Institute of High Performance Computing

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Digitalisation and Predictive Modelling of Berth Stay Time Windows for Tanker Operation Enhancement (MTEC 2019)

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Outline

- Motivation
- Objective
- Methodology
- Mathematical Formulation
- Optimization Algorithm
- Result
- Conclusion
- Acknowledgement

Motivation

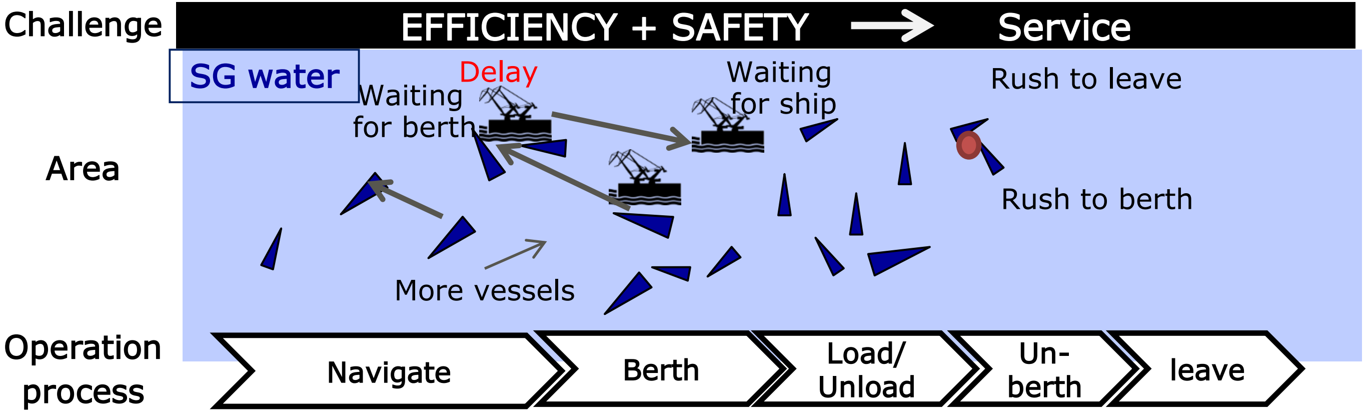
- Maritime industry plays an important role in economy worldwide.
- Singapore is one of the busiest ports all over the world, where it expects more than 11,000 vessel arrivals monthly.
- Among those arrivals, over 2,000 arrivals are contributed by tanker vessels. Looking into tanker vessels is one of the focal problems in maritime study.

Images from internet

The problem statement in tanker shipping

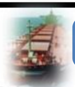
Problem statement:

- **Dis-connection** and lack of intelligent **coordination** detrimentally impact all stakeholders (e.g. port, terminal & carrier) in operation efficiency and safety



Operations

About 46 terminals & 182 jetties; 24 terminals & 99 jetties in Jurong Island
2300 monthly tanker arrivals



Loading → Arrival → Anchoring 1 → Unloading 1 → Anchoring 2 → Supplies → Unloading 2 → Anchoring 3 → Bunkering → Leaving sg

