Risk-Based Waterway Design

Pentti Kujala

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Content:

- Ways for Risk Assessment (RA)
- Decision Support Tools as a way for RA
- Ship Maneuverability
- Maneuvering Patterns in Waterways
- Waterway Complexity

Source: Mazaheri et al. (2014), "Assessing Grounding Frequency Using Ship Traffic and Waterway Complexity"

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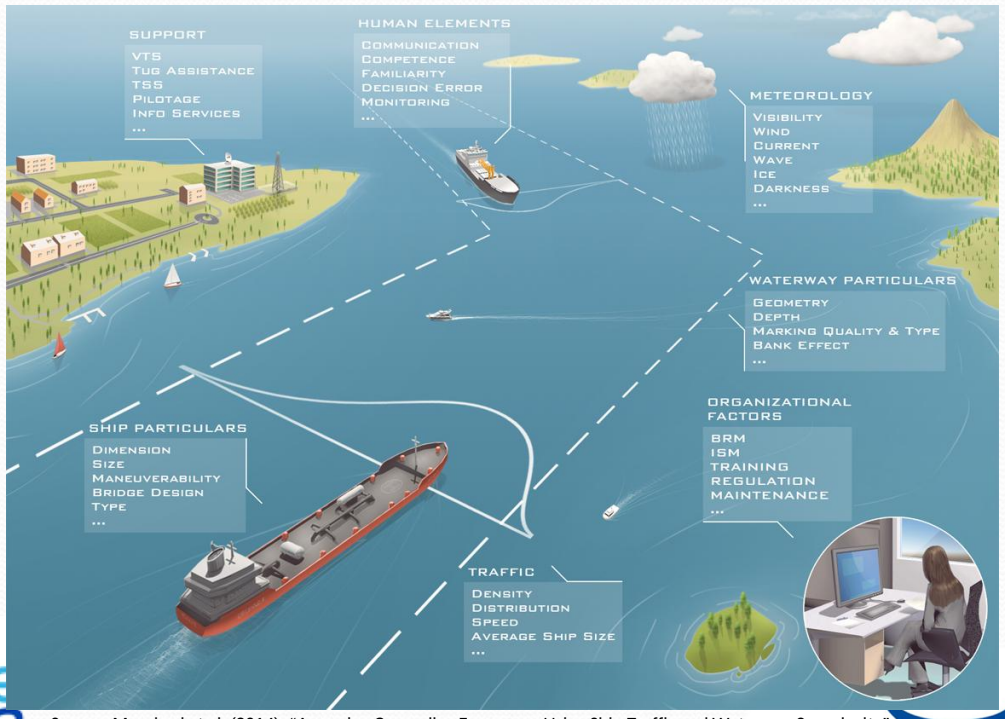
There are many factors that need to be considered …



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Practices to perform risk assessment

Approach	Main Advantages	Main Disadvantages
Statistical method	Long been regarded as the only reliable sources	Limitation with incident reports, difficulty in application to the future
Comprehensive risk analysis	Rational, includes consequences	Relies on accident data for benchmarking
Stochastic method	Predict unfavourable conditions, inexpensive	Targets known scenarios, limits choice of software/programs, restricted to occurrence probability
Computer simulation method	Target extreme condition	Could left out certain information in real life
Expert opinions	Long been used when limited by data	Subjective

Source: Sulaiman et al. (2011) "Safety and Environmental Risk and Reliability Model for Inland Waterway Collision Accident Frequency"

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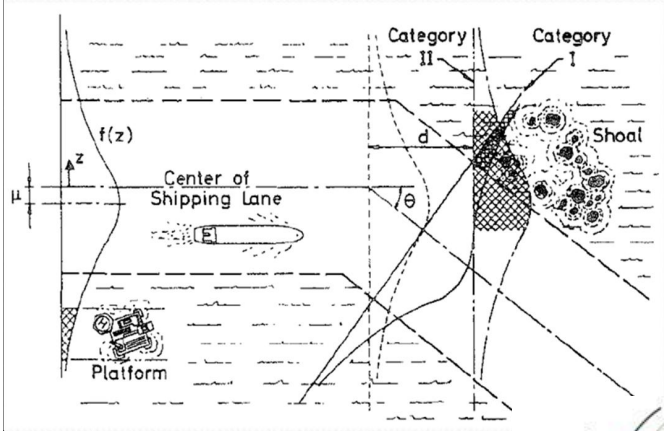
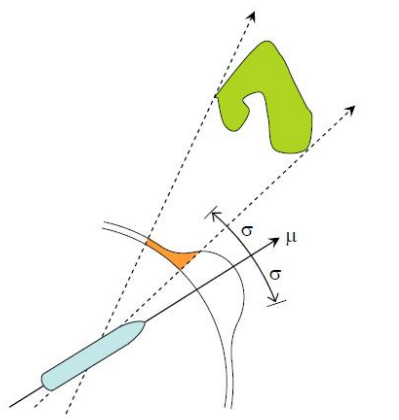
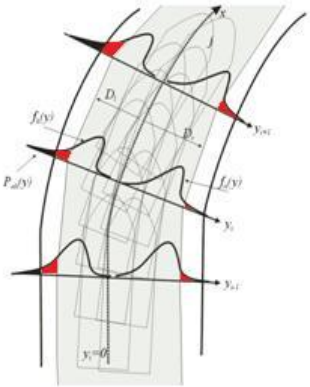
Traditional probability of frequency approaches



