17th PA SAFE Steering Committee Meeting, Gdynia 9th Nov 2017

COLLISION AVOIDANCE: METHODS AND ALGORITHMS

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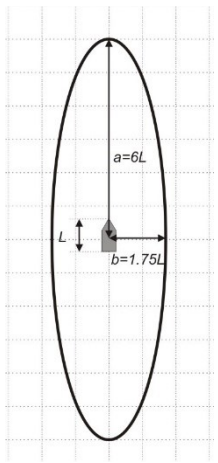
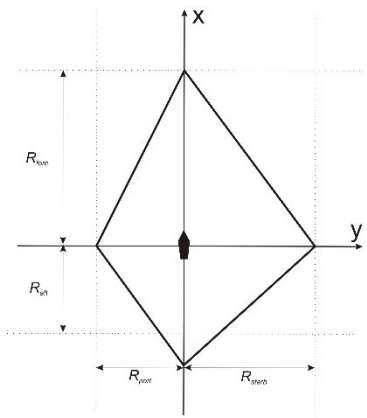
Agenda

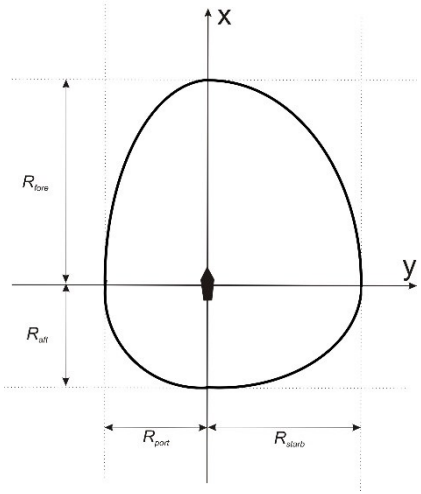
1. Ship domains and collision risk-related problems
   - ship domain: what is it?
   - why is it good to use it?
   - how and where can it be applied?
2. Optimisation methods in collision avoidance
   - evolutionary method: how does it work?
   - why is it good to use it?
   - how to make the most of it?

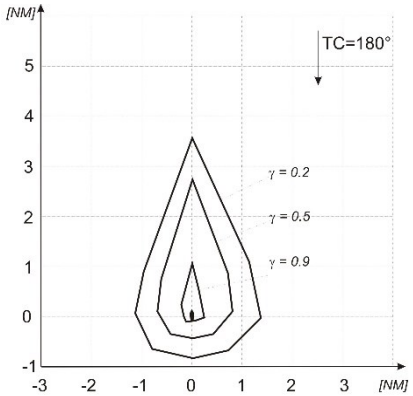
What a ship domain is?

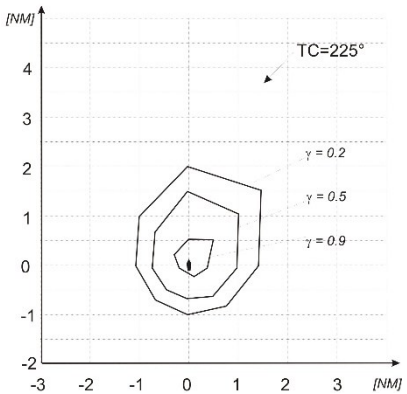
An area surrounding a ship which other ships must avoid











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Why is it good to use ship domains? (1)

Ship domain

- **is able to synthesize a number of collision risk-related parameters**
  - Distance at the Closest Point of Approach (*DCPA*)
  - target's bearing
- **may be directly used as a safety criterion (with little to no additional collision risk analysis)**
- **has a graphical representation, which a navigator can relate to**
- **has been already researched well**

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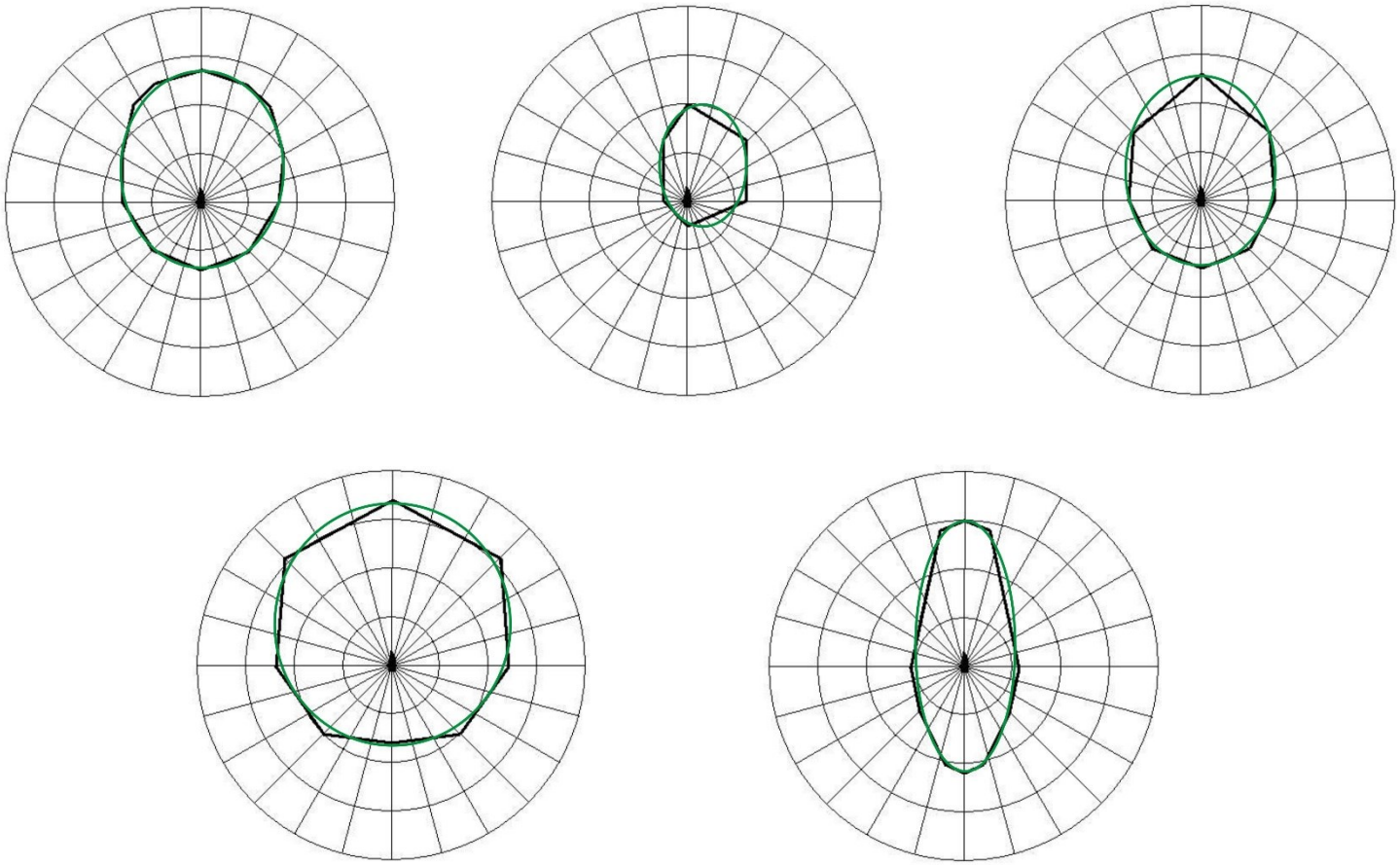
Why is it good to use ship domains? (2)

Ship domain

- **there are ready-to-use models applicable to**
  - various types of water areas – open or restricted waters
  - local water regions (e.g. research made for Danish waters, Singapore Port Area, etc.)
- **an additional AIS-based research for a local water region can be performed to obtain a regional ship domain**
    - ship's length as basic parameter
- **Practically any domain shape can be approximated**
  - by an off-centred ellipse
  - by a polygon of up to 16 nodes

Domain approximations



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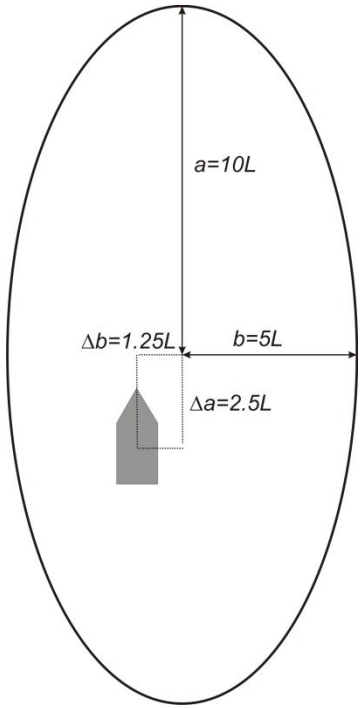
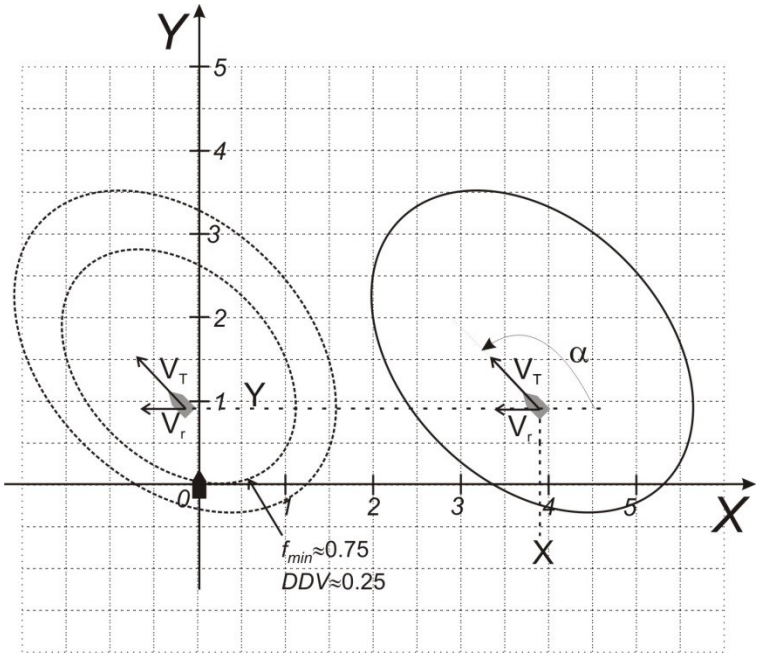
Measuring domain violations