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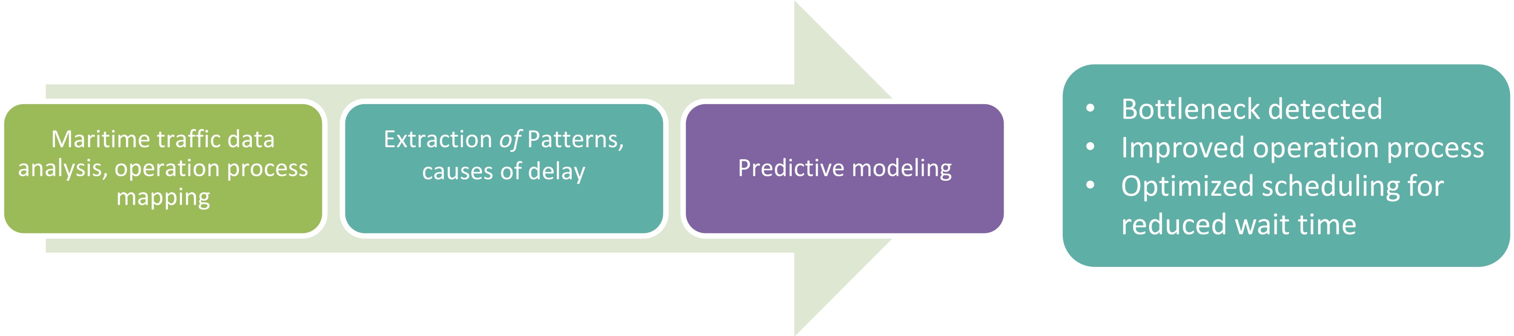
Objective

- To analyze patterns of tanker vessel operation, in which cargoes are transferred between terminals and vessels. Sophisticated procedures or activities have to be followed from vessel arrivals to departures.
- To predict berth stay time windows for loading and unloading operations of tanker vessels in ports.
- To provide decision support for optimizing the schedules of tanker vessels through simulation and optimization
- Provide decision supports for reducing vessels’ wait time and enhancing the overall operation efficiency in ports.
- To enable potentials to improve the performance and capacity in busy ports for handling tanker vessels and enhancing service levels of terminals.



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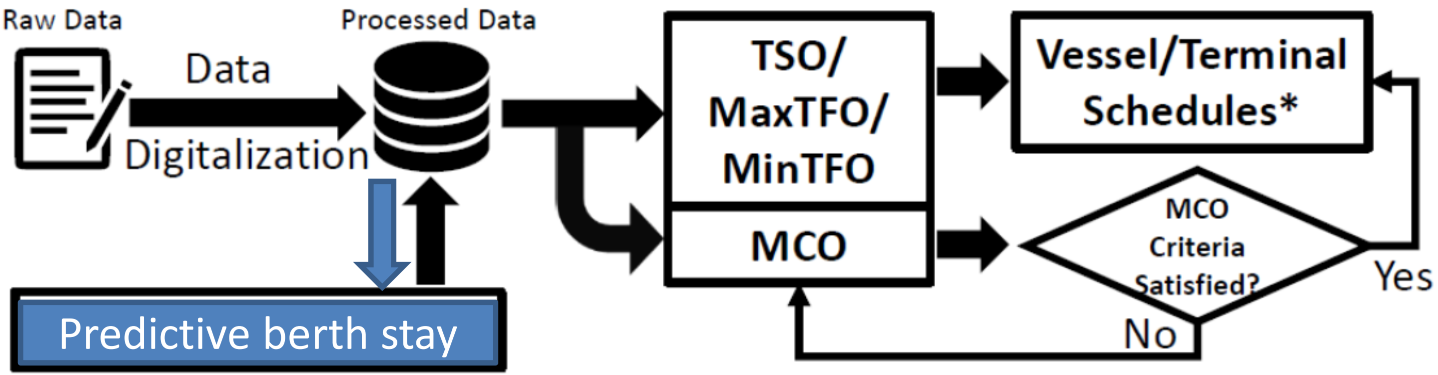
Methodology

- Firstly, the modelling framework and prototype model for the digitalization of data is proposed.