Pedersen, 1995



COWI, 2008



Gucma, 2006

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Best practice: Hybrid

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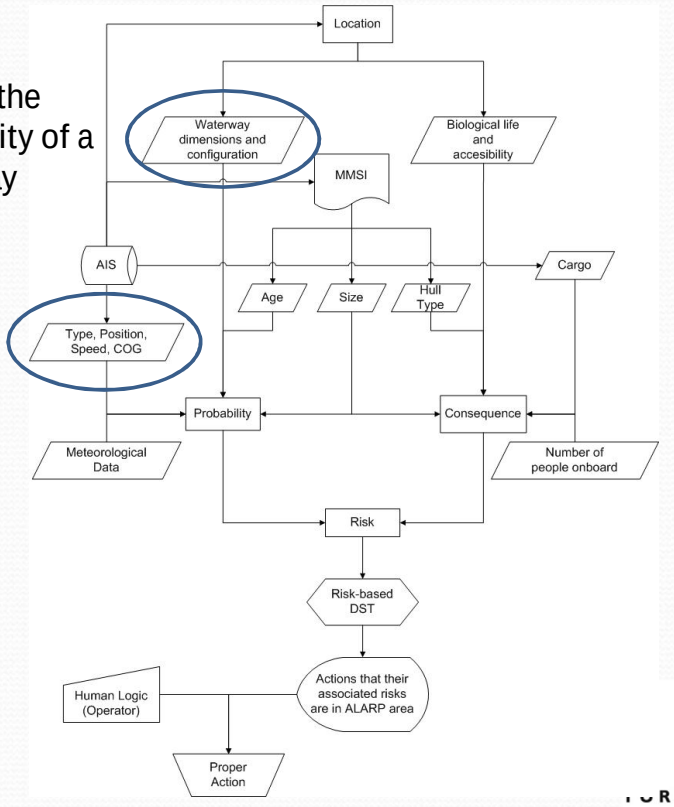
Risk-Based DST for Monitoring the Risk

Defines the complexity of a waterway

Defines the maneuverability of the vessels



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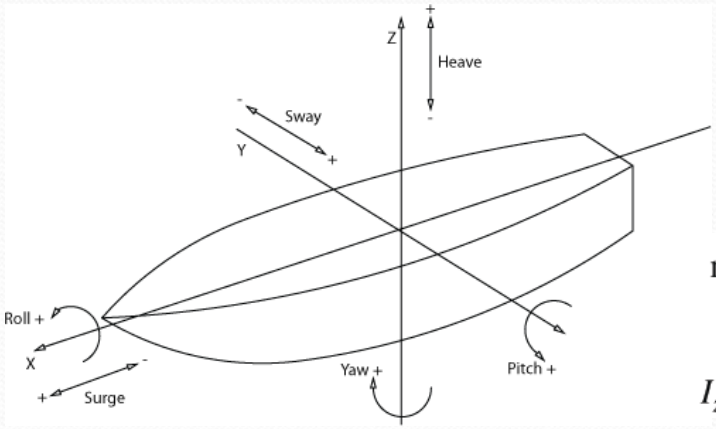
In-plane motion of a ship maneuvering

Quasi-linear modular hydrodynamic model

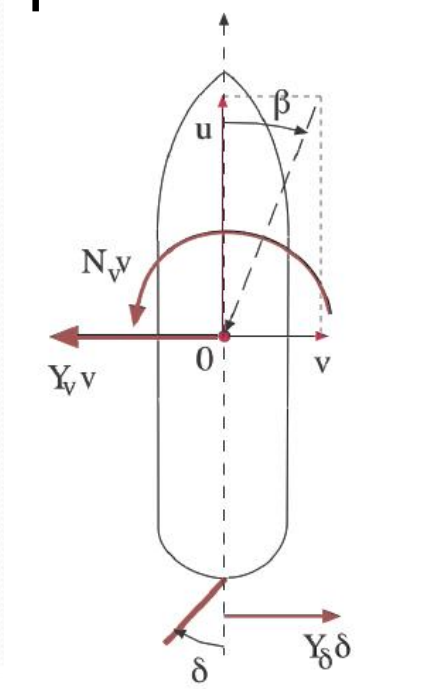


$$m(\dot{u} - rv) = X \quad \text{Surge}$$
$$m(\dot{v} + ru) = Y \quad \text{Sway}$$
$$I_z\dot{r} = N \quad \text{Yaw}$$

$$m\left(\dot{u} - rv - x_G r^2\right) = X \quad \text{Surge}$$
$$m\left(\dot{v} + ru + x_G\dot{r}\right) = Y \quad \text{Sway}$$
$$I_z\dot{r} + mx_G\left(\dot{v} + ur\right) = N \quad \text{Yaw}$$

