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Comparing **dispatching heuristics** in **harbour protection** problems using an **agent-based simulator**

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MOTTO

Doing more with less

or, at least,

Doing better with the same

→ Improve on effectiveness with same or fewer resources,
by considering **smarter TTP** (tactics, techniques and procedures)

→ **Cost** is relevant but **effectiveness** is (still) more important

SECUREPORT

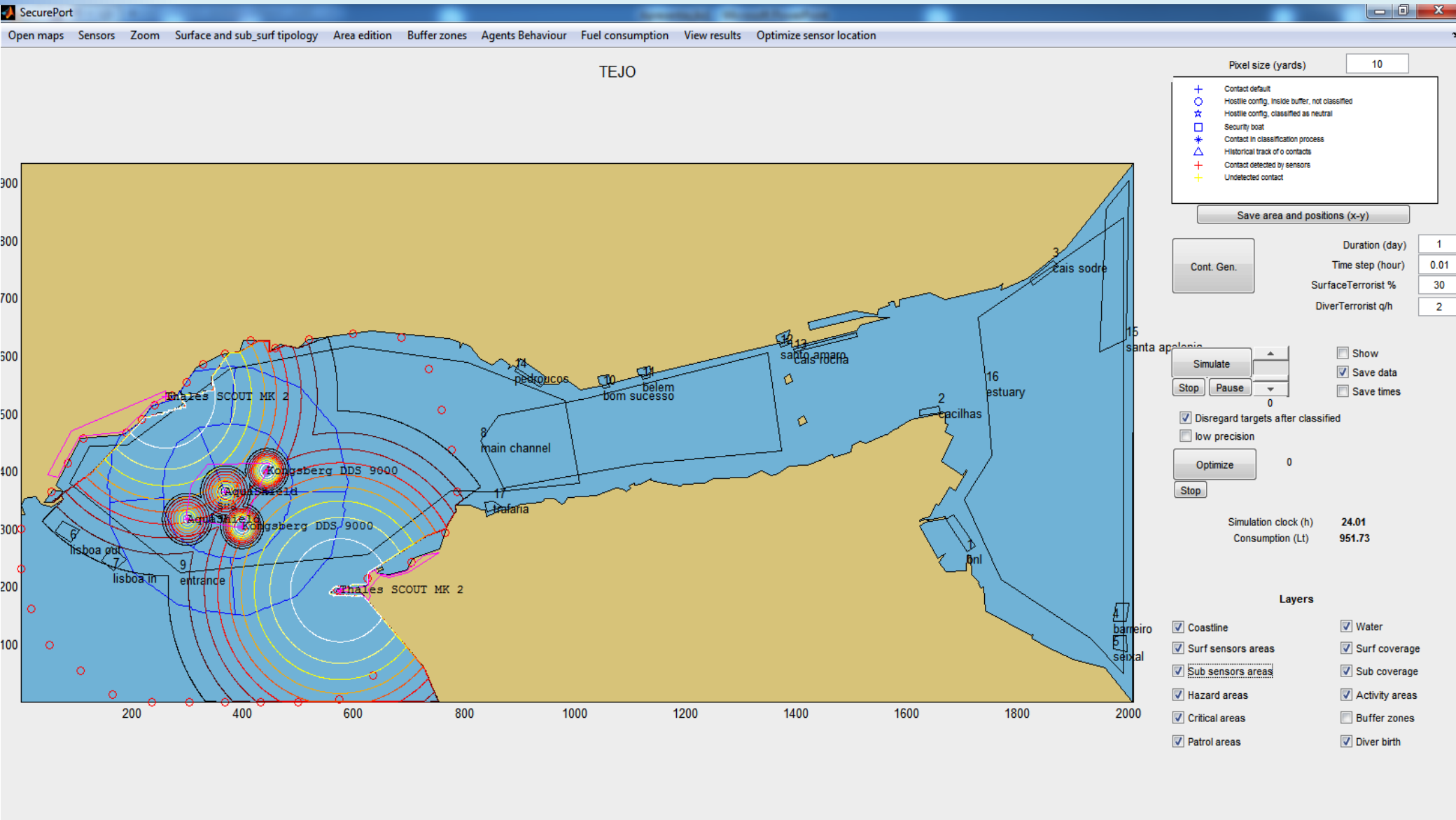
An elaborate agent-based simulator,
for fine assessment of harbour protection plans:

- (expeditionary) logistics
- layers of protection and areas of responsibility
- sensor locations
- TTP for mobile platforms

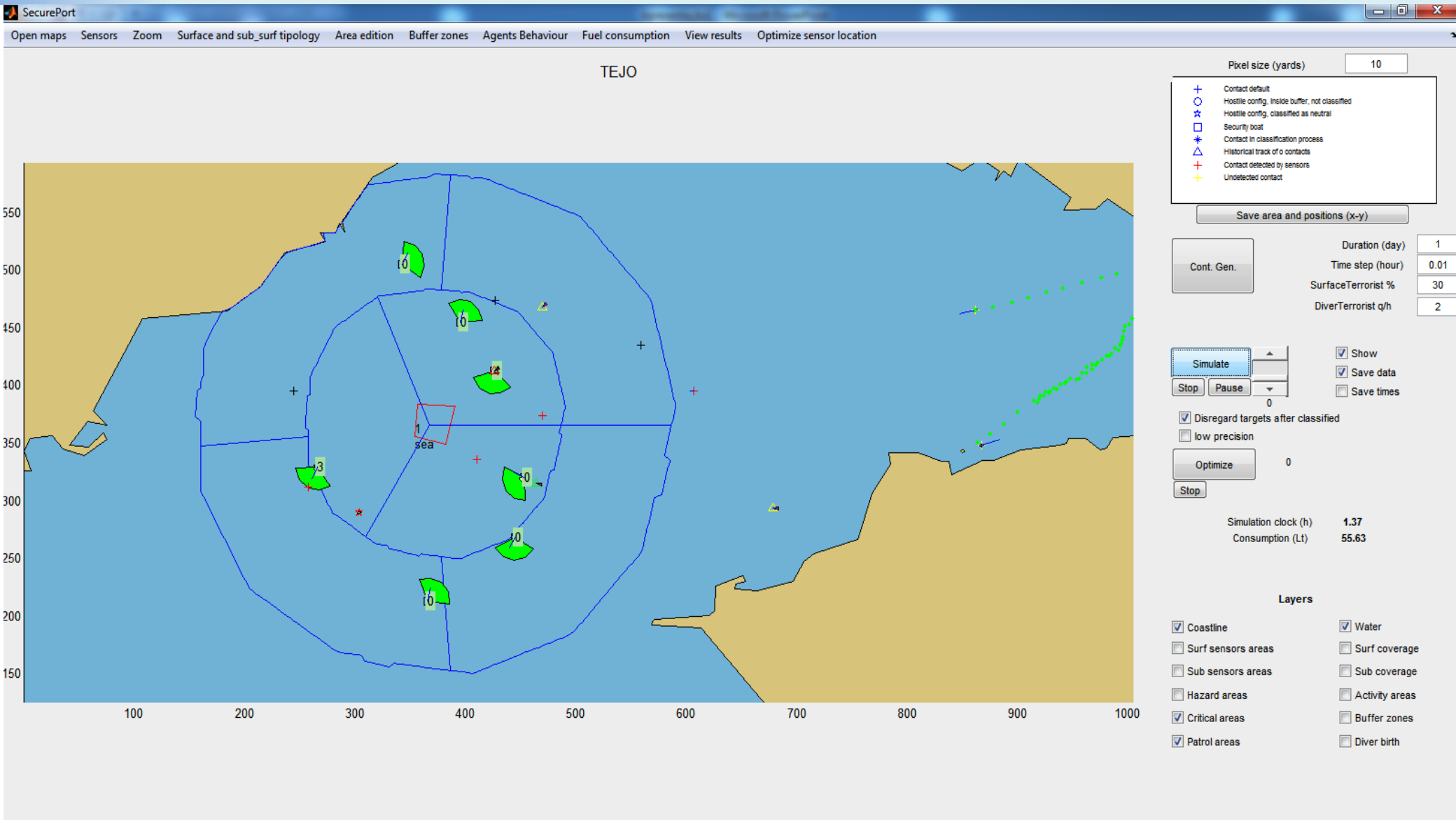
also taking into account:

- geodata, spatial constraints, LoS constraints
- realistic surface maritime traffic + divers
- probabilistic sensor models
- METOC conditions (emulation of real-world passage of time)
- …

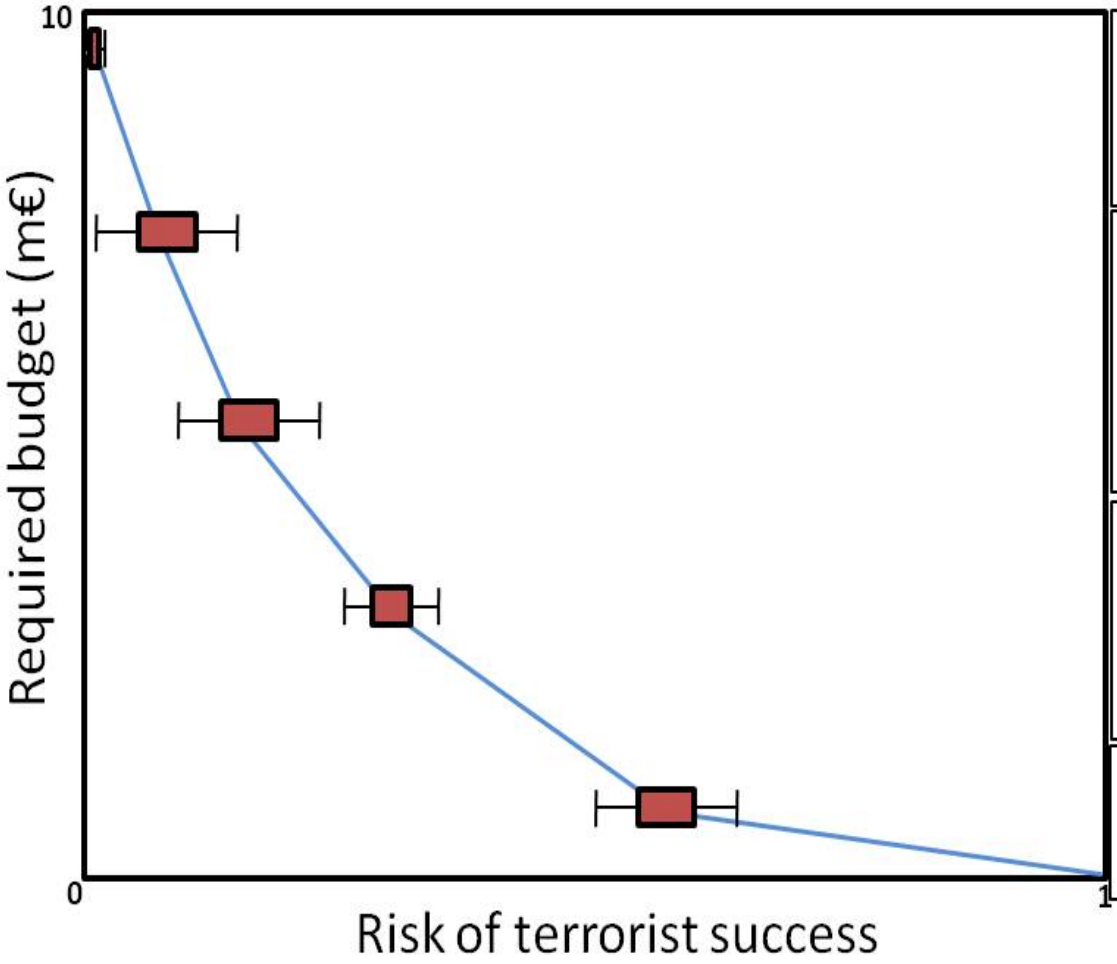
SECUREPORT: A SAMPLE SCENARIO



SECUREPORT: SIMULATION PHASE



SECUREPORT: GLOBAL MoMs



Each solution characterized by:

LOGISTIC ASPECTS

- Operation costs, with full relation of equipments and personnel
- Foot print, in square meters, required for accommodation and operation and volume and weight to be transported.

TACTICAL ASPECTS

- List of selected sensors and their locations.
- Patrol boats and land teams schedule (RD)
- Patrol boat quantity, real time rules of dispatching and surveillance equipment., observation and reaction posts.
- Patrol areas design.

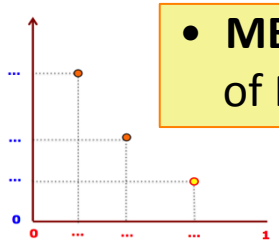
SUCCESS ASPECTS

- Risk, measured in terms of terrorist probability of success (successful terrorist attacks/attempted terrorist attacks).
- Successful terrorist routes, times and tactics (expected and worst case).

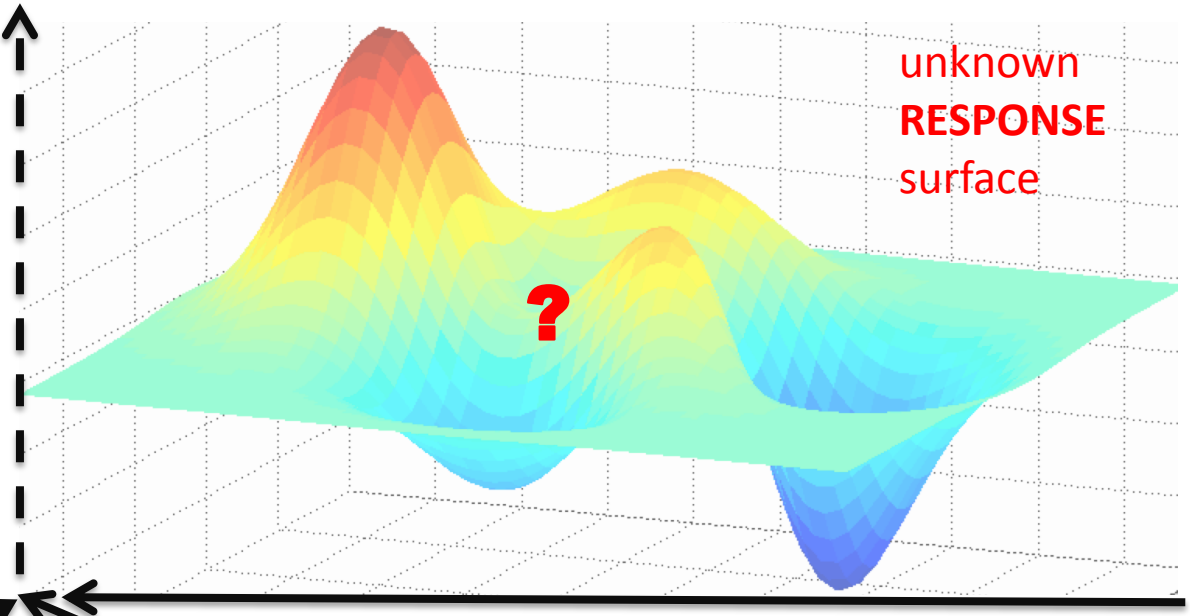
ADVERSARIAL ASPECTS

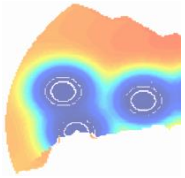
- Range of adversarial variables considered in the solution (density of attacks, terrorist behaviors and typology.