- **Binary info (domain violated or not) is not enough**
- **We may also be interested in**
  - **what is the degree of domain violation?**
  - **how much time we have before domain violation?**
- **That is why collision risk parameters are introduced**
  - **Time to Domain Violation (*TDV*)**
  - **Degree of Domain Violation (*DDV*)**
  - **Both are computed analytically for off-centred elliptic domains**
  - **Analytical solution means constant computational time – does not slow down the system**

Degree of Domain Violation



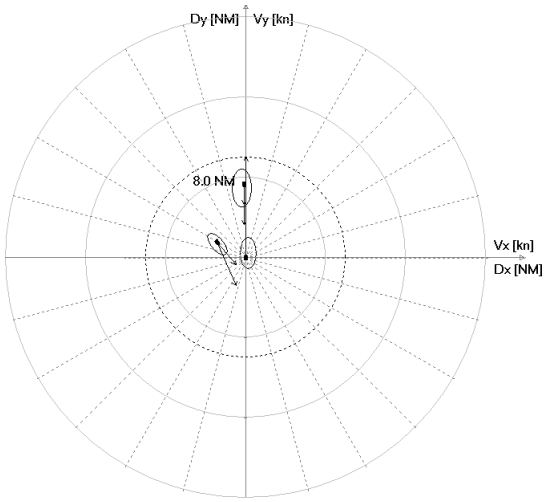
An off-centred elliptic ship domain (*L* – ship's length)



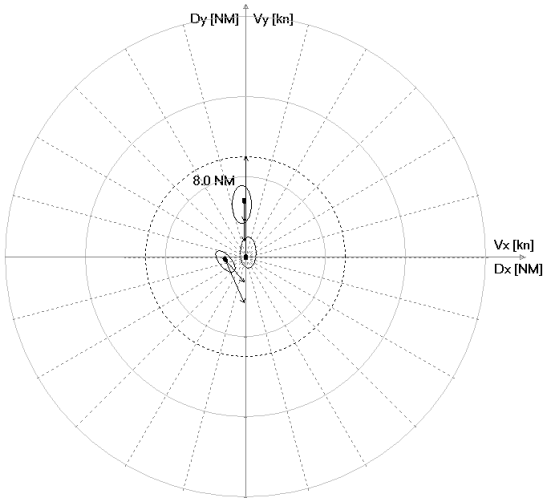
A predicted violation of a target's domain presented in the own ship's relative coordinate system
(V_T – true speed, V_r – relative speed)
DDV = 0.25

Domain applied to CAS

- ***TDV* and D*DV* can be applied in Collision Alert Systems**



A warning is generated for the target ahead: *DDV*=0.77, T*DV*=15 min.



An alarm is generated for the target ahead: *DDV*=0.77, *TDV*=10 min.

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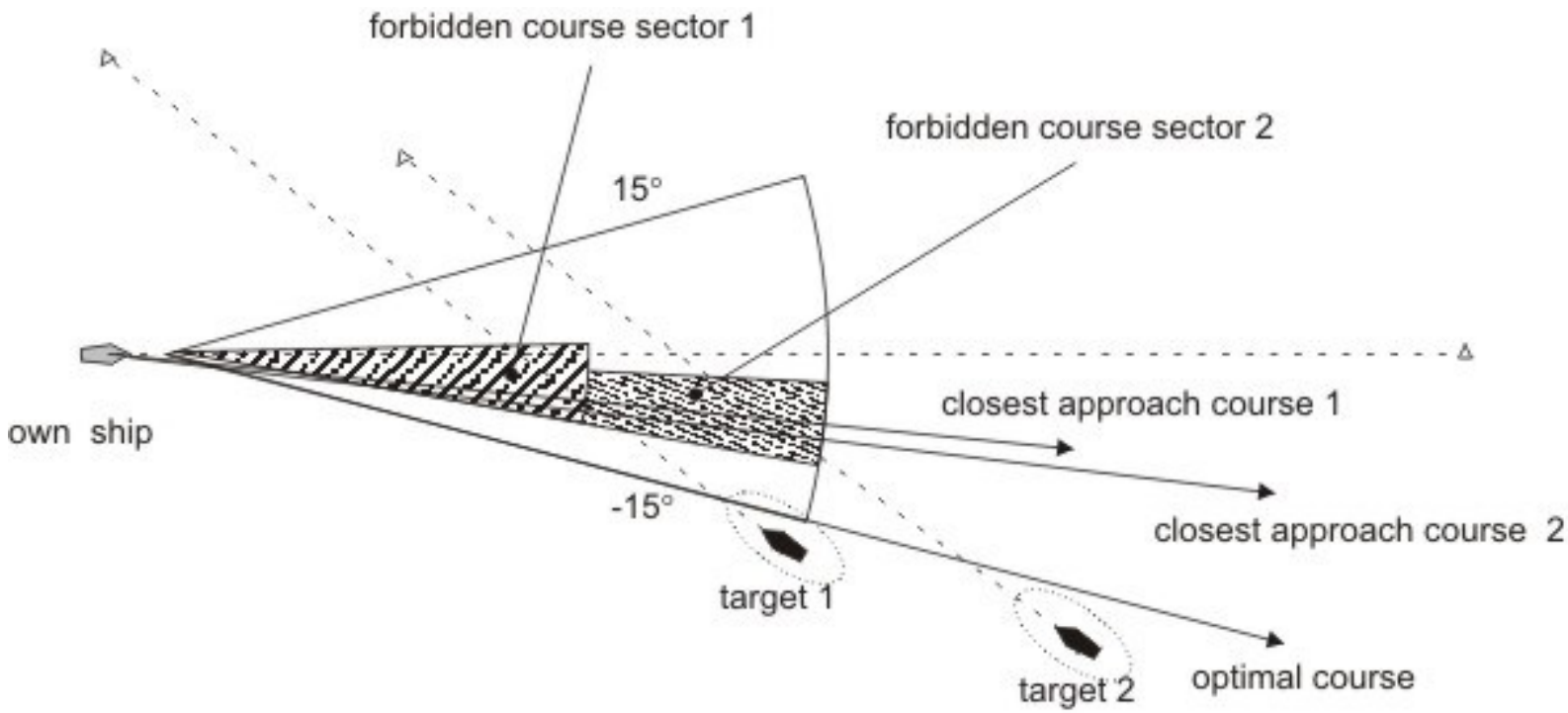
Domains applied for near-miss detection

- **Based on the *DDV* and V_r (relative speed), a set of simplified rules can be introduced**
  - ***DDV*=0 => safe**
  - **(*DDV*<0.1 & V_r<10kn.) => safe**
  - **(*DDV*<0.2 i V_r<5kn.) => safe**
  - ***DDV*≥0.4 => near-miss**
  - **(*DDV*>0.2 & V_r>15kn.) => near-miss**
  - **(*DDV*>0 & V_r>25kn.) => near-miss**
- **Rules are then transformed for fuzzy near miss detection method**

Collision avoid. manouvres

- **Based on the *DDV* a course alteration necessary to avoid domain violation can be determined by a fast gradient method**



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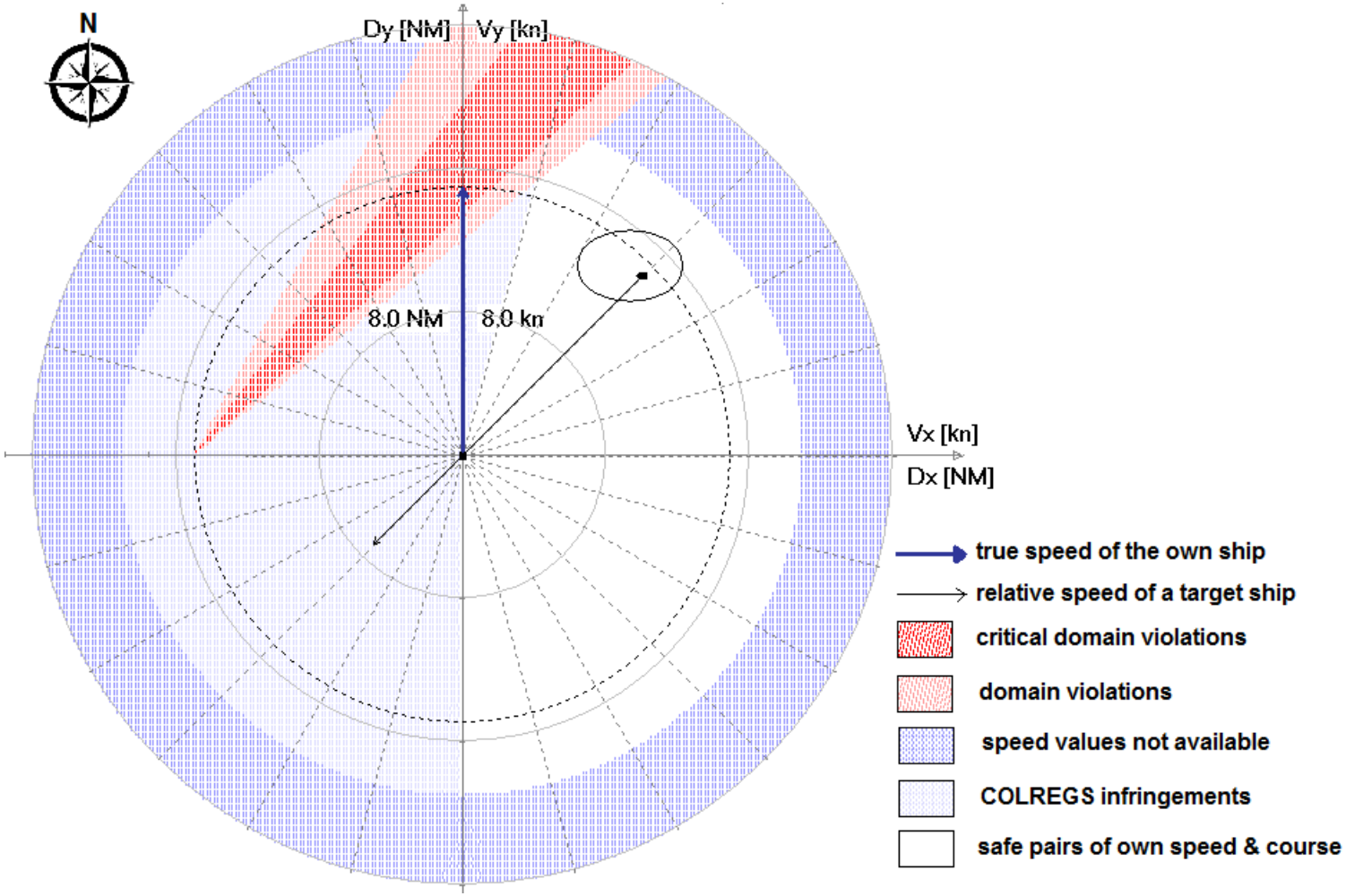
Visualising safe manouvres