Source: Jerzy Matusiak, Ship Dynamics

In-plane motion of a ship maneuvering

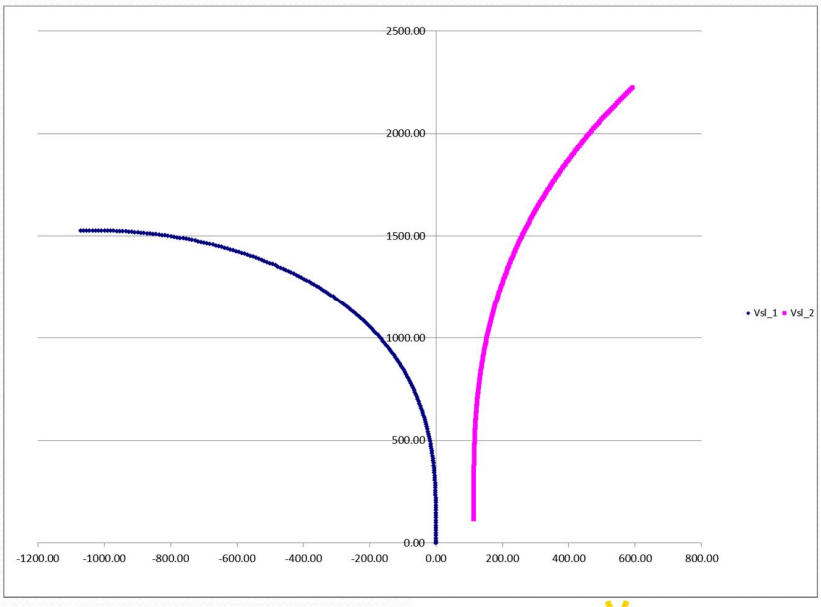


Source: Jerzy Matusiak, Ship Dynamics

- Applied forces:
  - Rudder Action
  - Hull Resistance
  - Propeller Thrust
  - Bank effect
  - Squat effect
  - Wind
  - Wave
  - Current

Ship maneuvering

- Duration: 3 min
- Vessel no.1
  - L = 300 m
  - B = 35 m
  - T = 15 m
  - V = 24 kn
  - Rudder = 45º Port
- Vessel no. 2
  - L = 300 m
  - B = 35 m
  - T = 15 m
  - V = 24 kn
  - Rudder = 15º Stb



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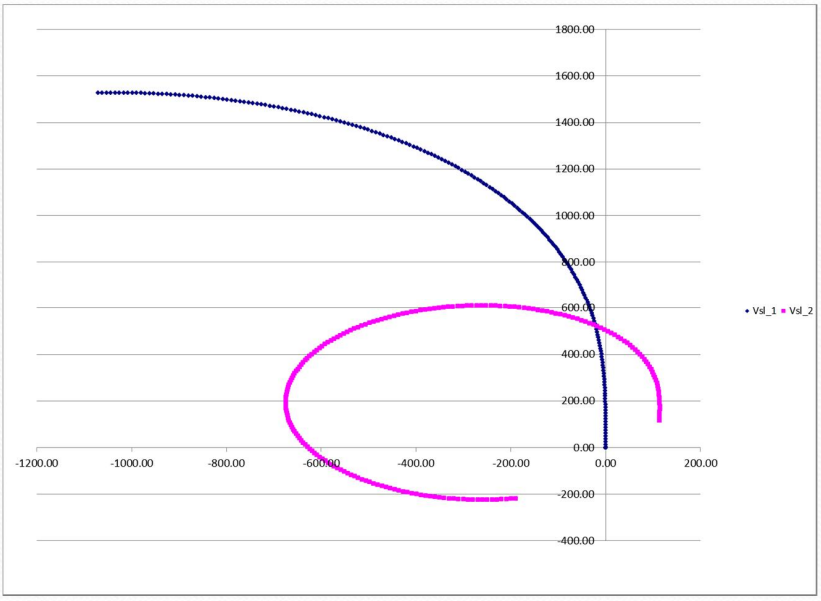
Ship maneuvering

- Duration: 3 min
- Vessel no.1
  - L = 300 m
  - B = 35 m
  - T = 15 m
  - V = 24 kn
  - Rudder = 45º Port
- Vessel no. 2
  - L = 150m
  - B = 15 m
  - T = 10 m
  - V = 24 kn
  - Rudder = 45º Port



