The **Supporting Secure and Resilient Inland Waterways** project is developing inland waterway disruption response decision support tools for maritime transportation stakeholders.

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Disruptions on the inland waterway system can have widespread economic and societal impacts.
We are utilizing operations research to prioritize barge cargo and allocate disrupted barges to terminals for rerouting on land.
Hazardous Cargo
Disrupted Barge Tows
We developed the Cargo Prioritization and Terminal Allocation Problem and formulated the model as a binary, non-linear integer program.

- **Sets**
  - $J$ Regular cargo set
  - $H$ Hazardous cargo set
  - $I$ Real terminal set
  - $D$ Dummy terminal set
  - $K$ Order set
  - $N$ Cargo set

- **Decision Variables**
  - $x_{ijk} \in \{0, 1\}$ 1 if barge $j$ is moved to terminal $i$ as the $k$th barge; 0 otherwise

(Tong and Nachtmann, Maritime Economics & Logistics, 2015)
Parameters

- $t_{ij}$ Water transport time of barge $j$ from its current location to terminal $i$
- $h_{ij}$ Handling time of barge $j$ at terminal $i$
- $a_{ij}$ Actual contributing time of barge $j$ that is assigned to terminal $i$
- $r_{ij}$ Land transport time of the cargoes on barge $j$ from terminal $i$ to their final destination
- $tv_j$ Total value of the cargoes on barge $j$
- $\alpha_j$ Value decreasing rate of the cargoes on barge $j$ per unit time unit volume
- $p$ Sinking threshold
- $u_{in}$ Capacity of cargo $n$ at terminal $i$ during the scenario period
- $wd_i$ Water depth at terminal $I$
- $s$ Safety level
- $m_{jn}$ 1 if barge $j$ carries cargo $n$; 0 otherwise
- $c_j$ Cargo volume on barge $j$
- $d_j$ Draft of barge $j$
Objective function

- To mitigate the total system impacts due to the inland waterway disruption
  - Minimize the total value loss of all barge cargoes within the affected region of inland waterway whose transport is interrupted by the disruption

- The value loss depends on
  - Cargo volume on the barge
  - Total time it takes the cargo to reach its final destination
  - Value decreasing rate which represents the rate at which the cargo’s economic and societal value diminishes as time elapses
  - Total value of the cargo

- Minimize

\[
\sum_{i \in I} \sum_{j \in J \cup H} \sum_{k \in K} \left\{ \left( \sum_{m \in J \cup H} \sum_{k \in K} a_{im} x_{im(k-1)} + a_{ij} + r_{ij} \right) c_j \alpha_j x_{ijk} \right\} + \\
\sum_{i \in d} \sum_{j \in J} \sum_{k \in K} x_{ijk} t v_j
\]

\text{Cargoes offloaded at the terminals}
\text{Cargoes remaining on the inland waterway}
### Constraint Sets

- \( \sum_{i \in I \cup D} \sum_{k \in K} x_{ijk} = 1 \quad \forall j \in J \) \hspace{1em} \leftarrow \text{Regular cargoes}
- \( \sum_{i \in I} \sum_{k \in K} x_{ijk} = 1 \quad \forall j \in H \) \hspace{1em} \leftarrow \text{Hazardous cargoes}
- \( \sum_{j \in J \cup H} x_{ijk} \leq 1 \quad \forall i \in I \cup D \) \hspace{1em} \leftarrow \text{Turn limit}
- \( \sum_{j \in J \cup H} x_{ijk} \geq \sum_{j \in J \cup H} x_{ij(k+1)} \quad \forall i \in I \cup D \) \hspace{1em} \leftarrow \text{Aesthetic}
- \( \sum_{j \in J \cup H} \sum_{k \in K} c_j m_n x_{ijk} \leq u_n \quad \forall i \in I \cup D, n \in N \) \hspace{1em} \leftarrow \text{Capacity constraint}
- \( \sum_{i \in I} \sum_{k \in K} (w_d_i - d_j) x_{ijk} \geq s \quad \forall j \in J \cup H \) \hspace{1em} \leftarrow \text{Water depth constraint}
- \( (\sum_{m \in J \cup H} \sum_{k \in K} a_{im} x_{im(k-1)} + a_{ij} + r_{ij}) c_j a_j x_{ijk} \leq t v_j p \quad \forall i \in I, k \in K, j \in J \cup H \) \hspace{1em} \leftarrow \text{Value loss constraint}
- \( x_{ijk} \in \{0,1\} \quad \forall i \in I \cup D, k \in K, j \in J \cup H \) \hspace{1em} \leftarrow \text{Binary variable}
After only being able to solve small problems to optimality, we developed and tested multiple variations of a Genetic Algorithm and Tabu Search Algorithm approaches.

Average Results Summary

<table>
<thead>
<tr>
<th>Problem Size</th>
<th>Optimal</th>
<th>Traditional GA</th>
<th>TS-Blind SWAP</th>
<th>Gap</th>
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<tr>
<td></td>
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<td>Min ($)</td>
<td>CPU (s)</td>
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</tbody>
</table>

where

- **Min**: Objective Function Value
- **CPU**: Computation Time
- **Gap**: \( \frac{\text{TS Min (or CPU)} - \text{GA Min (or CPU)}}{\text{GA Min (or CPU)}} \times 100\% \)
Systematic algorithm testing indicates that the Blind Swap variation of our Tabu Search algorithm gives the best solutions to medium and large sized CPTAP instances.
CPTAP GA and TS cargo prioritization strategies outperform an intuitive minimize distance (MD) approach on both Total Value Loss and Response Time performance.
Ongoing work is streamlining the optimization engine and developing a user-friendly interface.

(Nachtmann, Campo, et al., TRB, 2014)