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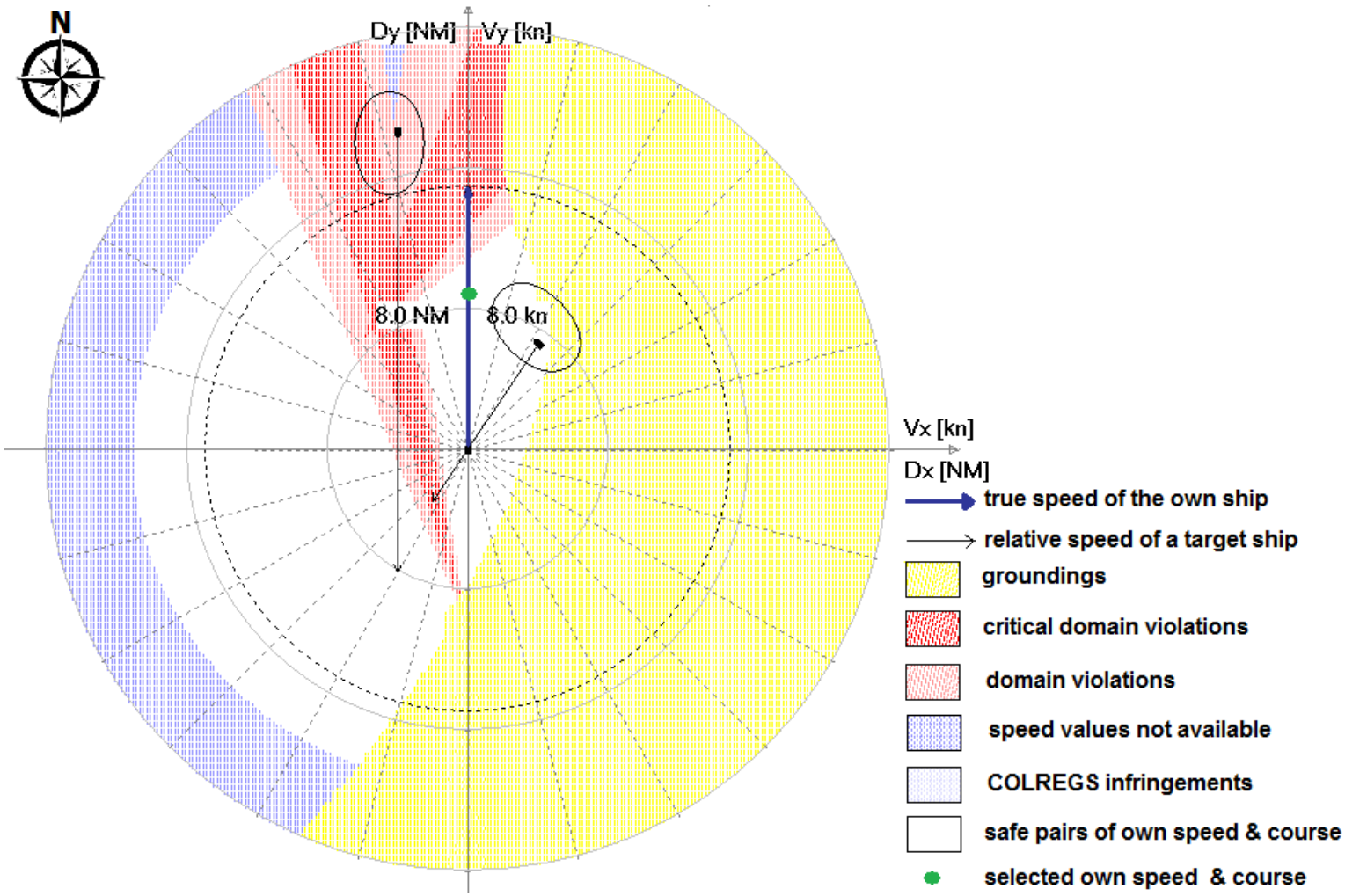
Restricted water manouvres



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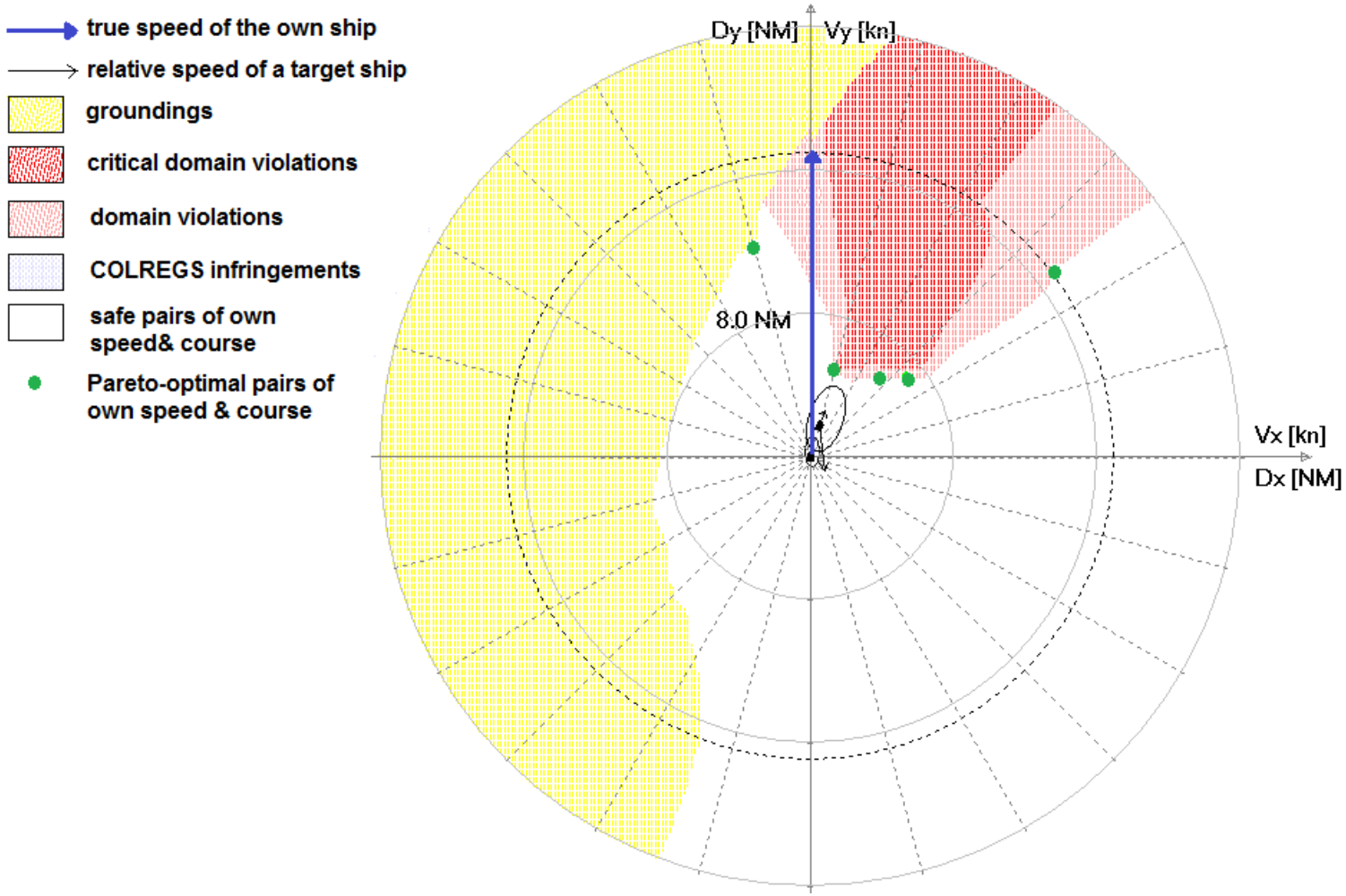
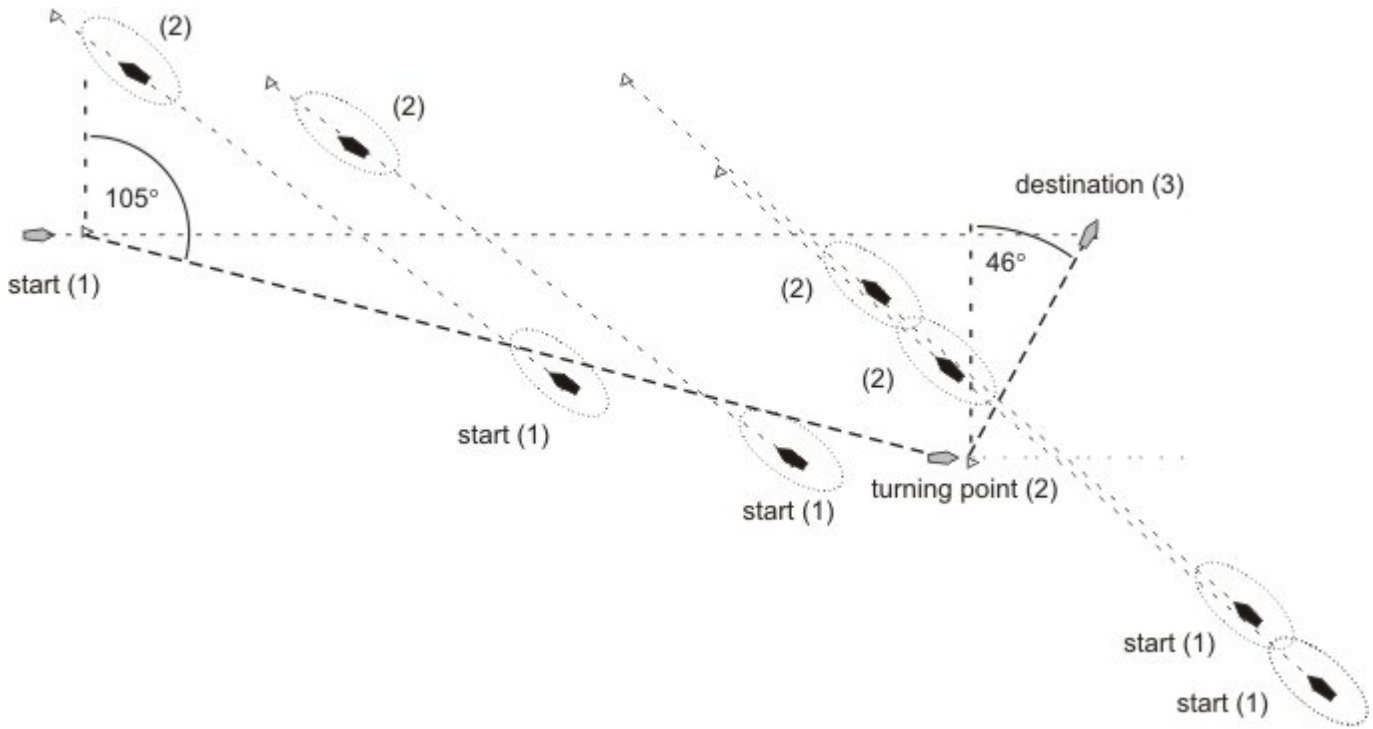
Pareto optim. (course&speed)