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Ship maneuvering

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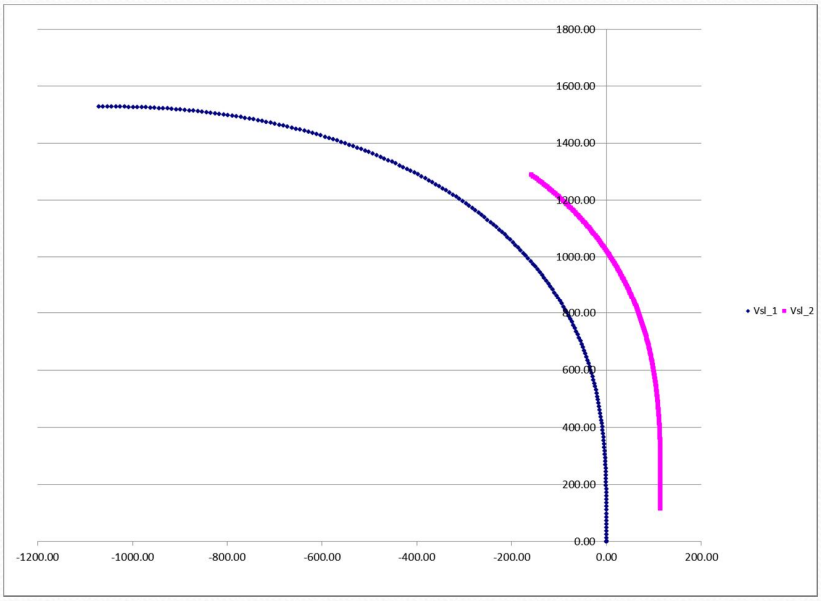
  - T = 15 m
  - V = 24 kn
  - Rudder = 45º Port
- Vessel no. 2
  - L = 150m
  - B = 15 m
  - T = 10 m
  - V = 12 kn
  - Rudder = 45º Port



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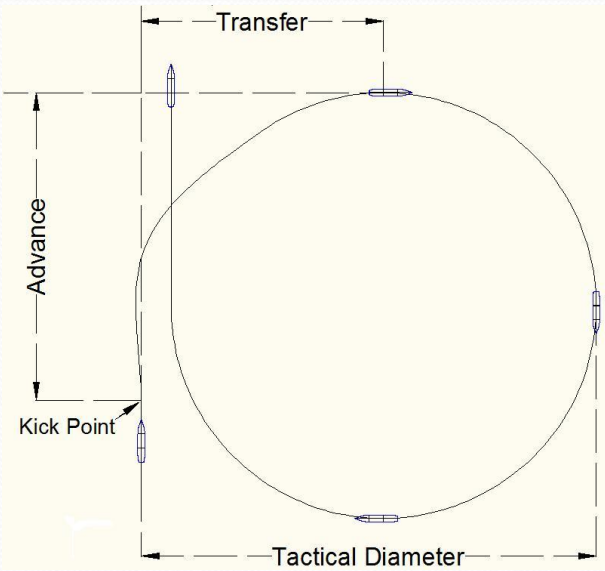
Ship Inner Domain concept based on the turning circle in maximum rudder angle



Turning Circle of a vessel

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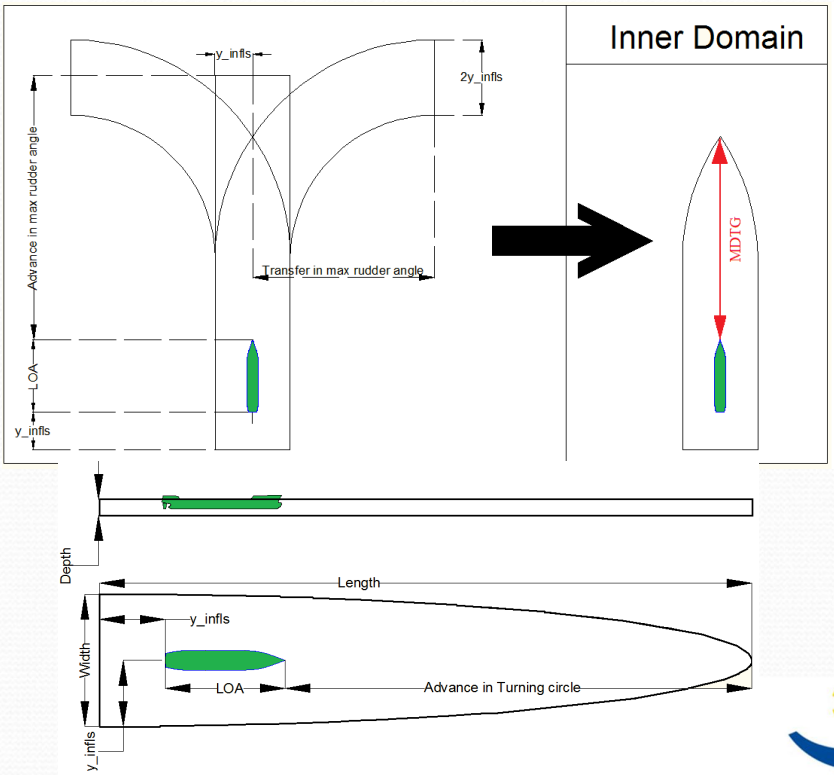
Ship Domain as a tool for monitoring the risk



Source: Mazaheri et al. (2012) A decision support tool for VTS centers to detect grounding candidates

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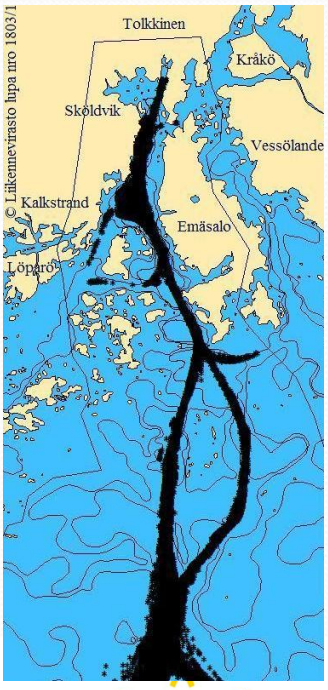
Maneuvering pattern in a waterway