- Secondly, operation data is analyzed and data-driven predictive models are developed
  - the key factors that effectively influence the time windows of berth stays are identified and
  - predictive models are developed with key factors extracted using machine learning techniques

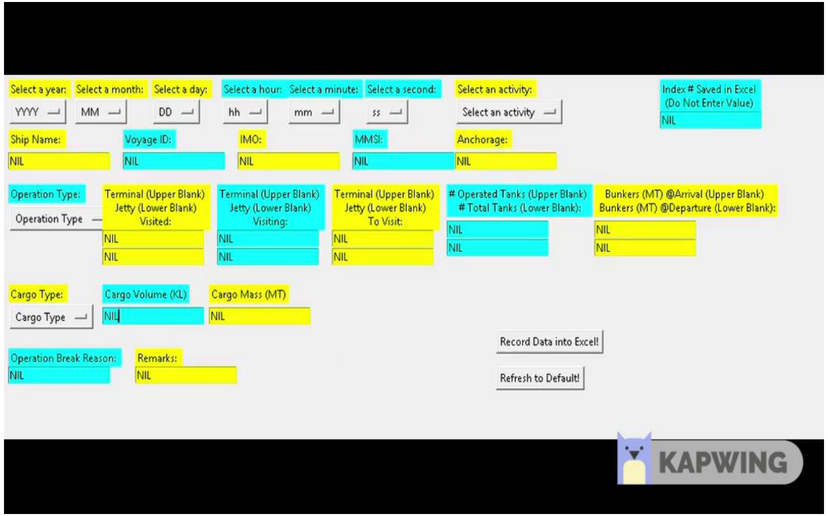
- Lastly, mathematical formulation of the problem and optimization for terminal operations are demonstrated.



TSO: Timing Sequential Optimizer; **MaxTFO**: Max Timing First Optimizer; **MinTFO**: Min Timing First Optimizer; **MCO**: Monte Carlo Optimizer.

Methodology

- Digitalization model for operation data
  - According to vessel ID and their corresponding activities, the necessary data is extracted and digitalized into a standard format.
  - A prototype model with user friendly interface is developed for terminal operators to input the data via portable devices and automatically store for facilitating information retrieval and data analysis.
  - Via our developed model, the data can be digitalized in a handy manner and can nimbly be further retrieved, analyzed, calculated and updated.



Mathematical Formulation

- Predictive Modeling for Berth Stay:

Regression Model and machine learning model:
$$\hat{O}_t = a_t \cdot I_t + b_t = [\hat{o}_{t,1}, \hat{o}_{t,2}, \cdots, \hat{o}_{t,m}]^T$$

Input Vector:
$$I_t = [i_{t,1}, i_{t,2}, \cdots, i_{t,m}]^T$$

Output Vector:
$$O_t = [o_{t,1}, o_{t,2}, \cdots, o_{t,m}]^T$$

MSE Cost Function:
$$C(a_t, b_t) = \frac{1}{m}\sum_{p=1}^{m}(\hat{o}_{t,p} - o_{t,p})^2$$

Partial Derivative:
$$\frac{\partial C}{\partial a_t} = \frac{2}{m}\sum_{p=1}^{m}(\hat{o}_{t,p} - o_{t,p}) \cdot i_{t,p}$$
$$\frac{\partial C}{\partial b_t} = \frac{2}{m}\sum_{p=1}^{m}(\hat{o}_{t,p} - o_{t,p})$$

Iteratively Update:
$$a_t^{new} = a_t^{old} - \eta \cdot \frac{\partial C}{\partial a_t}$$
$$b_t^{new} = b_t^{old} - \eta \cdot \frac{\partial C}{\partial b_t}$$

Iterative Approach
Batch Gradient Descent

Input Vector:
$$I_t = \begin{bmatrix} 1 & 1 & \cdots & 1 \\ i_{t,1} & i_{t,2} & \cdots & i_{t,m} \end{bmatrix}^T$$

Output Vector:
$$O_t = [o_{t,1}, o_{t,2}, \cdots, o_{t,m}]^T$$

Model Parameters:
$$\begin{bmatrix} b_t \\ a_t \end{bmatrix} = (I_t^T \cdot I_t)^{-1} \cdot I_t^T \cdot O_t$$