Multiple manouvres

If we are interested in more than a single course alteration manouvre

- **some optimisation method should be brought to the table**



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Evolutionary method: optimising ship trajectories

- The method uses Evolutionary Alhorithms (EA)
- Takes input data
  - stationary constraints
  - positions, courses and speeds of all ships involved
  - ship domains based on ships' lengths (optionally: speeds)
  - approximated ships' dynamics (if available)
- Returns a set of safe trajectories of all ships involved
- EA are open for incorporating user-defined operators and heuristics designed for the problem in hand

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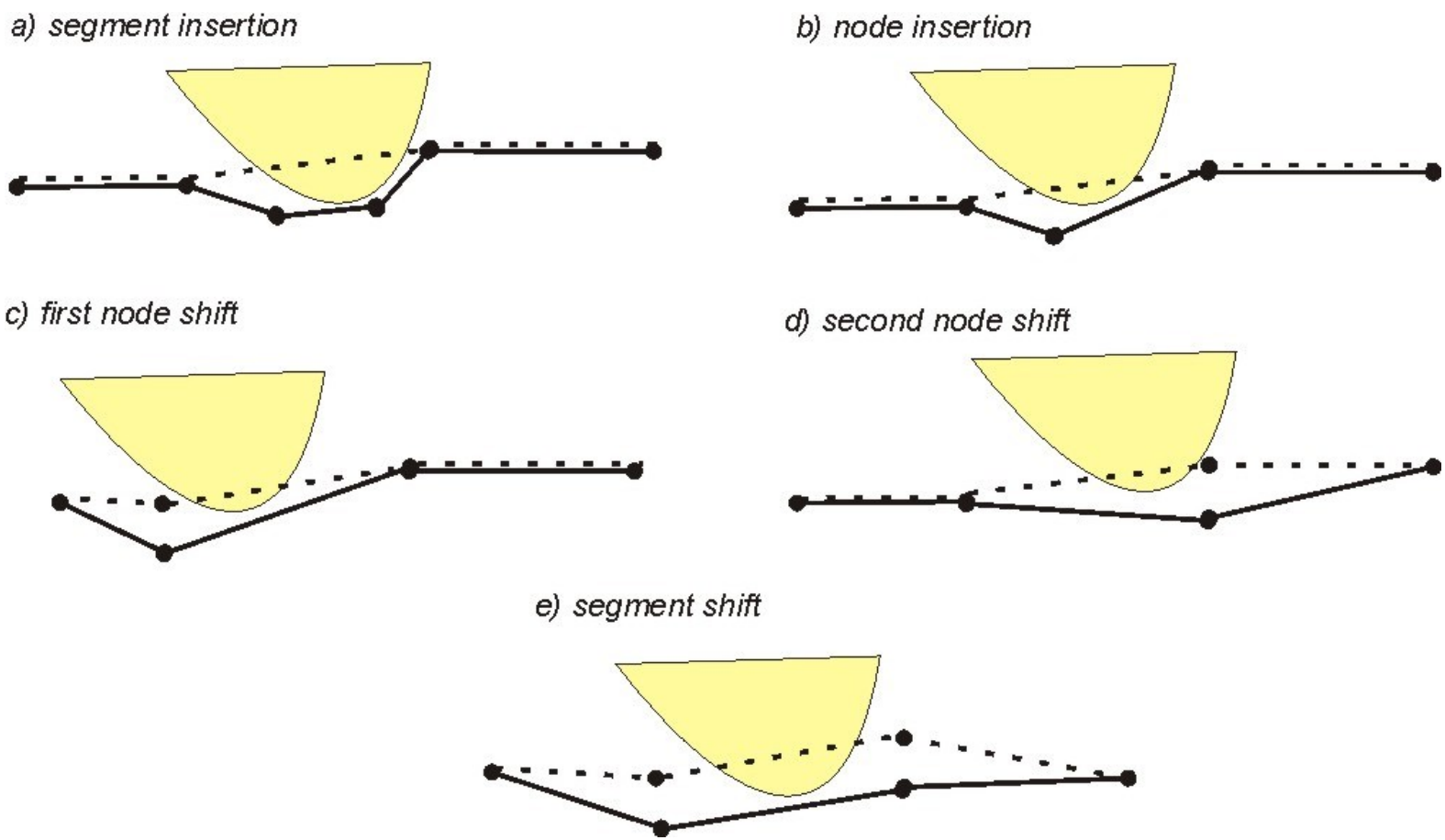
Operators for avoiding collisions with obstacles



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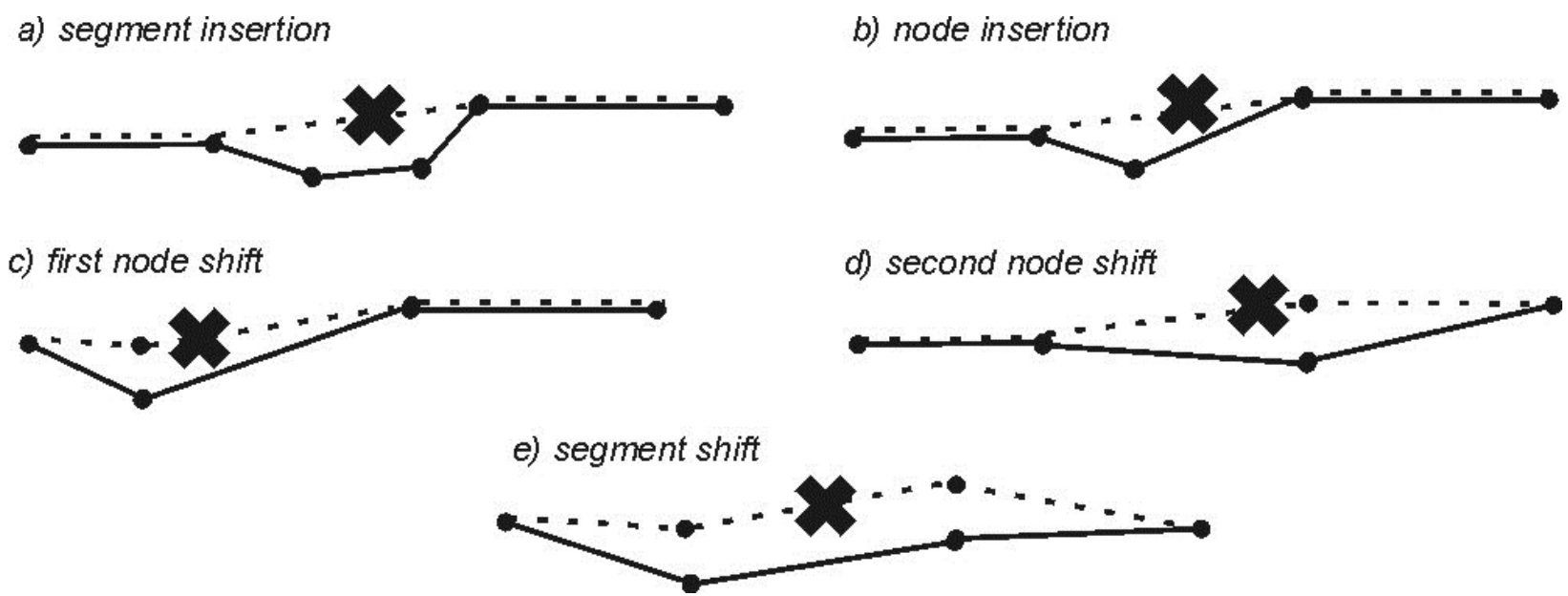
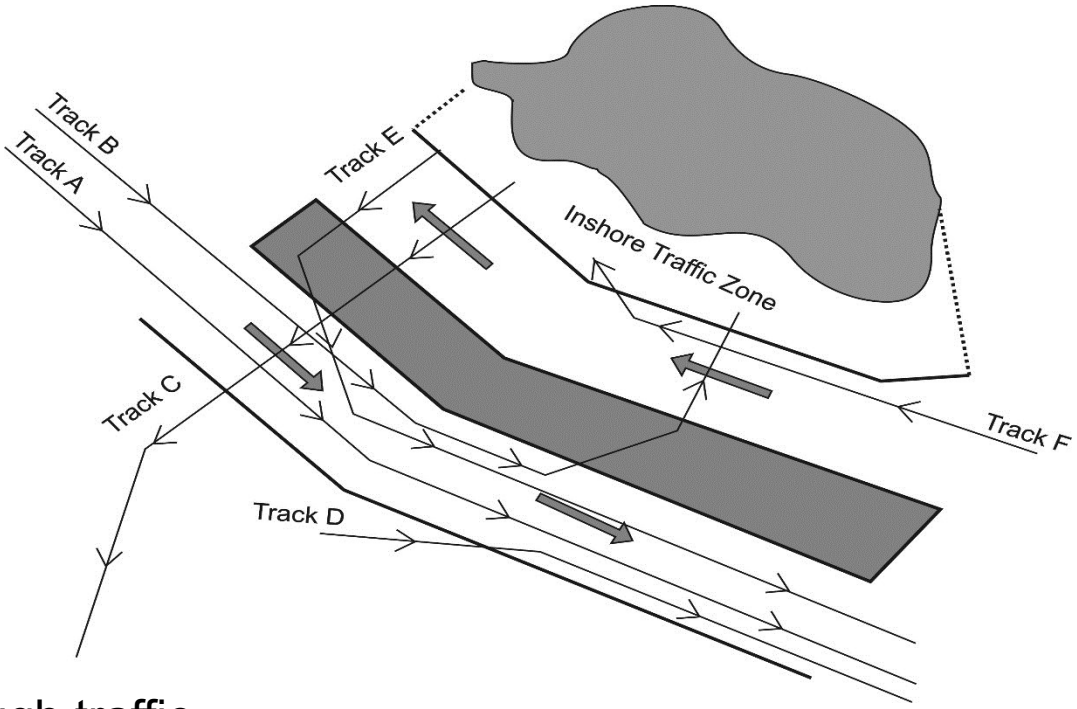
Operators for avoiding collisions with targets