THE DESIGN SPACE OF CONDITIONS AND SOLUTIONS



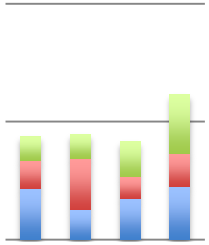
- **MEASURES** of Merit





- *Possible and reasonable* alternative protection **SOLUTIONS**

- *Plausible* **THREATS**



- ± *Probable*
  ± *worrisome*
  environmental **CONDITIONS**

"STATES OF NATURE"

OUTLINE

- SecurePort: an elaborate agent-based simulator
- Smart routing of mobile units
- A “thin” simulator of tactics
- Experiments on dispatching heuristics
- Conclusion

TASK-DRIVEN DYNAMIC ROUTING OF MOBILE UNITS

APPLICATIONS in security or safety:

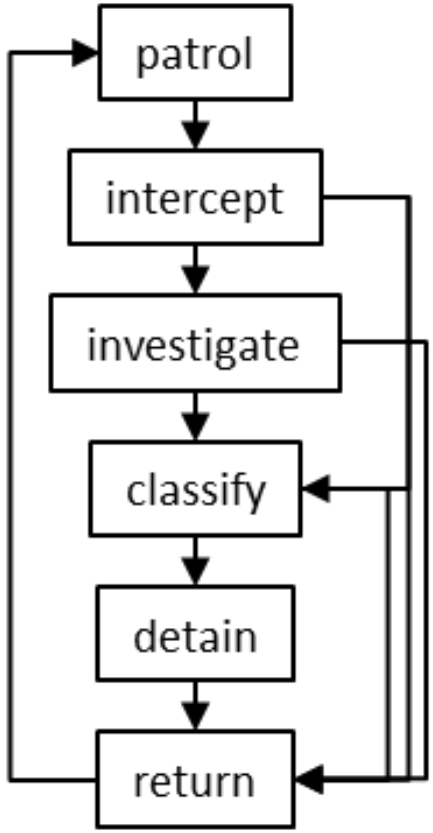
- **Emergency vehicles**
- **UAV** (e.g., A.I.Barros @ NATO OR&A Conf 2014)
- **Patrol boats** (e.g., NATO DAT-PoW Item 2, HP)
- **…**

DIFFICULTIES:

- Combinatorial in nature
- Highly dynamic and stochastic scenarios
- Uncertainty of adversarial behaviours
- Uncertainty in detection and tracking ability
- Time and spatial constraints
- …

JOB SEQUENCE FOR EACH PATROL BOAT

State	Flow	Description
1	patrol	Undefined duration. Could perform a random walk inside allocated area if associated with a sensor.
2	intercept	Application of rules to choose target. Duration dependent of initial positions, courses and speeds, target behaviour.
3	investigate	Associated with the loss of contact. Duration dependent of the initial contact nature (sea life, false contact, diver)
4	classify	Boarding process. Duration dependent of target behaviour.
5	detain	Detain process. Duration dependent of legal aspects.
6	return	Return to initial area or position, at best speed.



TTP IN WATERSIDE CLASSIFICATION TASKS

- **Prioritization:**

  Which pending task to do next?

- **Dispatching:**

  Which resource for which task?

- **Interception plan:**

  Which course and speed?

- **Continuous prediction:**

  What is the estimated point of interception?

- **Continuous reassessment of engagement:**

  Is there currently a more prioritary task?

- **Repositioning/loitering/searching:**

  What to do if no tasks pending?

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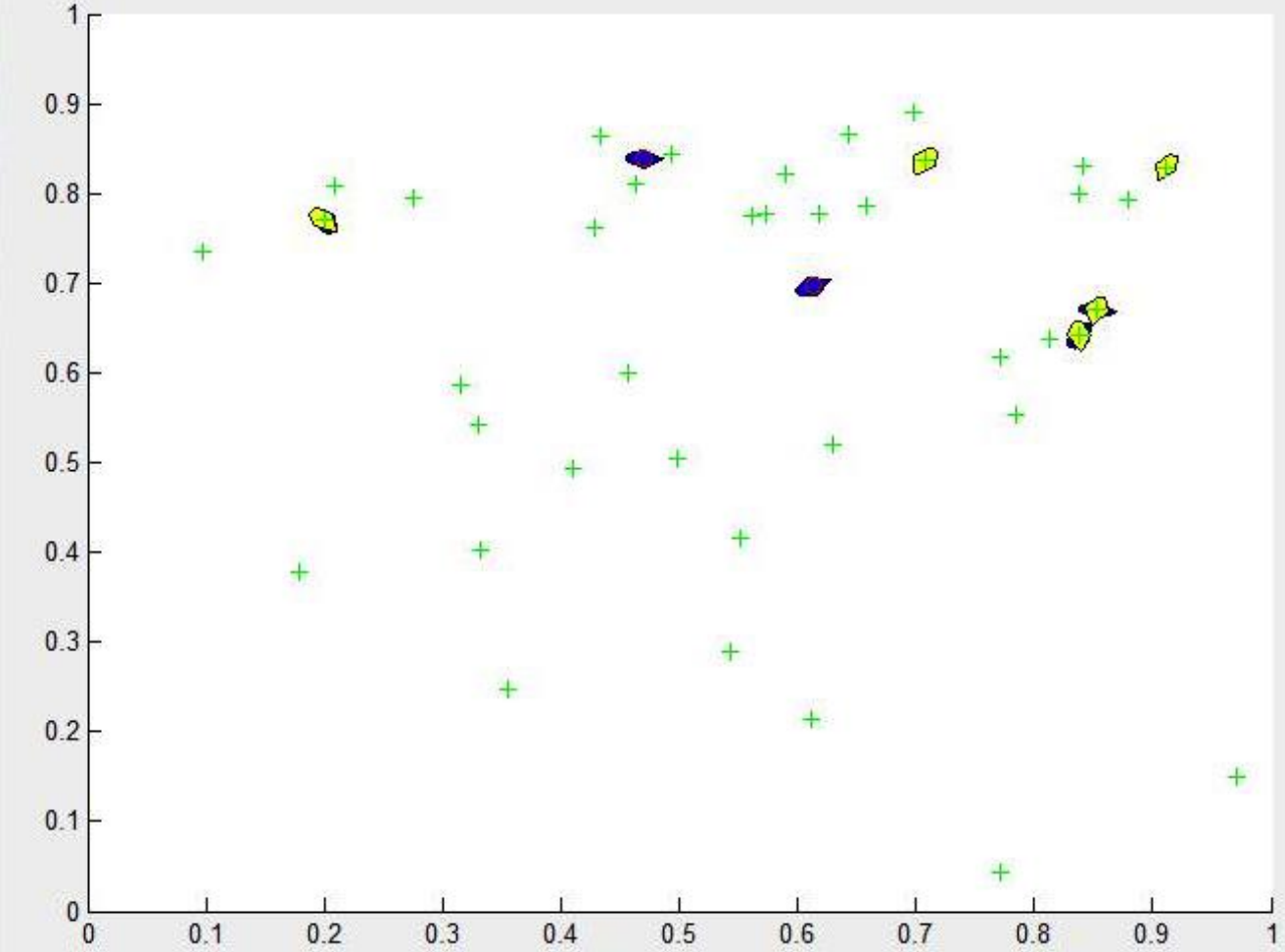
A “THIN” SIMULATOR OF TACTICS