- The way how the navigators handle ships along the analyzed waterway is called a maneuvering pattern,
- The maneuvering pattern can be obtained based on recorded, historic traffic through a waterway by utilizing Case Based Reasoning (CBR) method,
- To define the maneuvering pattern the following parameters can be analyzed:
  - Ship type
  - Main dimensions
  - Distance of the beginning of the maneuver related to the obstacle
  - Position across the waterway
  - Course over ground
  - Speed



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Maneuvering pattern in a waterway

Case Based Reasoning (CBR):

- Method of using previously experienced problems to find a solution for solving similar problems (Nagaiah, 2011).
- Method of using solutions of old cases to provide context for understanding or assessing a situation (Kolodner, 1993)
- For Maneuvering Pattern: how the performing maneuver of an observed vessel relates to the pattern of the historic traffic of the similar vessels in the same waterway

CBR requires:

- A database of solved problems (*AIS and meteorological data*).
- The indices to retrieve resembling cases from the database (*Location, Type, Length, etc.*); the more indices, the more similar the retrieved cases are.
- A pattern matching algorithm to detect the maneuvering pattern of the resembled cases

NAGAIAH, M. D. (2011) Agent-based CBR for decision support system. International Journal of Scientific & Engineering Research, 2.
KOLODNER, J. (1993) Case-Based Reasoning, Morgan Kaufmann Publishers.

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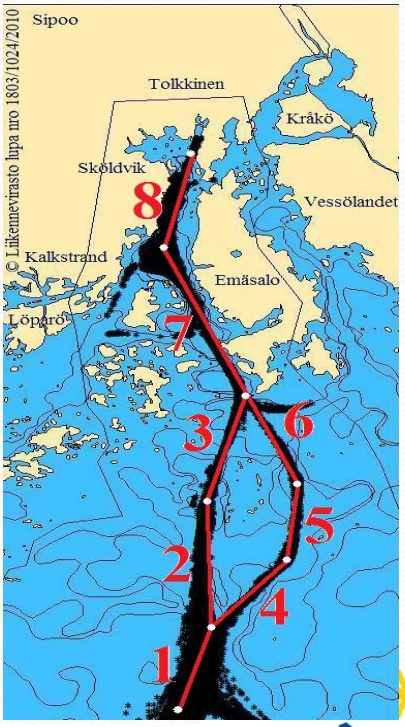
Maneuvering pattern in a waterway

- One of the elements of the maneuvering pattern is the location at which navigators started to turn their ships in order to follow the waterway.



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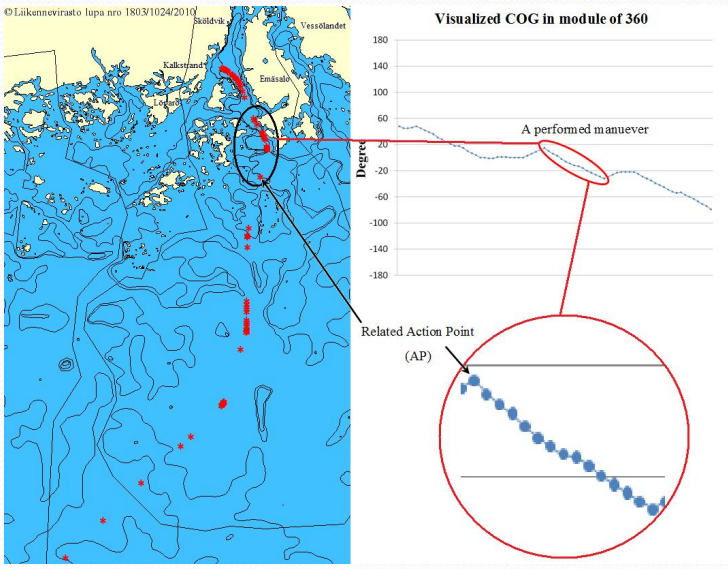
Maneuvering pattern in a waterway

- One of the elements of the maneuvering pattern is the location at which navigators started to turn their ships in order to follow the waterway.
- That location for a given bend can be obtained through the analysis of the changes of the course over ground of a vessel.



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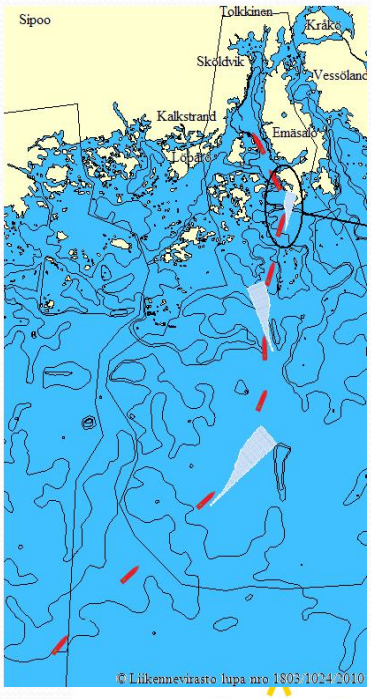
Maneuvering pattern in a waterway

- Histograms of the starting points can be converted into continuous cumulative density functions (CDF)
- Thus each bend gets its own indicator showing continuously to a ship approaching a bend, a percentage of ships that already made a turn in front of this bend.