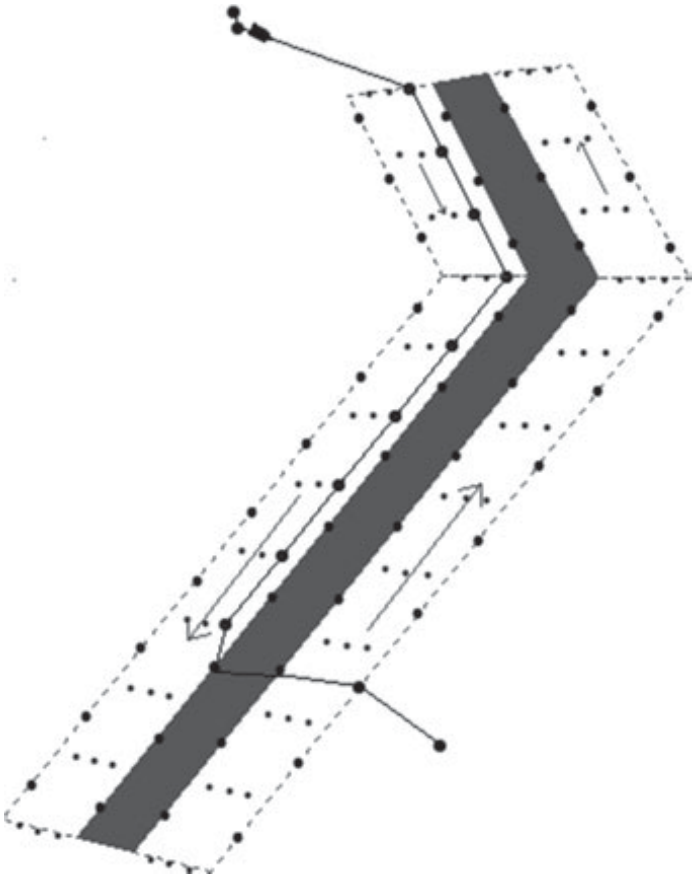
ESoSST: TSS traffic patterns



Track A – through traffic
Track B – traffic using a lane and crossing another lane to reach an ITZ
Track C – traffic crossing TSS at right heading
Track D – traffic joining lane from the side
Track E – traffic leaving the ITZ, crossing one lane and joining the other lane
Track F – traffic leaving the lane at a small angle

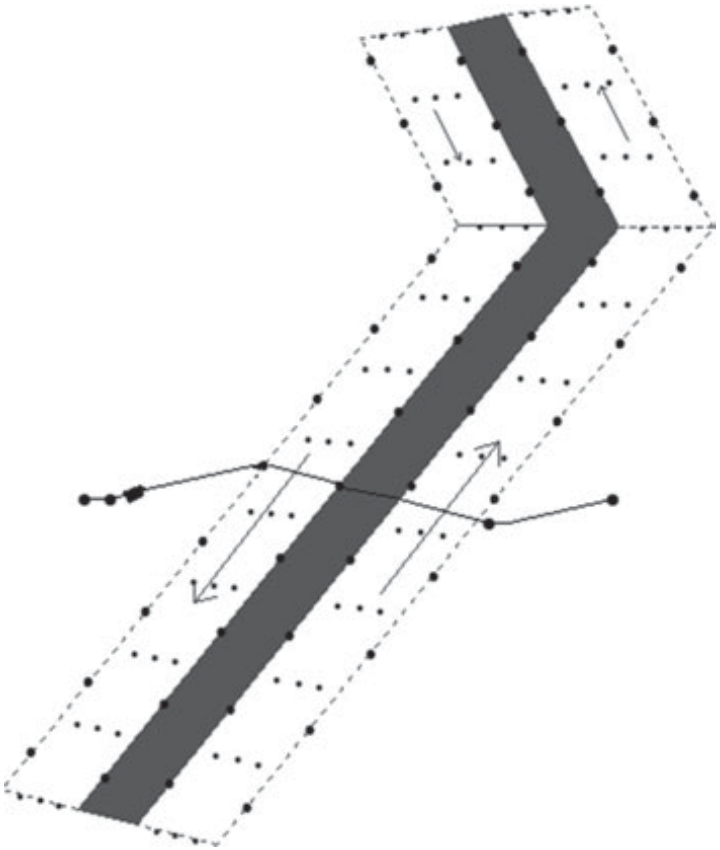
ESoSST: adding traffic patterns to EA (1)

Through traffic

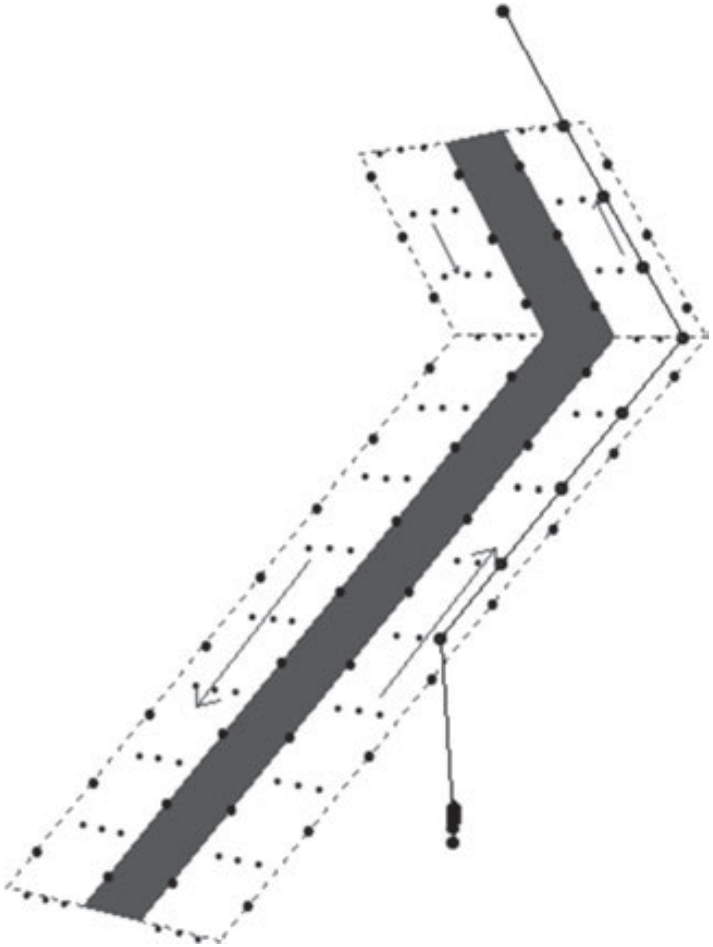


Traffic using a lane and crossing another lane

ESoSST: adding traffic patterns to EA (2)

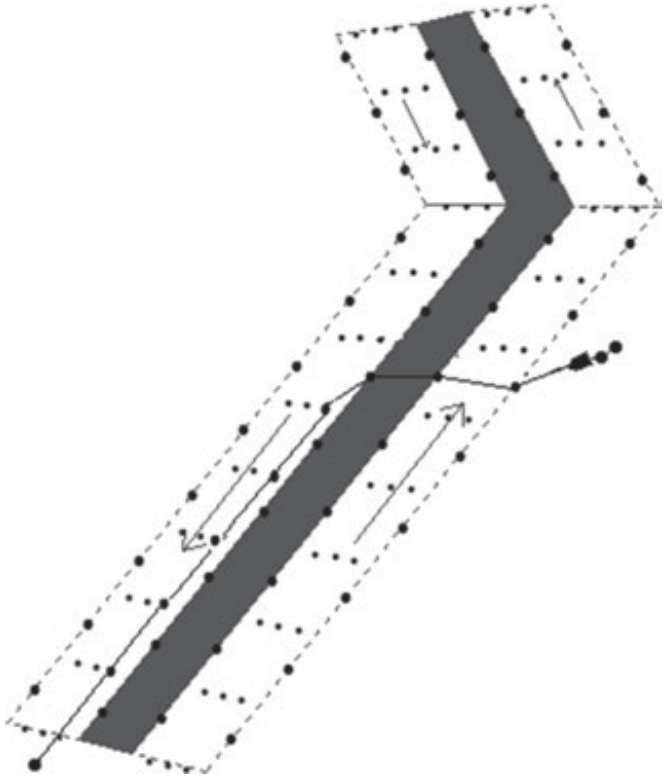


Traffic crossing TSS

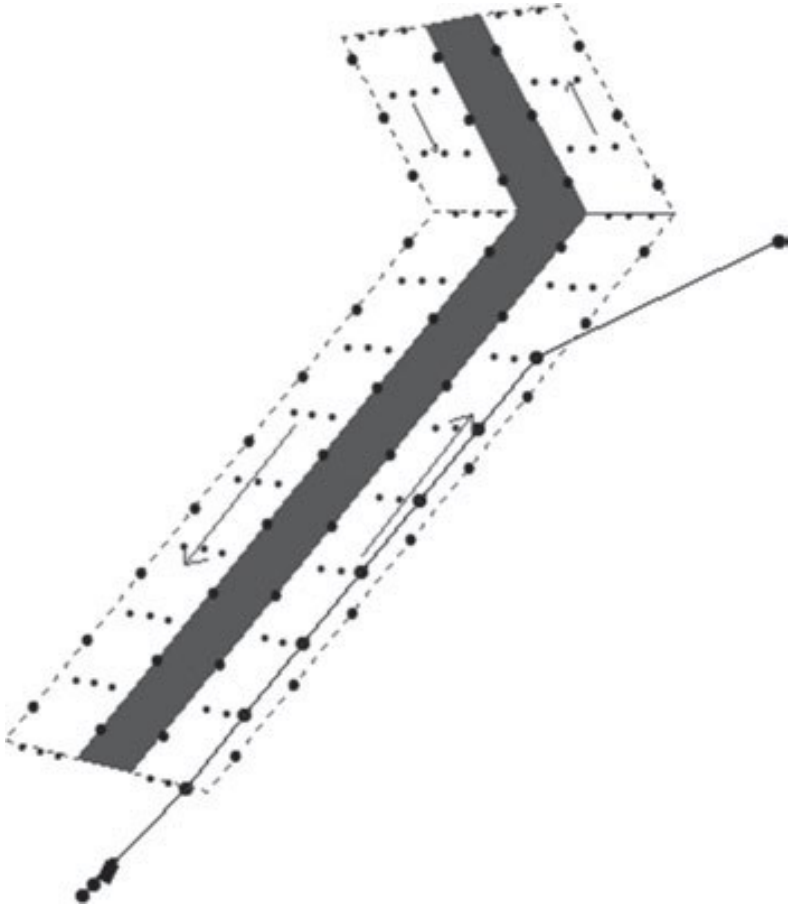


Traffic joining lane from the side

ESoSST: adding traffic patterns to EA (3)