Parameters

		Variable			
Fixed		Min	Interv	Max	
Boat quantity	5	1	1	10	Boats
Patrol axes	0.5	0.05	0.1	0.95	Axes
Boarding duration	10	10		10	
Boat speed	1.5	1.0	0.1	1.9	Speed

Run

Visualize

Use stored data

Trials for each dataset: 1

Simulation 356

Navigation 39

Rules

Target priority: First in / Closest to boat / First out

Interception solution: Actual position / Interception position

Boat selection: Closest to target / Shortest interception time / Closest to critical area

Interrupt current task: 0-No/1-Yes

Method for navigation generation

Normal distribution

Uniform distribution

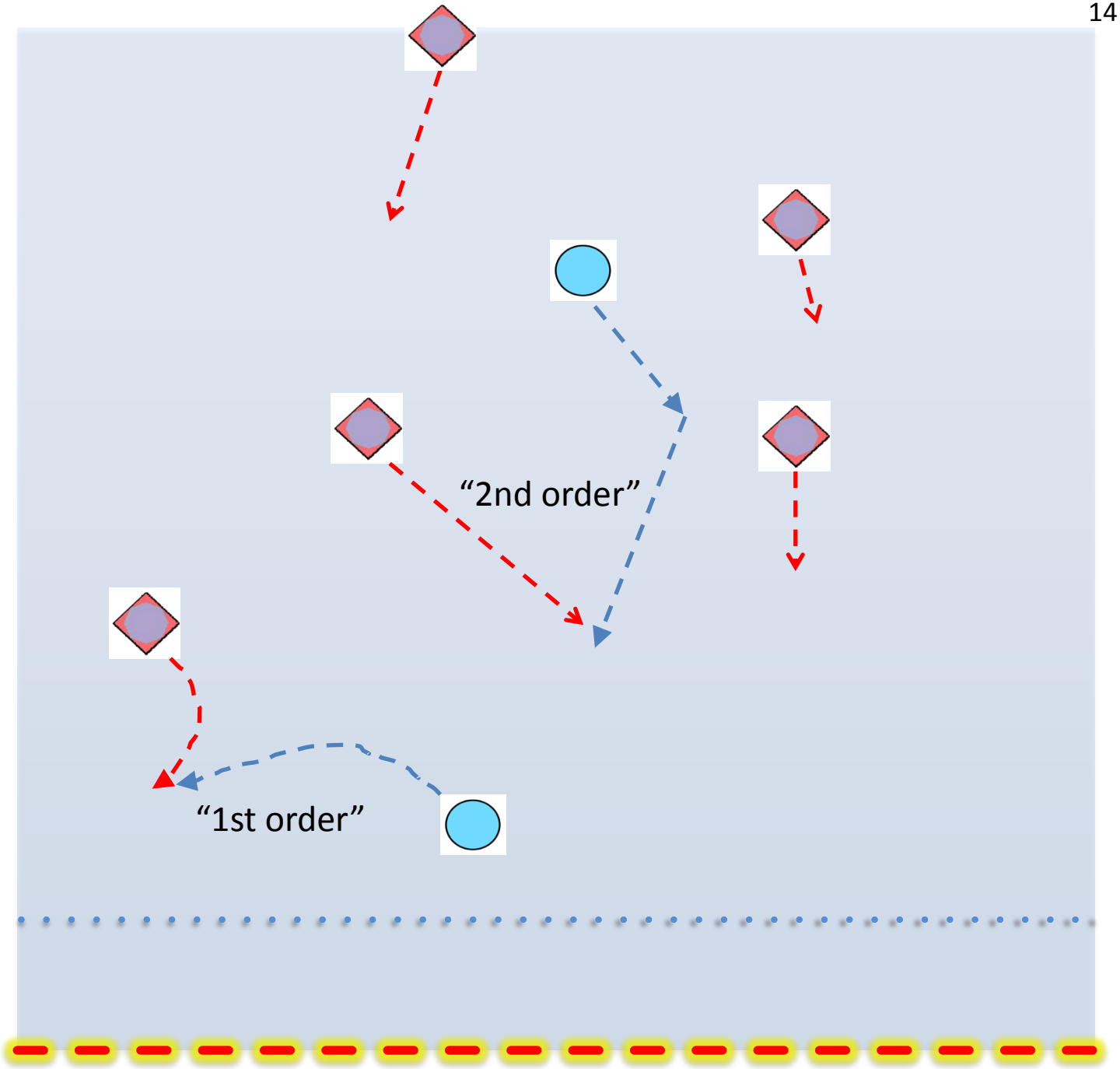
Negative exponential

Navig.	Interval	Duration
500		5000
500	10	

Generate and save navigation

Number of datasets: 1

ARRIVAL PROCESS:
WHEN, WHERE, WHAT ?



PERFORMANCE

By decreasing order of "**disutility"**:

- not preventing successful attacks
- not intercepting all contacts
- costs (no. of resources, fuel usage)

Main **factors**:

- the "geometry" of the area of operations (incl. critical areas)
- the relation between "offer" and "demand"
- the degree of uncertainty in adversarial behaviours
- the degrees of awareness and agility

PRIORITY RULES

A priority rule is based on one or more attributes, as an evaluation function:

At time *t*, choose as next contact to intercept, for classification,

the one with **smallest** value of $f_i(t)$

An example:

$$f_i(t) = \frac{slack_i(t)}{weight_i(t)}$$

"**Priority** = Importance x Urgency"

Importance = estimated/perceived danger

Urgency = scarcity of spare time to accomplish task (*)

(*) taking into account estimates of:
"travel time", "processing time" and "deadline"

PRIORITY RULES +

Further examples:

$$f_i(t) = \min_{\mathbf{z} \in Z(t)} \|\mathbf{x}_i(t) - \mathbf{z}\|$$

Choose the unclassified contact, positioned at $\mathbf{x}_i(t)$,
that is "**closer**" (taking speeds into account) to some set of points, $Z(t)$
e.g.

- Z = positions of idle resources (smaller travel time)
- Z = HVUs or other critical areas (*)
- Z = the border of the area of operations (*)

(*) conditional to interception in time still possible

→ The ultimate challenge is to find a "best mix" of different criteria, taking into account all relevant attributes