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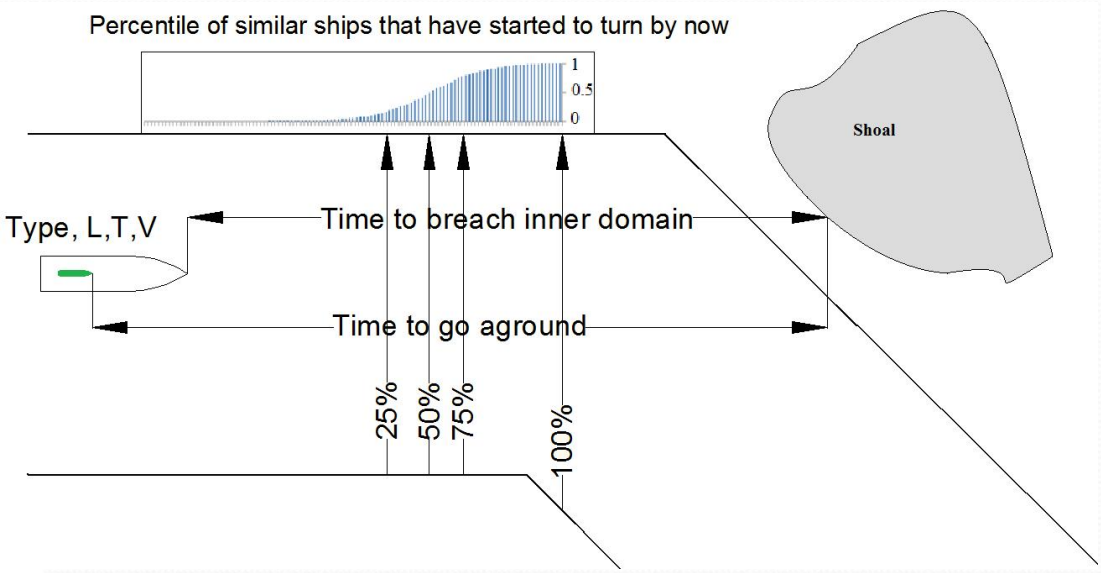

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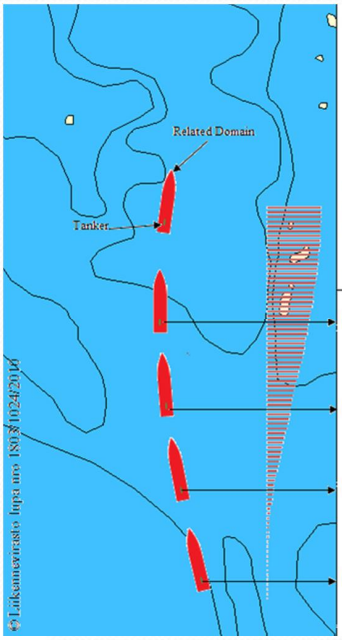
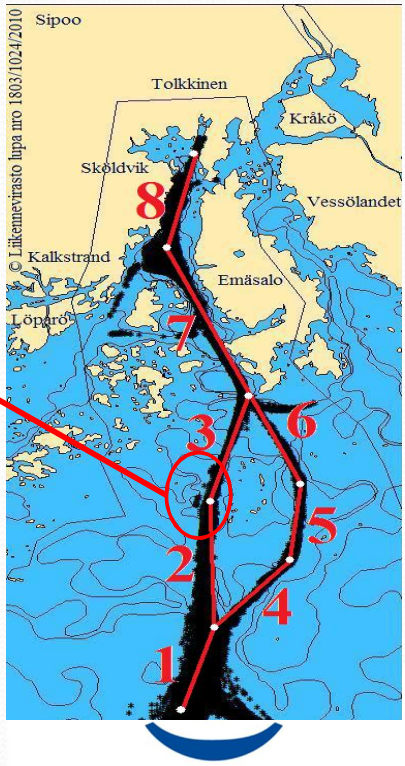
Maneuvering pattern in a waterway



Speed [kn]	Percentile of Similar ship that have turned by now [%]	Time to breach the domain, maintaining speed and COG [min]	Time to go aground , maintaining speed and COG [min]
15.6	81	9	11
15.5	36	7	9
15.3	11	9	11
15.3	0	11	13