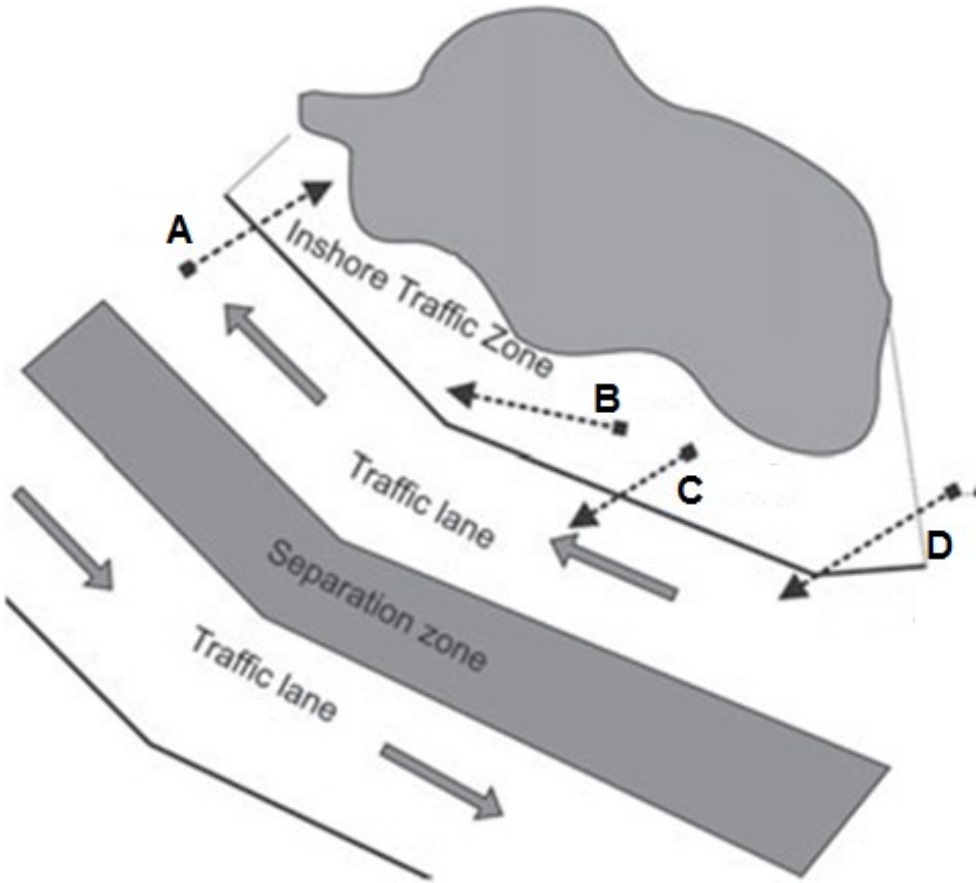


Traffic crossing one lane and joining the other lane



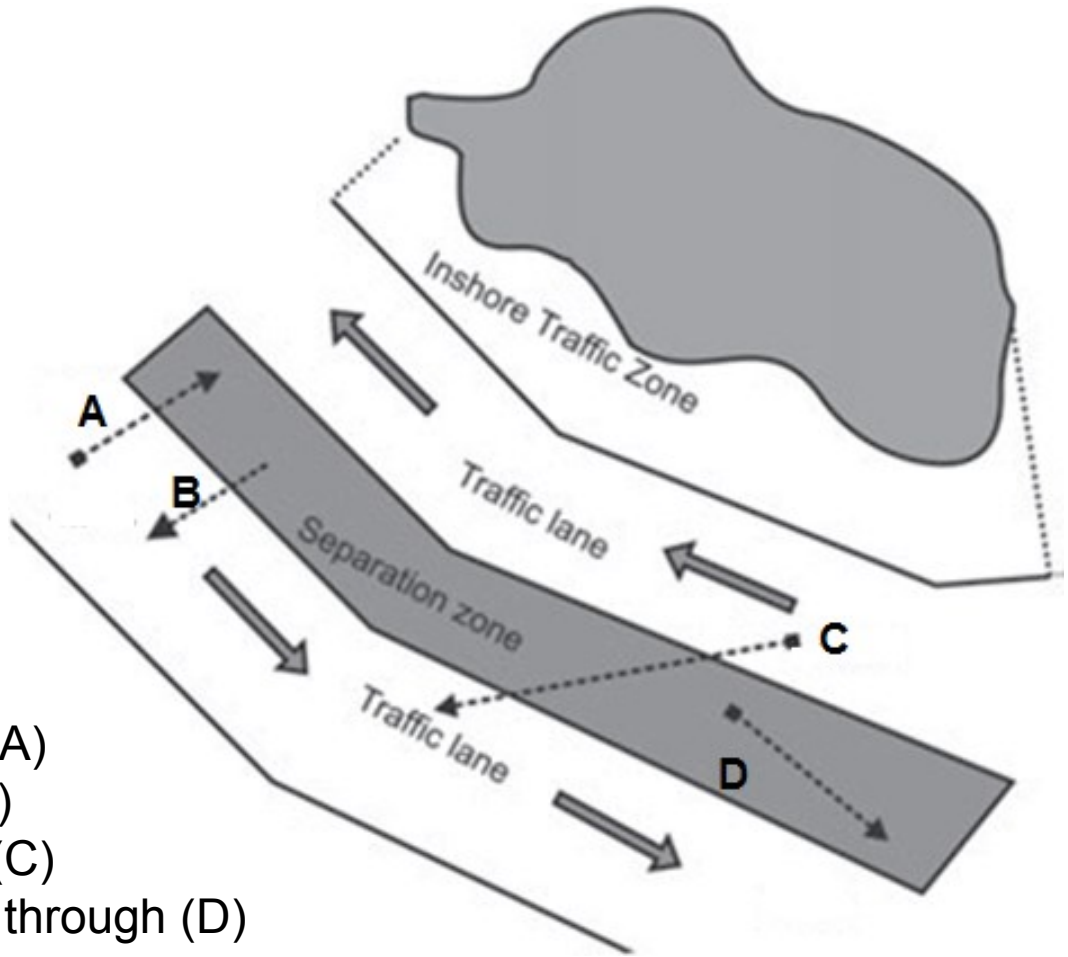
Traffic leaving the lane

ESoSST: violations of Inshore Traffic Zone



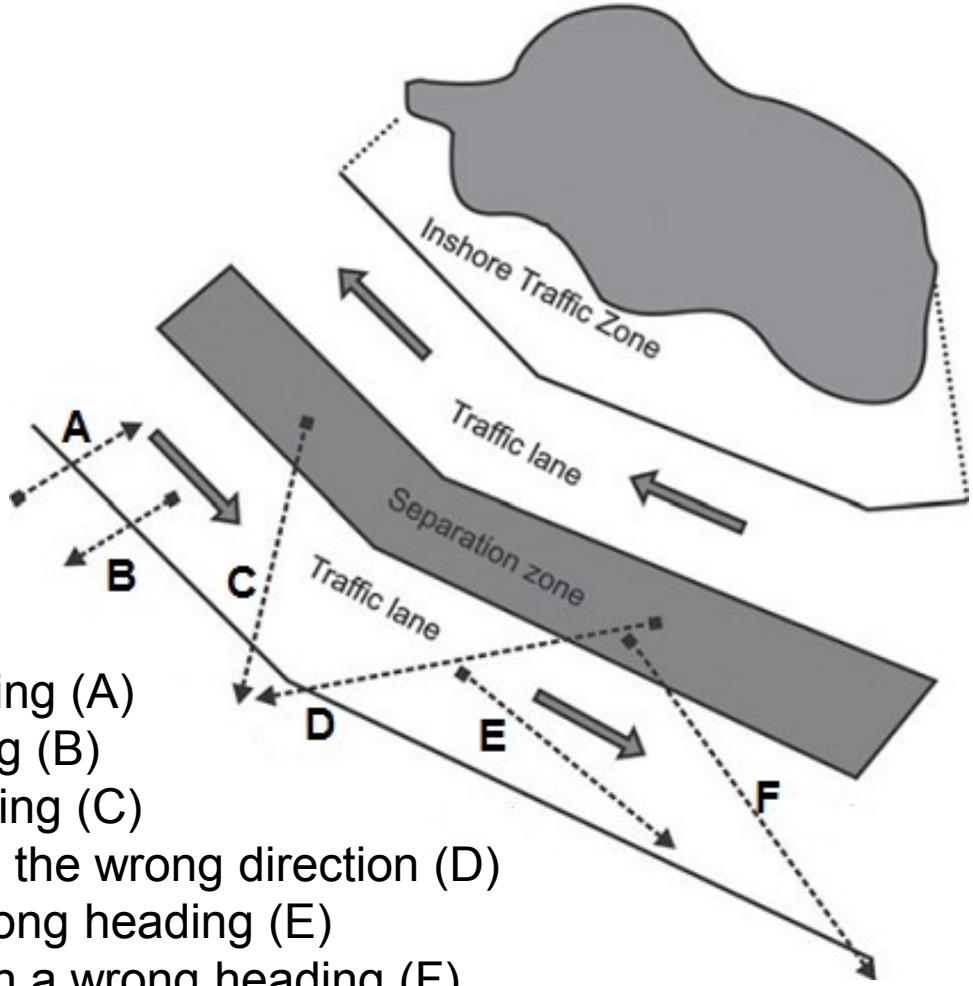
ITZ entered (A)
ITZ transited through (B)
ITZ exited (C)
ITZ crossed (D)