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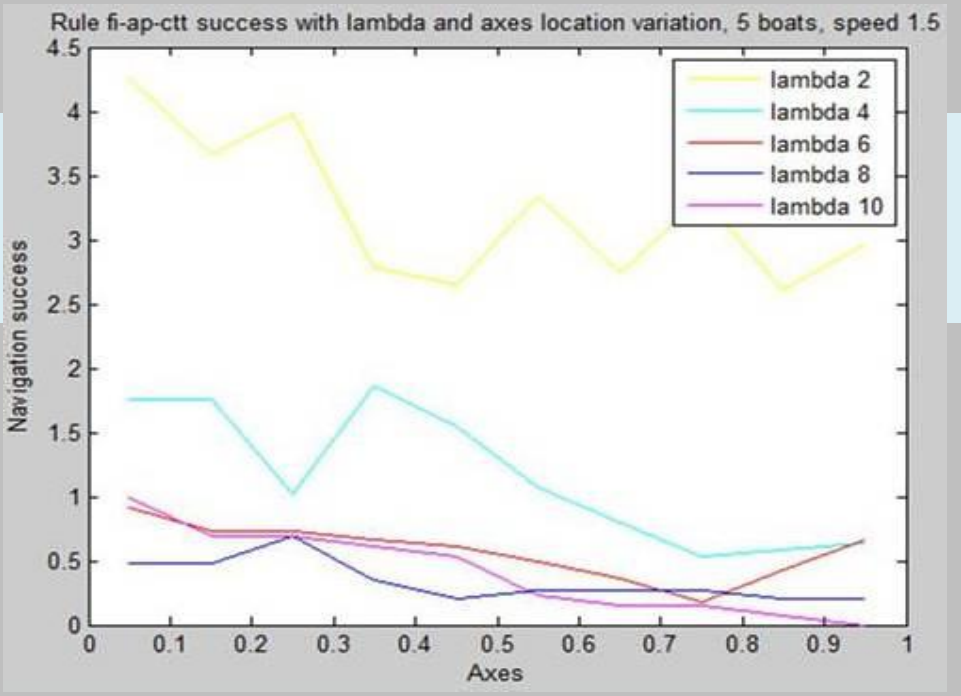
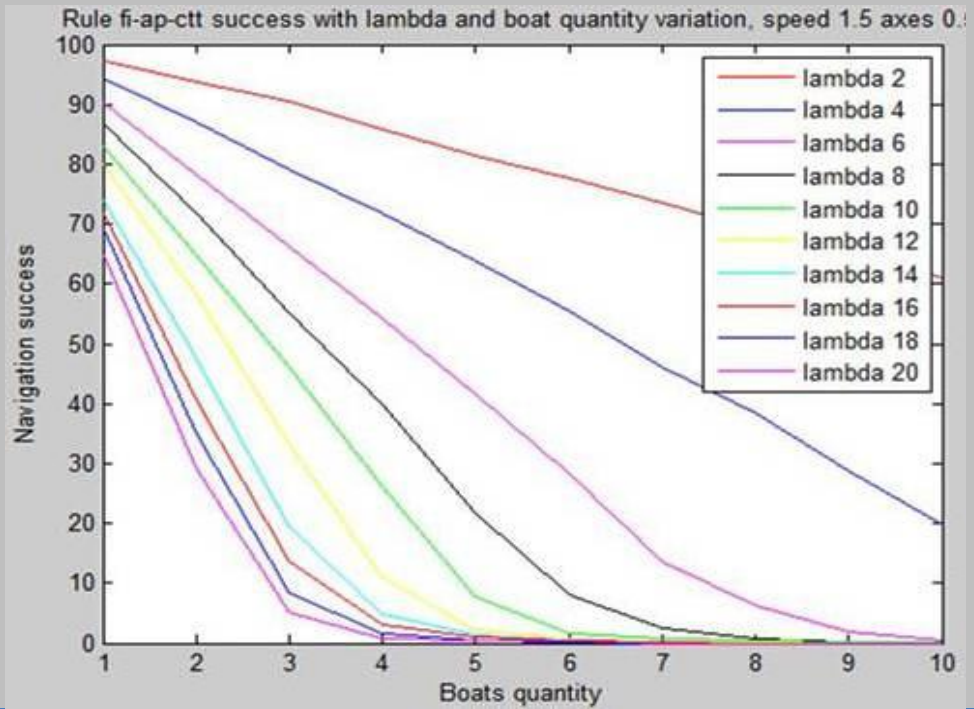
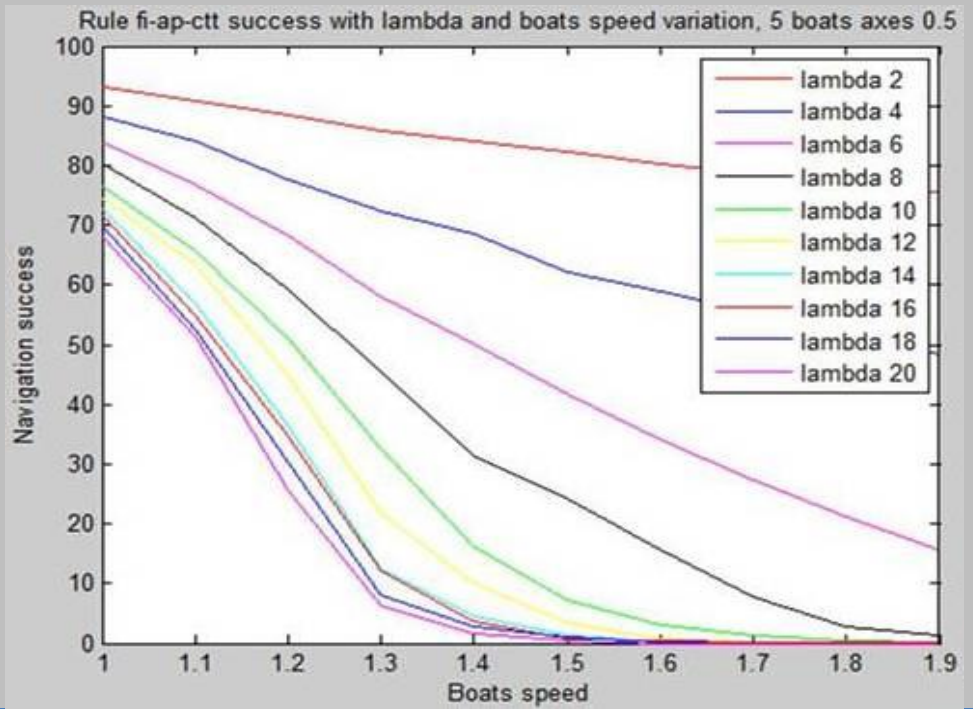
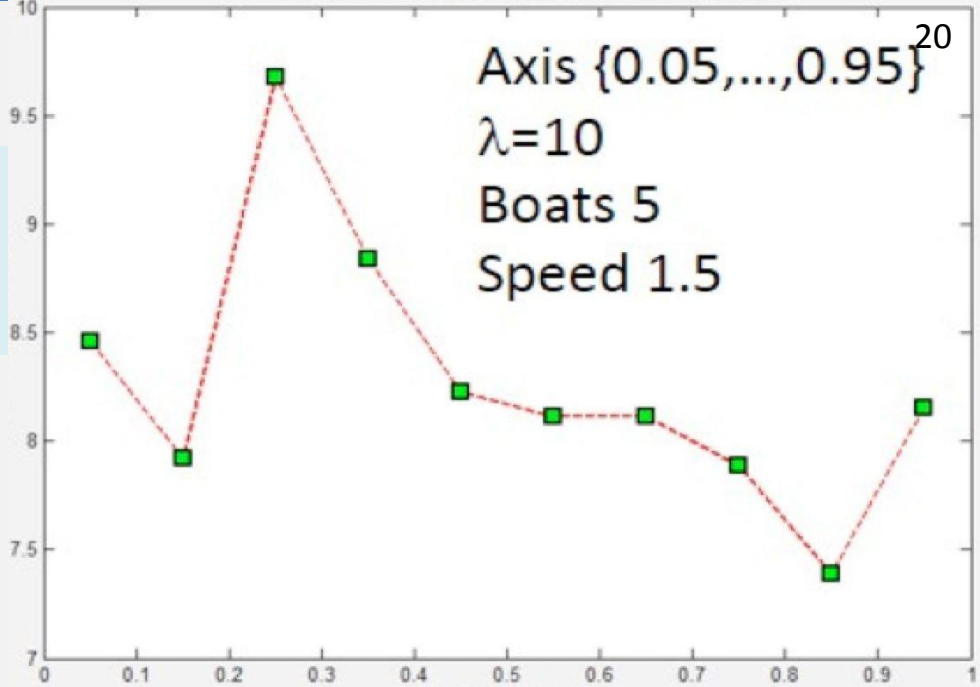
SAMPLE RESULTS
FROM A SIMPLE HEURISTIC RULE