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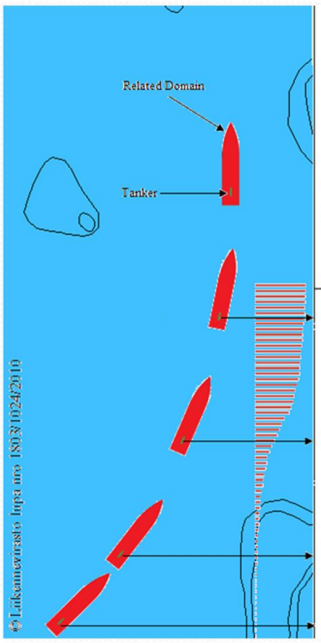
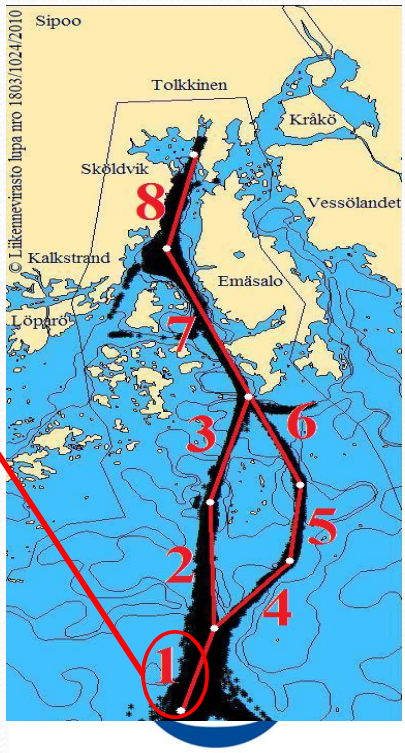


Speed [kn]	Percentile of Similar ship that have turned by now [%]	Time to breach the domain, maintaining speed and COG [min]	Time to go aground , maintaining speed and COG [min]
15.7	99	8	10
15.7	34	13	15
15.8	8	15	17
15.7	0	18	20



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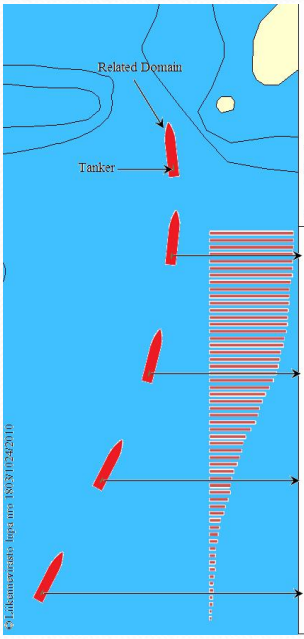
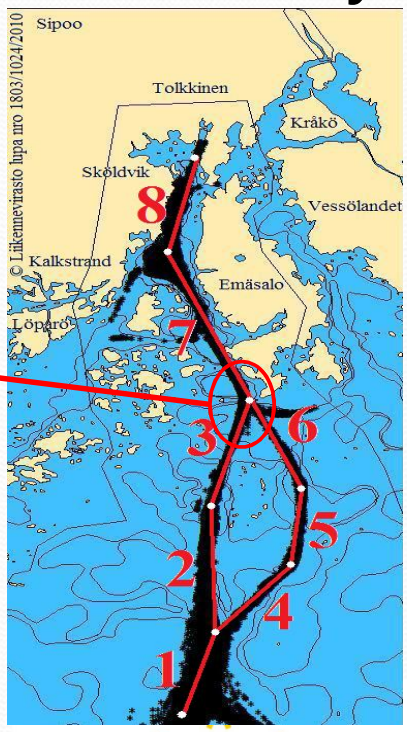


Speed [kn]	Percentile of Similar ship that have turned by now [%]	Time to breach the domain, maintaining speed and COG [min]	Time to go aground , maintaining speed and COG [min]
15.5	99	3	5
15	84	5	7
15.7	18	6	8
15.8	4	8	10