ESoSST: violations of Separation Zone



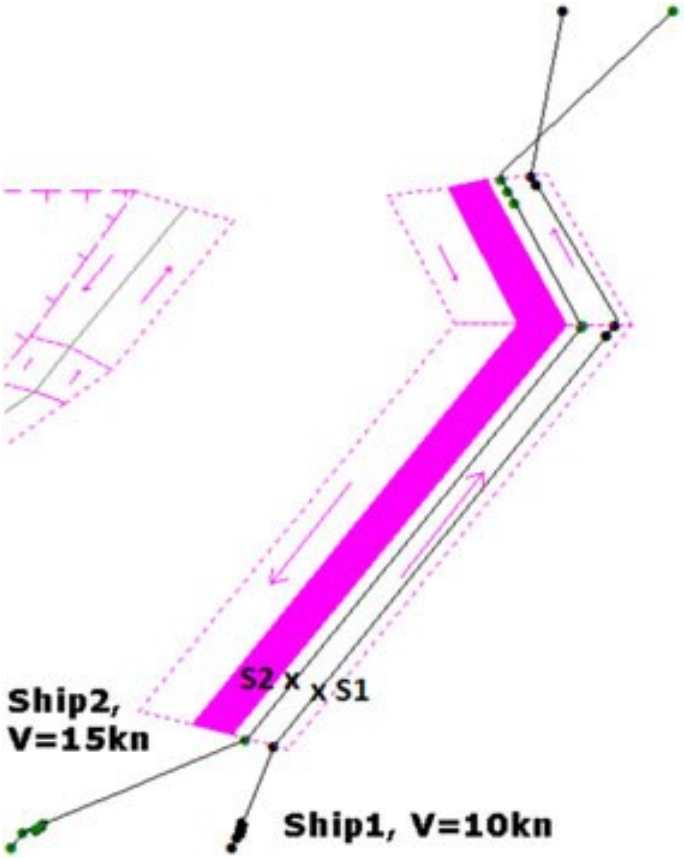
Separation zone entered (A)
Separation zone exited (B)
Separation zone crossed (C)
Separation zone transited through (D)

ESoSST: violations of Traffic Lane

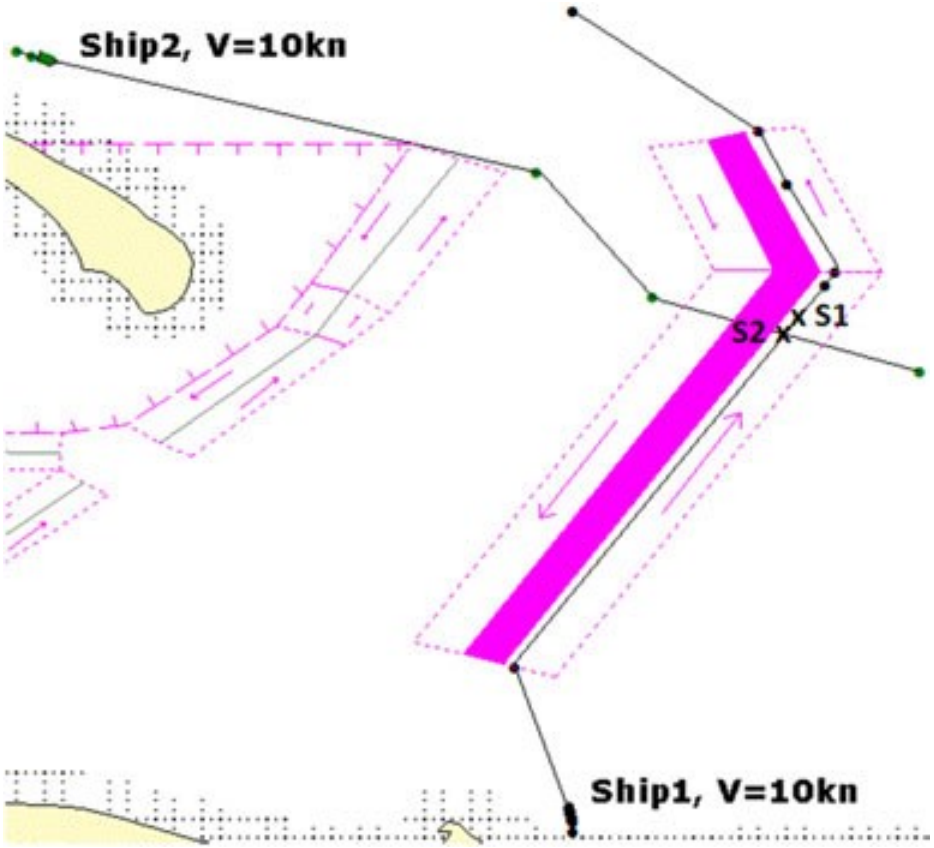


Traffic lane entered on a wrong heading (A)
Traffic lane exited on a wrong heading (B)
Traffic lane crossed on a wrong heading (C)
Traffic lane cross-transited through in the wrong direction (D)
Traffic lane transited through on a wrong heading (E)
Traffic lane cross-transited through on a wrong heading (F)

ESoSST: results for TSS (1)