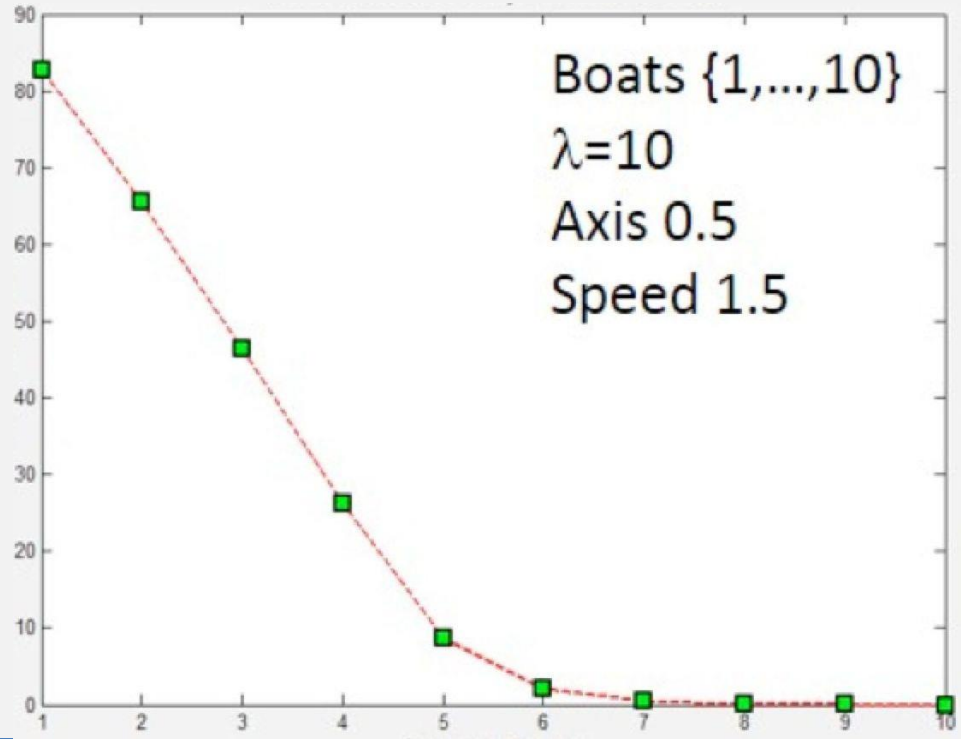


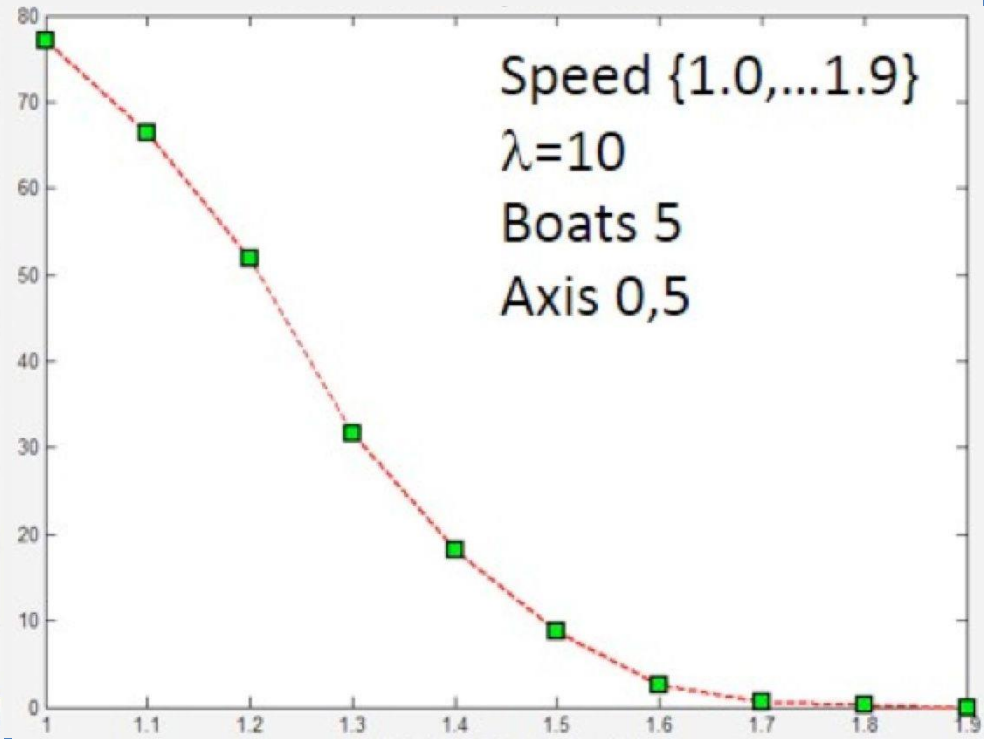




SAMPLE RESULTS
FROM A SIMPLE HEURISTIC RULE







AN EXPERIMENTAL DESIGN

— 15 dispatching rules evaluated

— 5x5x5 experimental scenarios, each one defined by a combination of 3 factors:

  — "**Lambda**": avg interarrival time of new contacts to the AO;
    levels: {2, 6, 10, 14, 18}

  — "**Boats**": number of patrol boats used;
    levels: {1, 3, 5, 7, 9}

  — "**Speeds**": ratio between speed of patrol boats and avg speed of maritime traffic;
    levels: {1.1, 1.3, 1.5, 1.7, 1.9}