Analytic Approach
Least Squares Error

Result

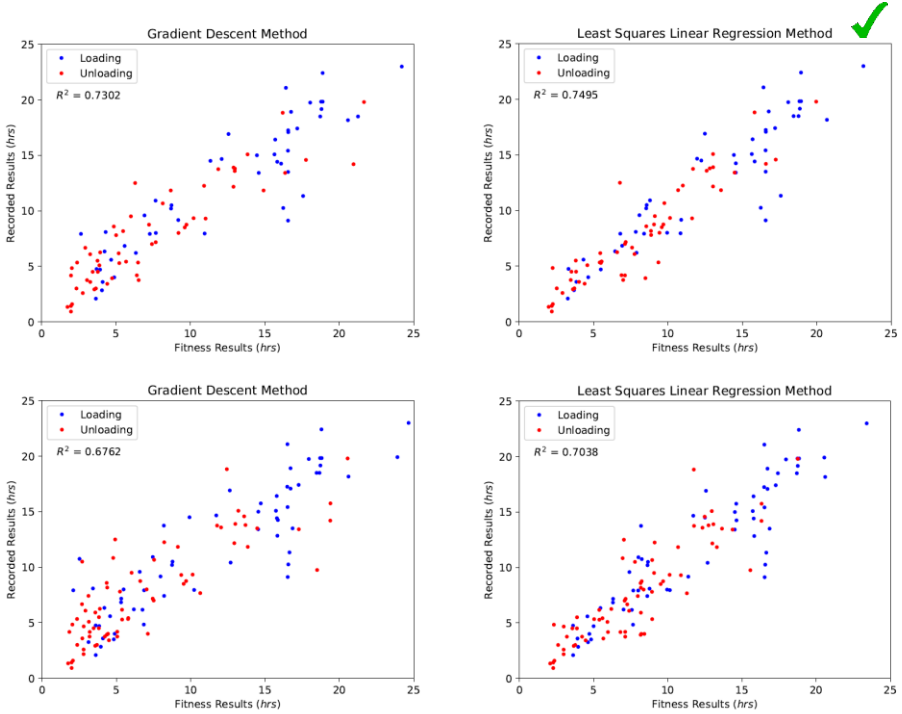
➢ Predictive Modeling for Berth Stay:

Iterative Approach

Analytic Approach

Volume-Based

Mass-Based



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Mathematical Formulation for Scheduling

➢ Objective Function Formulation: (m Tanker Vessels, n Operation-Available Terminals to minimize wait time)

Operation Duration Vector:

$$\boldsymbol{X} = [x_1, x_2, \dots, x_m]^T$$

Operation Coefficient Matrix:

$$\boldsymbol{\omega} = \begin{bmatrix} \omega_{1,1} & \omega_{1,2} & \cdots & \omega_{1,m} \\ \omega_{2,1} & \omega_{2,2} & \cdots & \omega_{2,m} \\ \vdots & \vdots & \ddots & \vdots \\ \omega_{n,1} & \omega_{n,2} & \cdots & \omega_{n,m} \end{bmatrix}$$

where $\omega_{i,j} \in \{0,1\}$ for $\forall i$ and $\forall j$

$\omega_{i,j} = 0$, i.e. vessel j is not berthing at terminal i.

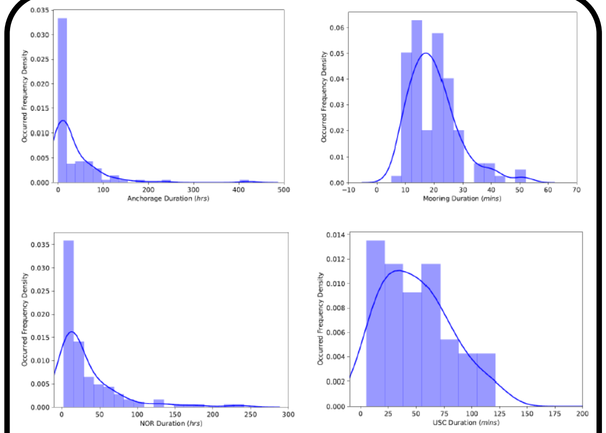
$\omega_{i,j} = 1$, i.e. vessel j is berthing at terminal i.