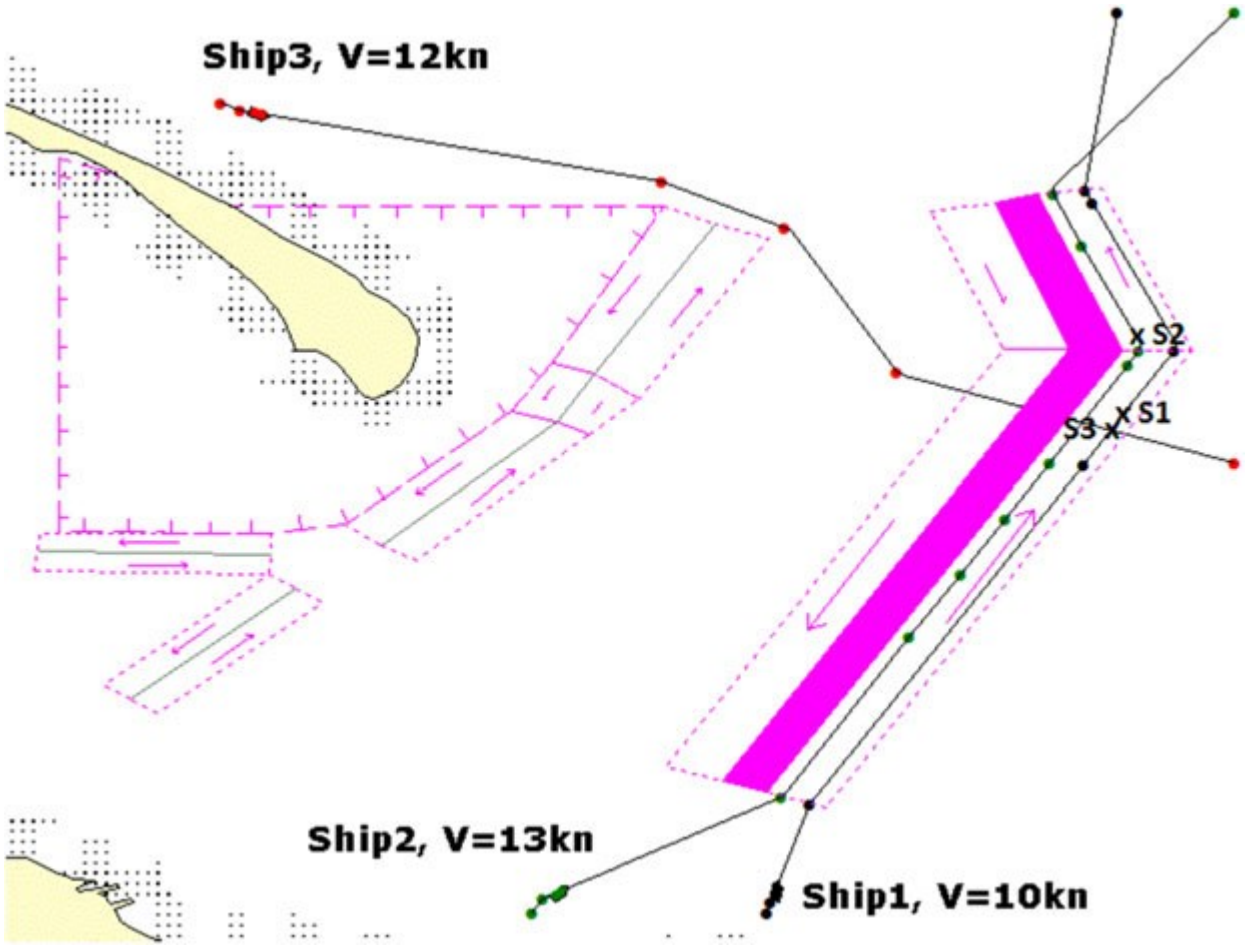


Overtaking on a traffic lane



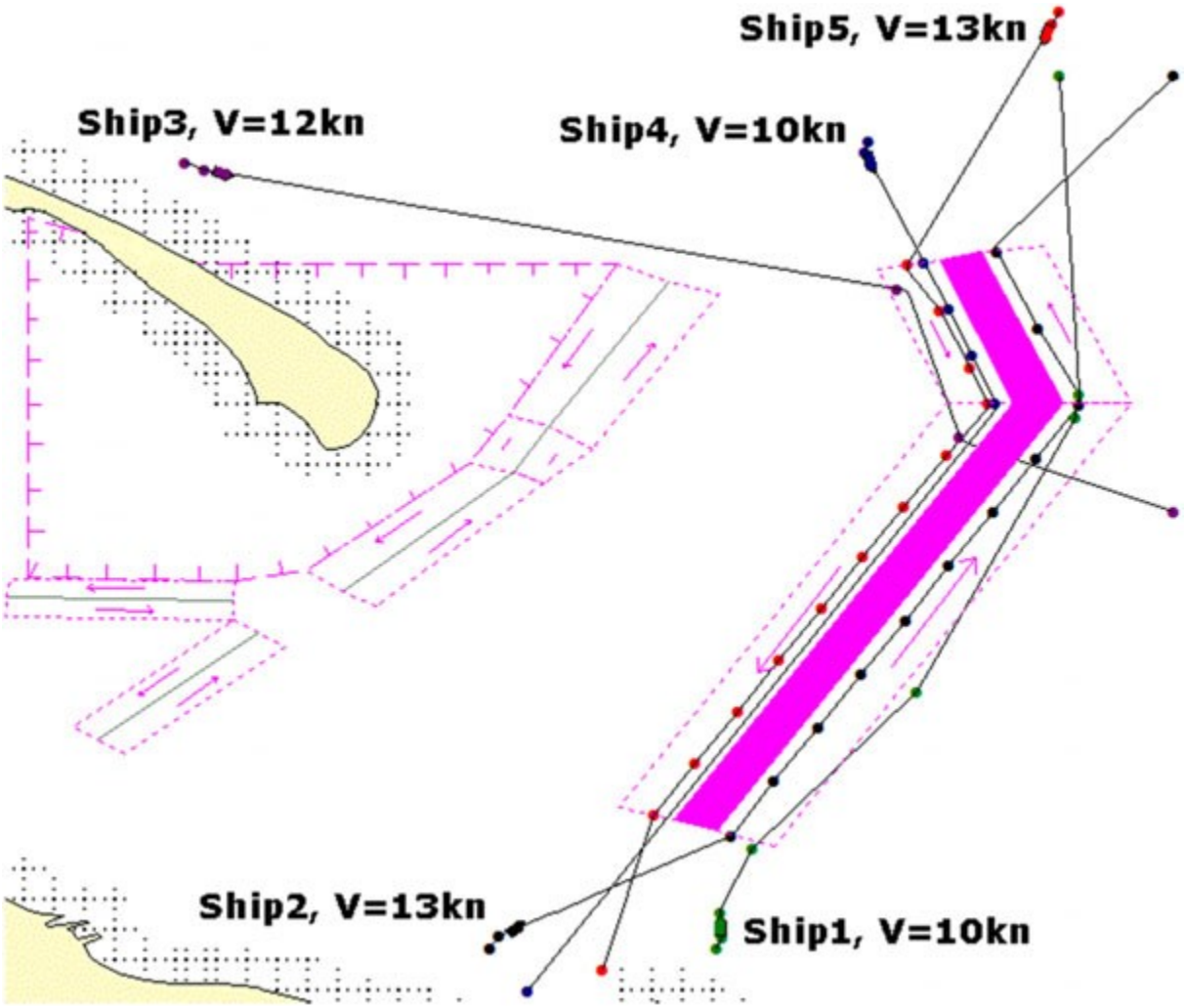
Avoiding collision when crossing a lane

ESoSST: results for TSS (2)



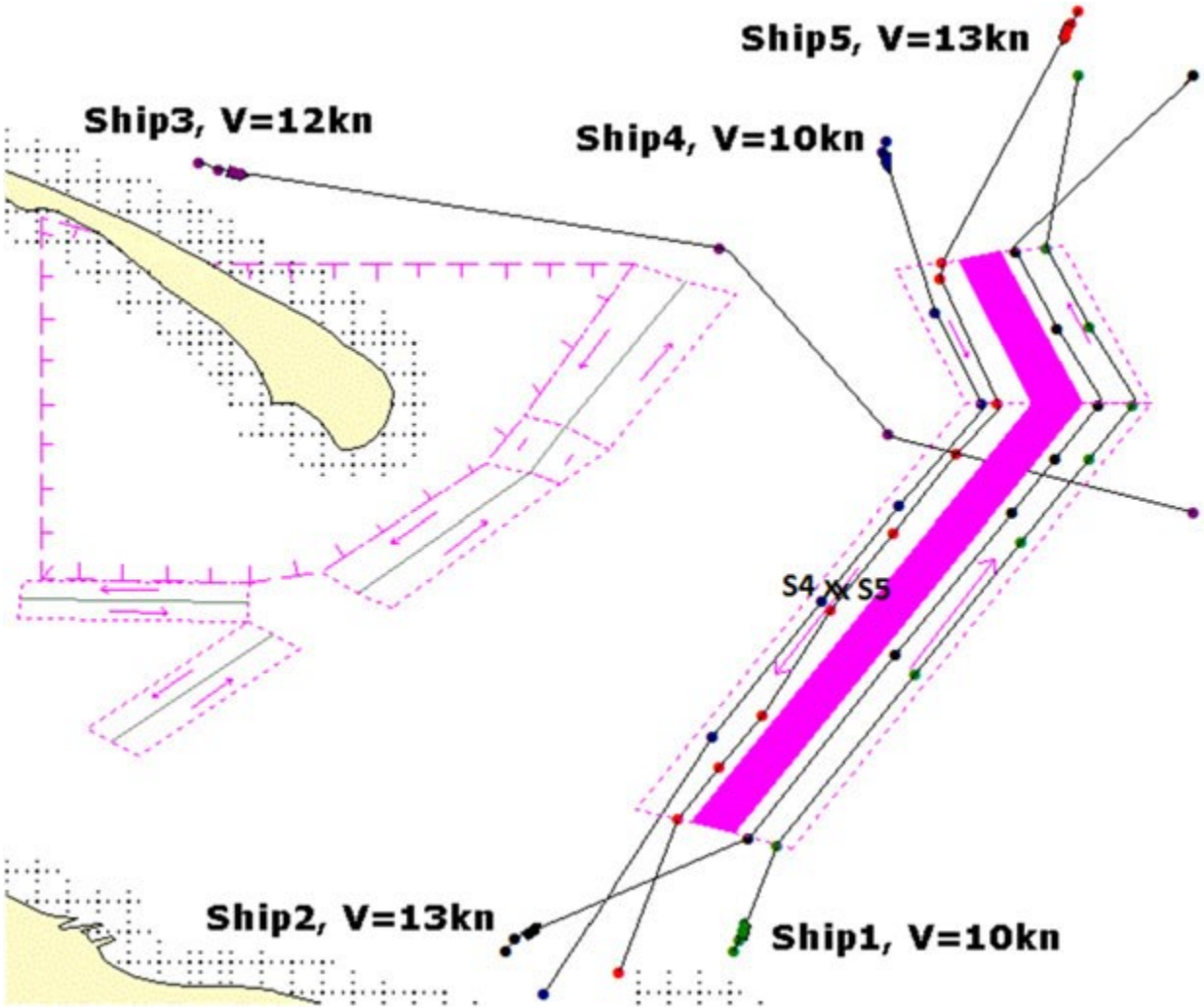
Overtaking and crossing a lane

ESoSST: evolution of results (1)



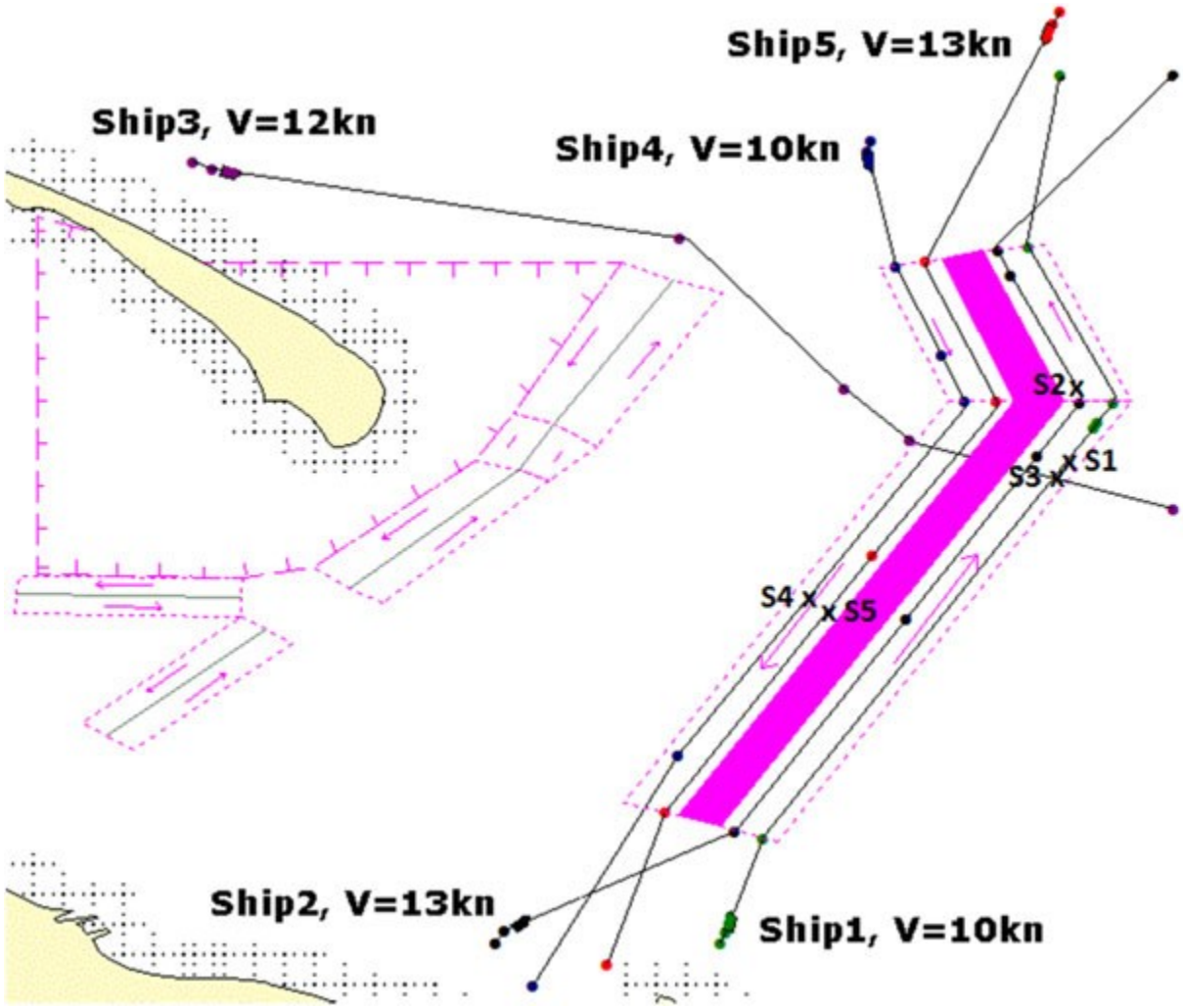
Solution after **5 generations** of evolution: a total mess

ESoSST: evolution of results (2)



Solution after **20 generations**: it is getting better…

ESoSST: evolution of results (3)



Solution after **100 generations**: safe – no collisions or TSS violations

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Conclusions

- A standard „off-the-shelf” EA is about as good as any other EC method, but there is no need to be satisfied with „off-the-shelf”
- EA are extremely open for custom-made extensions
- If we know the optimisation criteria and constraints we are able to design a custom-made optimisation method
- Method designed especially for the problem in hand will outperform any state-of-the-art general purpose optimisation tool

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Conclusions

- **Ship domains have been used in EA method without any rise in computational time**
  - **domain-based collision risk parameters (*TDV*, *DDV*) can be computed analytically for an off-centred elliptic ship domain**
- **The same is true when applying ship domains to**
  - **determining collision avoidance manoeuvres**
  - **near-miss detection**
  - **Collision Alert Systems**

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Thank you for your attention

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