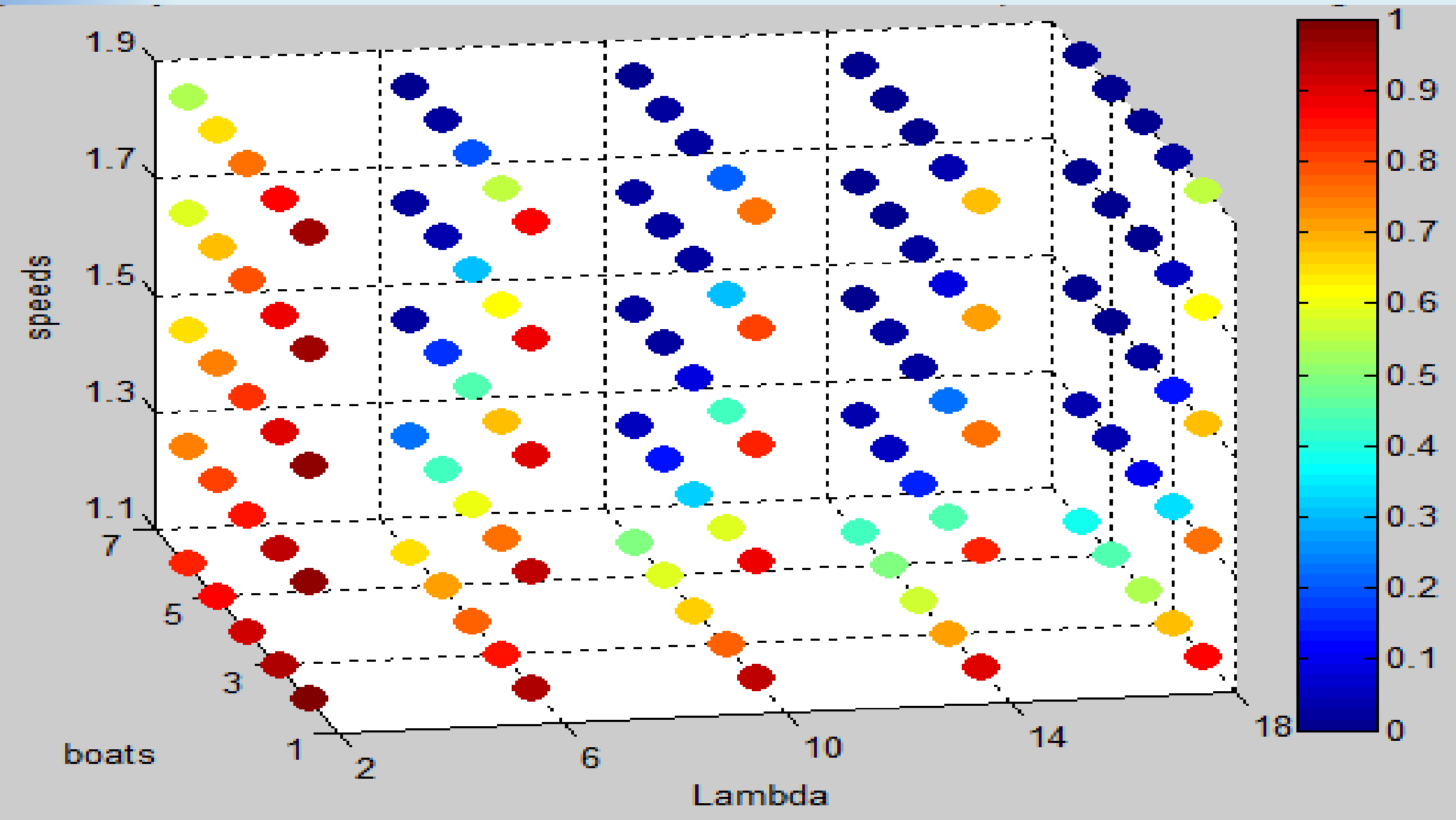
— **MoM**: % of contacts that reached the critical area without being classified (and cleared)

RULE ID 1:

Target priority: "First in" (= FCFS)

Boat priority: closest to target

Interception mode: "1st order" (= head to current target position)

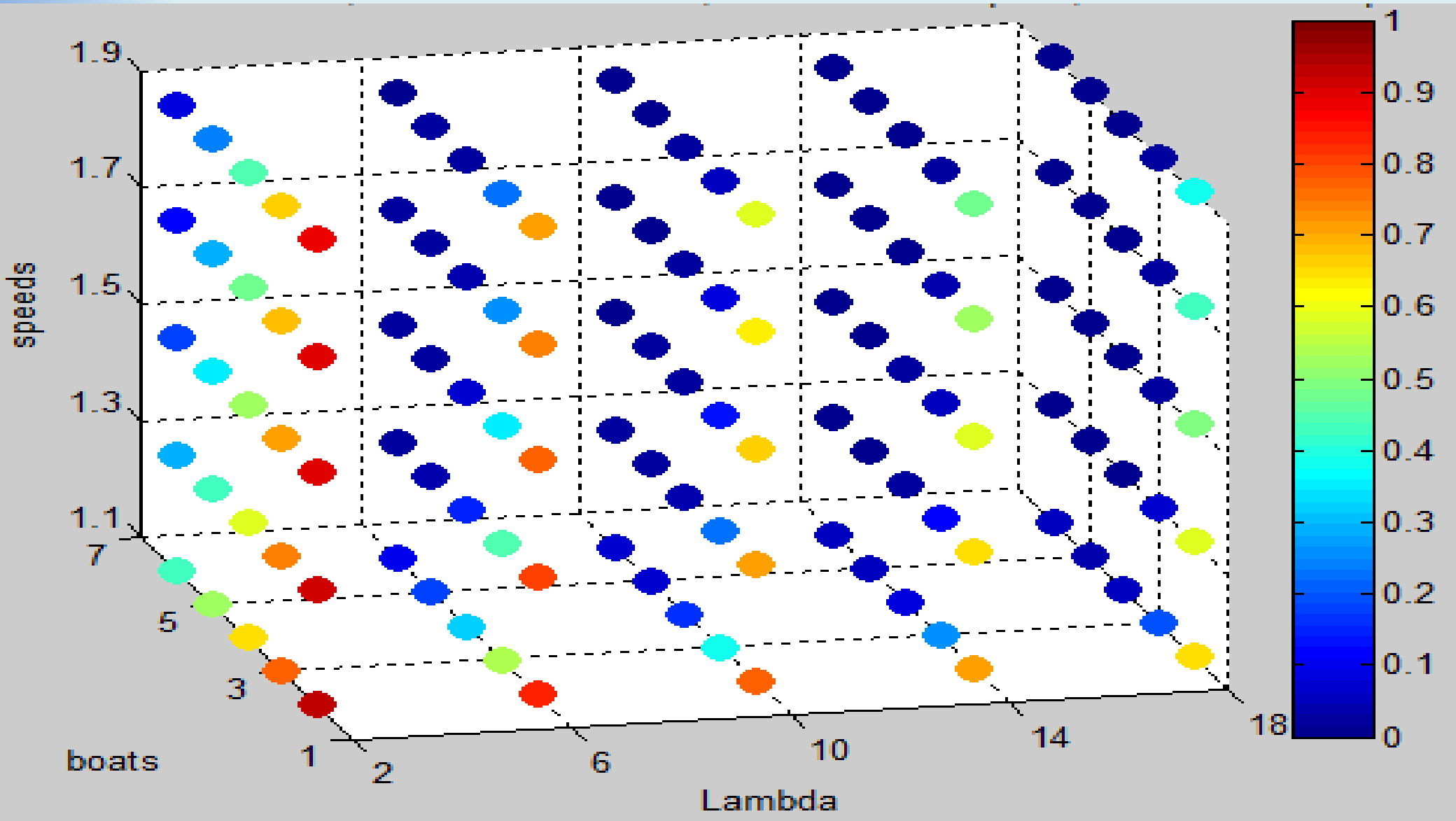


RULE ID 8:

Target priority: closest to patrol boat

Boat priority: shortest estimated interception time

Interception mode: “2nd order” (= head to estimated interception position)



Number of patrol boats	speed factor	lambda 2		lambda 6		lambda 10		lambda 14		lambda 18	
1	1.1	92.1	7	83.1	7	76.3	7	70.1	7	65.0	7
	1.3	90.9	6	79.7	7	70.6	7	64.0	7	58.2	7
	1.5	89.7	6	76.3	7	65.6	7	57.2	7	48.3	7
	1.7	88.8	6	73.5	7	61.9	7	51.7	7	42.4	7
	1.9	88.1	6	70.9	7	58.1	7	46.3	7	37.3	7
3		76.7	7	51.5	7	36.8	7	24.1	7	17.2	10
		73.5	6	42.6	7	21.6	7	10.2	10	5.4	7
		69.7	6	33.6	8	11.6	8	3.2	10	1.5	8
		66.5	6	24.9	7	6.6	8	1.5	10	0.2	13
		64.7	6	20.7	7	3.4	7	0.6	2	**0.0**	
5		62.5	7	29.5	7	13.1	7	5.0	7	2.0	10
		57.0	7	14.2	8	2.7	8	0.4	12	**0.0**	
		50.8	6	4.2	7	0.5	7	**0.0**	**10**	**0.0**	
		46.1	6	2.3	7	**0.0**	**12**	**0.0**		**0.0**	
		42.4	6	1.0	7	**0.0**		**0.0**		**0.0**	
7		49.6	7	15.9	8	3.6	10	1.2	10	0.6	10
		41.2	7	2.4	7	0.3	3	**0.0**		**0.0**	
		33.3	7	0.2	7	**0.0**	**13**	**0.0**		**0.0**	
		26.9	6	**0.0**		**0.0**		**0.0**		**0.0**	
		22.5	8	**0.0**		**0.0**		**0.0**		**0.0**	
9		38.6	7	6.7	7	1.2	5	0.5	10	0.5	
		27.8	8	0.4	8	**0.0**		**0.0**		**0.0**	
		17.1	8	**0.0**	**15**	**0.0**		**0.0**		**0.0**	
		10.2	7	**0.0**		**0.0**		**0.0**		**0.0**	
		6.9	6	**0.0**		**0.0**		**0.0**		**0.0**	