Buffer Time Vector:

$$\boldsymbol{T_{buffer}} = [t_1, t_2, \dots, t_n]^T$$

Total Duration for All Terminals:

$$\boldsymbol{Y} = \boldsymbol{\omega} \cdot (\boldsymbol{X} + \boldsymbol{T_{buffer}}) = [y_1, y_2, \dots, y_n]^T$$



Statistical Analyses for Buffer Time

Objective Function:

$$\boldsymbol{\omega}^* = arg \min_{\omega}(\max(\boldsymbol{Y}))$$

s.t. $\sum_{i=1}^{n} \omega_{i,j} = 1$ for $\forall j$

$\omega_{i,j} \in \{0,1\}$ for $\forall i$ and $\forall j$

Optimization Algorithm

Rule-Based

Algorithm 1 Timing Sequential Optimizer (TSO)

function: TSO(X)
$X_{sorted} \leftarrow X$ (Sorted by vessels' **arrival** time)
for (i^{th} vessel in X_{sorted}):
if $i \leq$ TerminalNumber **then**
  i^{th} terminal $\leftarrow$ i^{th} vessel
  Update i^{th} terminal's accumulated operation time
else
  k^{th} terminal has minimum accumulated operation time
  k^{th} terminal $\leftarrow$ i^{th} vessel
  Update k^{th} terminal's accumulated operation time
end if
end for
Data visualization

Rule-Based

Algorithm 3 Min Timing First Optimizer (MinTFO)

function: MinTFO(X)
$X_{sorted} \leftarrow X$ (Sorted **ascendingly** by predicted vessels' **operation** time)
for (i^{th} vessel in X_{sorted}):
if $i \leq$ TerminalNumber **then**
  i^{th} terminal $\leftarrow$ i^{th} vessel
  Update i^{th} terminal's accumulated operation time
else
  k^{th} terminal has minimum accumulated operation time
  k^{th} terminal $\leftarrow$ i^{th} vessel
  Update k^{th} terminal's accumulated operation time
end if
end for
Data visualization

Rule-Based

Algorithm 2 Max Timing First Optimizer (MaxTFO)

function: MaxTFO(X)
$X_{sorted} \leftarrow X$ (Sorted **descendingly** by predicted vessels' **operation** time)
for (i^{th} vessel in X_{sorted}):
if $i \leq$ TerminalNumber **then**
  i^{th} terminal $\leftarrow$ i^{th} vessel
  Update i^{th} terminal's accumulated operation time
else
  k^{th} terminal has minimum accumulated operation time
  k^{th} terminal $\leftarrow$ i^{th} vessel
  Update k^{th} terminal's accumulated operation time
end if
end for
Sort vessels by their arrival sequence in each terminal
Data visualization

