improving the performance of transportation networks.

In the several years I have been serving as railroad advisor to the company, a team now numbering about twenty members has developed:

- ARMS – a railroad inventory management system
- Optiswitch – our focus today
  - AI-based system to sequence switch movements to best meet an objective
  - Honed with feedback from conductors, yard masters and industry experts
Demo of Simulation Based on Optiswitch Recommendations

Here, CedarAI, using train assembly objectives, outputs a JSON file, which is then selected by the user, the sequence of switching instructions are extracted and the computer simulates them.

To simulate the recommendations:
- The user selects the desired JSON file and observes:
  - Number of moves
  - Time required
  - Number of cars moved and distance moved
Demo of Simulation Based on Optiswitch Recommendations
Lessons Learned

Provide a visual check that the recommended switching sequence was logical and efficient
Generate estimates of time required to execute the recommended sequence – minimizing time, not the number of moves, is the objective
Understand the relationship among time, number of moves, number of tracks used, number of cars pulled, etc.
Identify and quantify constraints that may have not been considered
  • Length of switch lead limiting number of cars pulled in one move
  • Inadequate engine power’s effect on acceleration and deceleration
  • Time required for the ground crew to walk
  • Impact of different crew sizes and remote control locomotive operations
  • Randomness of car sort order on incoming trains
## Comparison of Alternatives Achieving Same Objective

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Number of Moves</th>
<th>Tracks Used</th>
<th>Time</th>
<th>Cars Pulled</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
<td>2</td>
<td>06:28</td>
<td>11</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>3</td>
<td>05:45</td>
<td>15</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>3</td>
<td>05:45</td>
<td>12</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>3</td>
<td>08:51</td>
<td>9</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>3</td>
<td>08:49</td>
<td>9</td>
</tr>
</tbody>
</table>
When fully developed and deployed, I anticipate Optiswitch will have a significant impact on terminal and network operations

Consider

• A detailed computer-based switching plan will be available within the yard and across the network – know what the yard will be doing for the next shift

• Hours before train departure, the cars expected to depart on an outbound train will be known, informing downstream yards and trip planning systems early

• Will run in real-time, reacting to changes in the yard
Continued

Better exchange of information between yards can foster better communication and coordination – consider the situation of a yard in trouble

• Today, there might be a phone call where the yard requests some relief from an upstream yard

• In the future, the requesting yard would know what the upstream yard’s plan was, and they could jointly negotiate alternatives; the upstream yard could run What-If’s to see what alternatives were plausible
Possible Next Steps

- Extend to industry switching
- Develop a training package
- Develop general-purpose yard analysis tool
- Better integration with Optiswitch
- Data capture development – deployment of improved sensors and intelligent camera systems to maintain yard inventory
Automated Updating of Yard Inventory

Today, yardmasters mark switch lists to provide switching instructions for conductors and ground crews; once a switching sequence is completed hours after it begins, it is assumed that the crews executed the instructions flawlessly and the computer inventory is updated.

Can an array of cameras and sensors employing low cost components automatically update yard inventory as switching progresses, flagging switching errors when they occur?

This is an area I am researching and have some tools under development.
Two Useful Reference Books

Handbook of Operations Research Applications at Railroads

Handbook of Optimization in the Railway Industry
Concluding Remarks

Thanks for your attention
Contact information:
rwbaugher@gmail.com
770-656-8886
Questions and Comments?