Only one rule reached this performance
Rule ID is shown

Several rules reached this performance

Rules

ID				Score
1	first in	closest to target	1st order	16
2	first in	closest to target	2nd order	32
3	first in	shortest interception time	2nd order	32
4	first in	closest to critical area	1st order	14
5	first in	closest to critical area	2nd order	27
6	closest to boat	closest to target	1st order	30
7	closest to boat	closest to target	2nd order	76
8	closest to boat	shortest interception time	2nd order	61
9	closest to boat	closest to critical area	1st order	18
10	closest to boat	closest to critical area	2nd order	57
11	first out	closest to target	1st order	17
12	first out	closest to target	2nd order	32
13	first out	shortest interception time	2nd order	33
14	first out	closest to critical area	1st order	13
15	first out	closest to critical area	2nd order	31

Score: No. times the rule was best (in 125 scenarios)

DECISION SUPPORT

Given **adversarial conditions**, such as:

- maritime traffic density
- average traffic speed

and given **budgetary constraints**:

- number of patrol boats

… **which rule to apply**, and at **what cost**?

- E.g., for lambda = 10, and speed factor = 1.5,
  "0% risk" would be attained with 7 boats and by using Rule ID 13

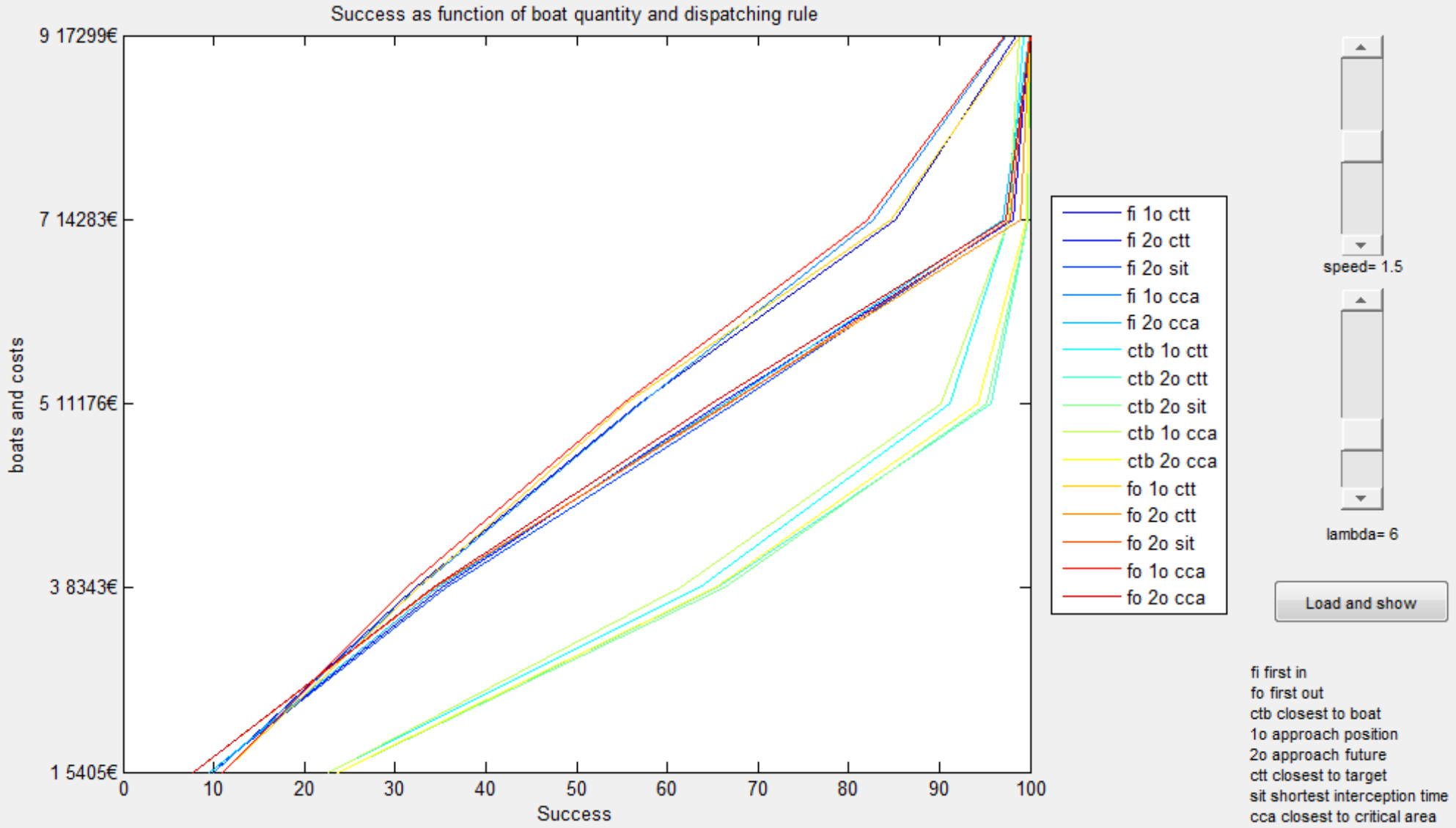
OPERATIONAL COSTS

- The daily operational cost for a projected force is derived from the number of patrol boats to be used:

Boats	Personnel	Weigth (ton)	Volume(m3)	Total daily cost (€)
1	62	45	590	5405
3	92	53	922	8343
5	120	62	1255	11176
7	151	73	1627	14283
9	180	84	1992	17299

- These costs are precisely estimated by a separate tool, where all logistics aspects are taken into account through an atomized evaluation process

DECISION SUPPORT TOOL



STRATEGIC & TACTICAL DECISIONS

- The Decision-maker is provided a decision support tool
  to explore the knowledge base of experimental results

- In general, he/she is able to promptly estimate

  the effect of any **alternative solution** *(no. of resources; tactics)*
  on the **measures of merit** *(financial costs; expected mission success)*
  given assumptions on **adversarial variables** *(traffic density; traffic avg speed; …)*

- Under a given budget, he/she may then decide upon:
  - — the number of patrol boats **to include in a mission**,
    according to the expected worse case traffic conditions;
  - — the number of patrol boats to engage and the tactics **to employ along time**,
    according to the current traffic conditions

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CONCLUSION

In summary:

- **heuristics** are not only convenient but necessary
- **priority** may be driven by many (dynamic) task attributes
- the **thin simulator** enables an intensive/extensive experimentation
- the **elaborate simulator** enables a realistic assessment
- **decision support** at all levels: strategic, operational, tactical

Way ahead:

- comprehensive comparison of many heuristics; combination
- POR Navy responsibilities and activities wrt NATO DAT-PoW
- SCI-280 RTG: SoS approach for task driven sensor resource mgmt for MSA
- possible adaptation to UAV dynamic mission planning
- …

Questions / suggestions

welcome

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