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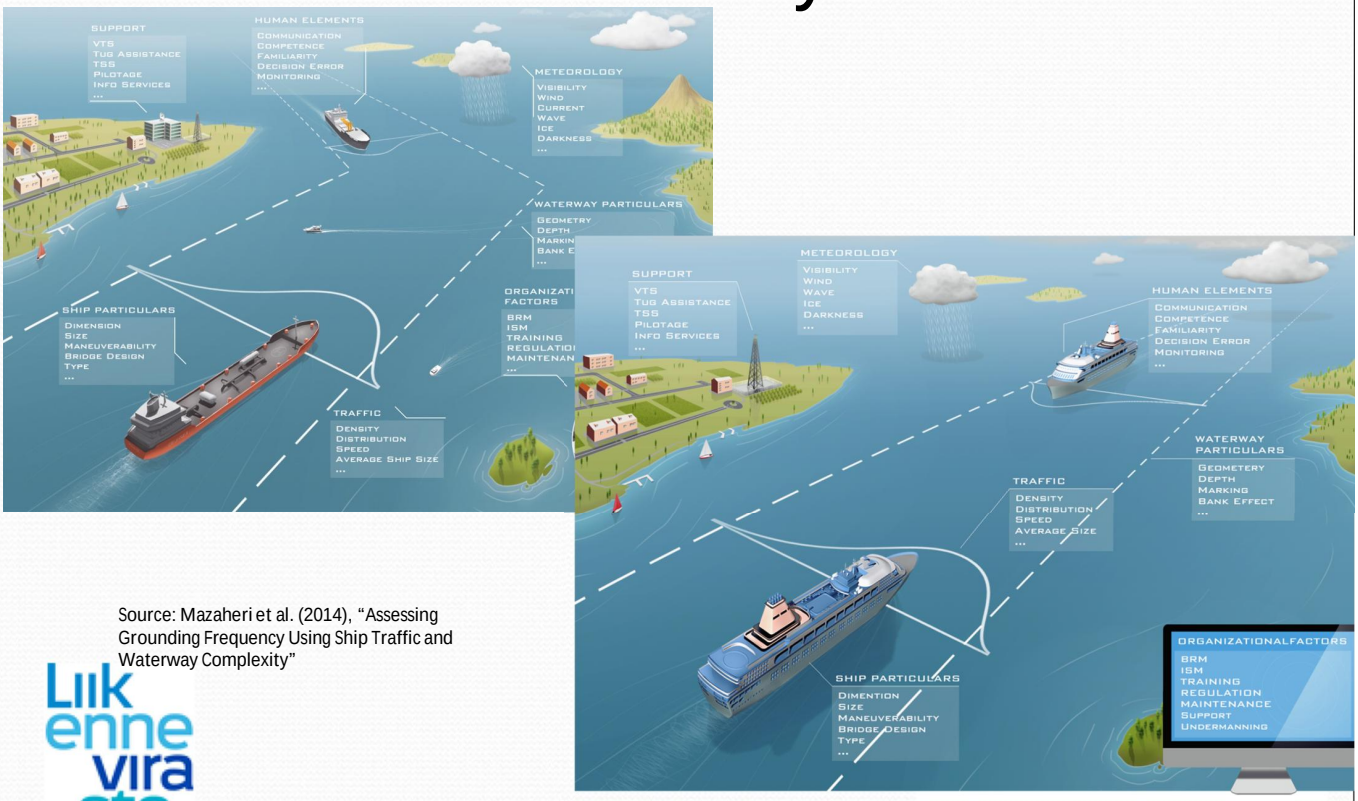
Waterways



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Waterway Complexity Index as a tool

Waterway	Pilot 1	Pilot 2	Pilot 3	Pilot 4	Pilot 5	Pilot 6	Pilot 7	Pilot 8	Pilot 9	Pilot 10	Pilot 11	Pilot 12	Average	WCI
Kotka	–	–	8	–	–	9	–	–	8	10	8	8	**8·5**	**0·75**
Sköldvik	8·5	8	9	10	7	9	9	8	–	–	–	–	**8·6**	**0·76**
Helsinki-West	7	9	8·5	9	8·5	–	–	8·5	–	–	–	–	**8·4**	**0·74**
Helsinki-South	6	8	8	8	5	–	–	8	–	–	–	–	**7·2**	**0·53**
Hamina	–	–	7	–	–	8	–	–	7·5	8·5	8	8	**7·8**	**0·64**

Affecting parameters:

- Ship draught and size in relation to the available space.
- The need for reduction of ship speed under certain circumstances, e.g. in the presence of two-way traffic.
- Width of the waterway, especially when two-way traffic is allowed.
- Number of turns and the magnitude of course alteration.

Source: Mazaheri et al. (2014), "Assessing Grounding Frequency Using Ship Traffic and Waterway Complexity"

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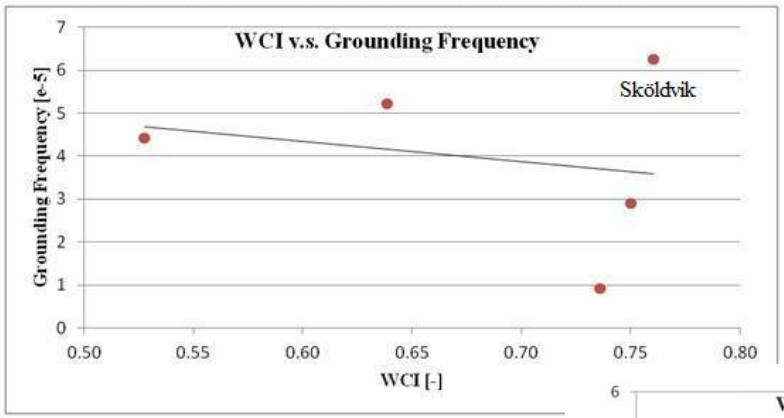

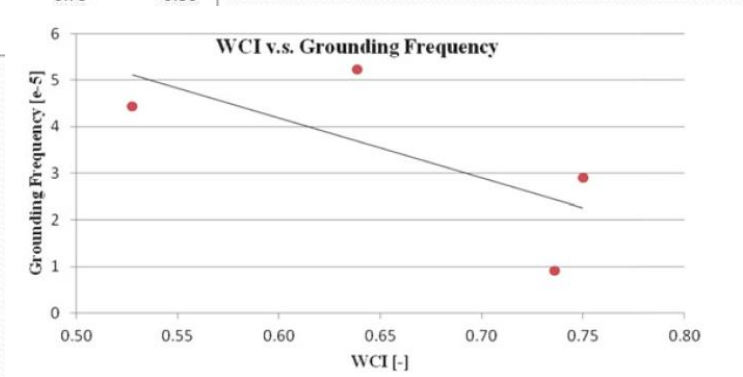

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