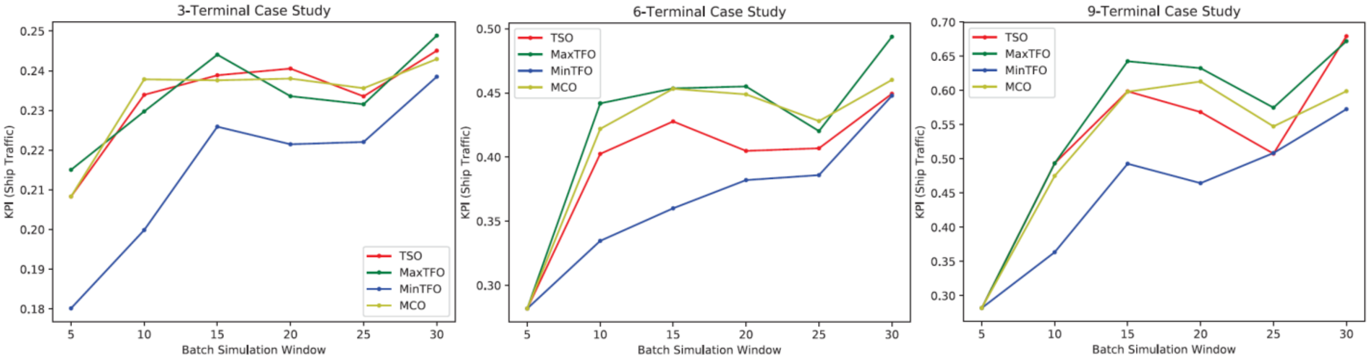
Monte Carlo-Based

Algorithm 4 Monte Carlo Optimizer (MCO)

function: MCO(X)
for (i in $iteration$):
  Randomly generate matrix of operation $\omega^{(i)}$
  Evaluate Y based on $\omega^{(i)}$
end for
$\omega^* \leftarrow \arg\min_{\omega}(\max(Y))$
Data visualization

Result (Continued)

➢ Scheduling performance: (m Tanker Vessels, n Operation-Available Terminals)



Vessel Index	Cargo Type	Cargo Volume (KL)	Operation Type	Operation Duration (hrs)
1	150N	5000	Loading	17.8867
2	600N	2000	Unloading	6.3228
3	TOLUENE	1000	Loading	4.0197
4	BUTADIENE	1000	Loading	5.6113
5	500N	2000	Unloading	6.3228
6	YUBASE 3	3000	Unloading	11.3249
7	MTBE	2000	Unloading	6.7379
8	LIGHT CYCLE OIL	3000	Unloading	7.3312
9	CAUSTIC SODA	2000	Unloading	9.876
10	CUMENE	1000	Loading	5.4979
11	STYRENE MONOMER	3200	Loading	11.6465
12	EHC 50	1000	Loading	5.4979
13	BUTANE	1000	Unloading	6.216
14	METHYL ACETATE	1500	Unloading	4.2487
15	SK500N	1500	Unloading	8.7359
16	YUBASE 6	5000	Unloading	17.9942
17	DACO	2300	Loading	9.9221
18	PHENOL	1200	Unloading	5.5161
19	LIGHT CYCLE OIL	3000	Unloading	7.3312
20	WHITE SPIRIT	2500	Unloading	6.827
21	MTBE	6000	Loading	14.6288
22	ISOPAR L	1000	Loading	4.8896
23	SK120BS	2800	Unloading	14.6089
24	YUBASE 6	4500	Unloading	16.3269
25	OX	3200	Loading	11.545
26	SN100	2600	Unloading	13.7054
27	ACETIC ACID	3400	Unloading	7.7346
28	STYRENE MONOMER	3900	Loading	14.0733
29	D-SOL 200	2000	Unloading	6.7379
30	PYGAS	1800	Unloading	6.5016

Given scenarios, $m = 30$ and $n = \{3,6,9\}$.

KPI (Ship Traffic) is defined as follows:

$$KPI = \frac{m}{T}$$

where T is the total handling period from the first vessel berthed to the last vessel unberthed in the port.

Conclusion

- In this study, multiple predictive models for predicting berth stay of tanker vessels are evaluated with various kinds of cargo types.
  - The results show that the volume-based least squares model outperforms others with R^2(0.7495)

- In this study, four optimizers for scheduling operations of tanker vessels are studied for three given simulation scenarios.
  - MaxTFO effectively outperforms the other optimizers based on the selected KPI, which indicates that the utilization efficiency of terminals.
  - MCO is more applicable for narrow window cases (i.e. when the information of future vessel and cargo is relatively limited).

- A number of assumptions have to be highlighted in this study
  - Assumptions made for research simplicity purpose, some aspects in practical maritime operations are not taken into considerations, such as multiple-cargo, multiple-terminal visit, etc.
  - These are the tasks of our near future research in the field of maritime.

Acknowledgement

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Thanks!
Q&A