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Modeling swarm mission with COTS characterization: a series of return on experience

Key take-away

1. Return on experience using COTS for collaborative combat: fielded tests fails
2. Systems engineering models cannot help in feedback loops because it should include information in all views - 3D, electrical, electromagnetic, environment, weather, topography, therefore no iteration is possible
3. Robotic platforms emerging behavior from multiple COTS is knowable only when real systems act together on field, with environment and deployment conditions
4. Adding views to existing models in architecture frameworks create exponential modeling effort, revealing the NP-Hard nature of architecture views selection in given <Q,R,T> constraints
5. Adding artefacts (requirements, constraints, objectives) on-the-go during architecture is an online problem, which can only be addressed with adequate tools and connections to simulation
6. Choosing not to use adequate heuristics and create blindness and result in exponential length of delays in engineering: seamless generative approach is necessary
7. The only possibility to scale up from platforms to collaborative combat is pursuing seamless approaches between simulation, optimization and systems engineering

Outline

1. Definitions, terms and experimentation: NAF, Robotic challenge, Swarm of robots,

2. Adding views to MBSE from fielded experience, the Engineering Leakage Problem (ELP), an online problem

3. Mathematical formulation of systems engineering for the next challenges

4. Facing ELPs with appropriate means

5. Conclusions and outlook

1. Definitions, terms

- Views
- Artefacts
- Nato Architecture Framework
- IVVQ
- Our objectives using NAF is to apply systems engineering and prepare for the next challenge edition in 2025

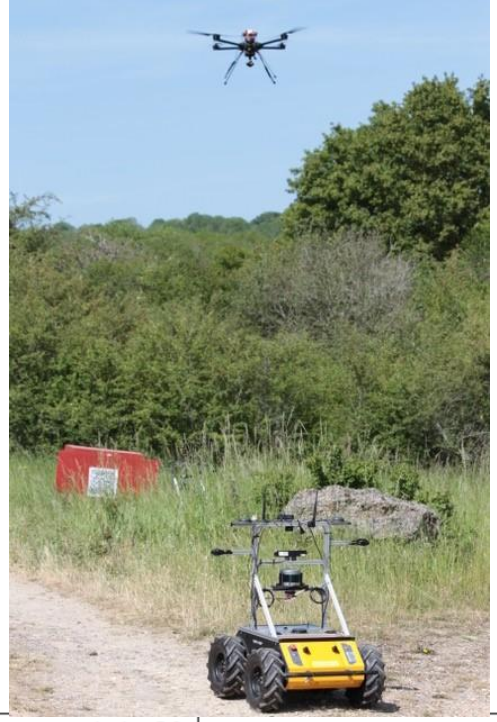
view
representation of a *system* (3.46) from the perspective of a related set of *concerns* (3.10)

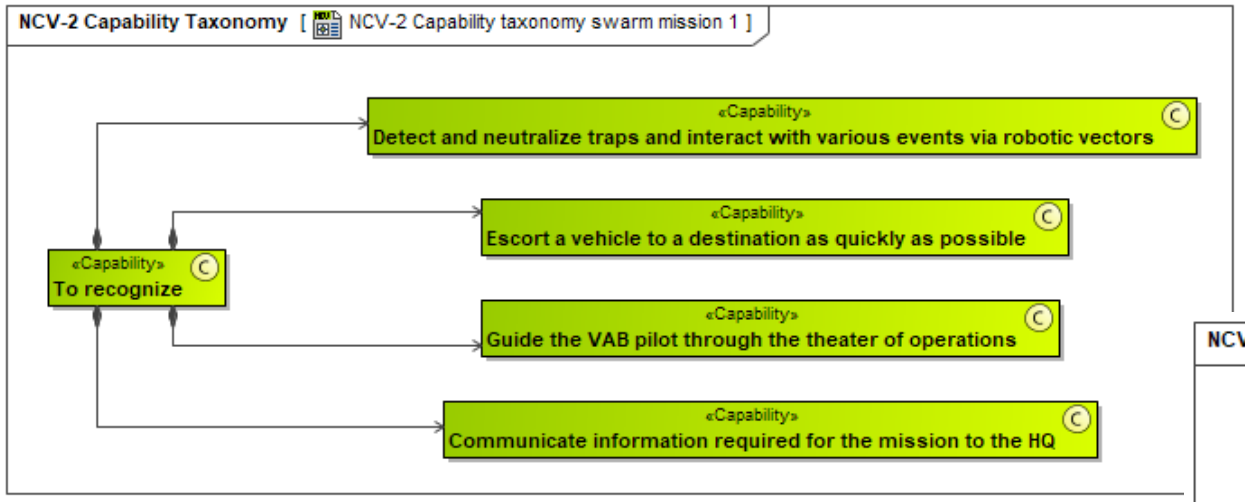
artefact
work *product* (3.32) that is produced and used during a project to capture and convey information

NAF provides the rules, guidance, and products for developing and presenting architecture descriptions that ensure a common denominator for understanding, comparing, and integrating architectures. The application of the Framework will enable architectures to contribute most effectively to the acquiring and fielding of cost-effective and interoperable military capabilities. The Framework will ensure that the architectures developed by NATO and the Nations can be compared and related across NATO and National boundaries, including multi-national boundaries.

1. Experimentation

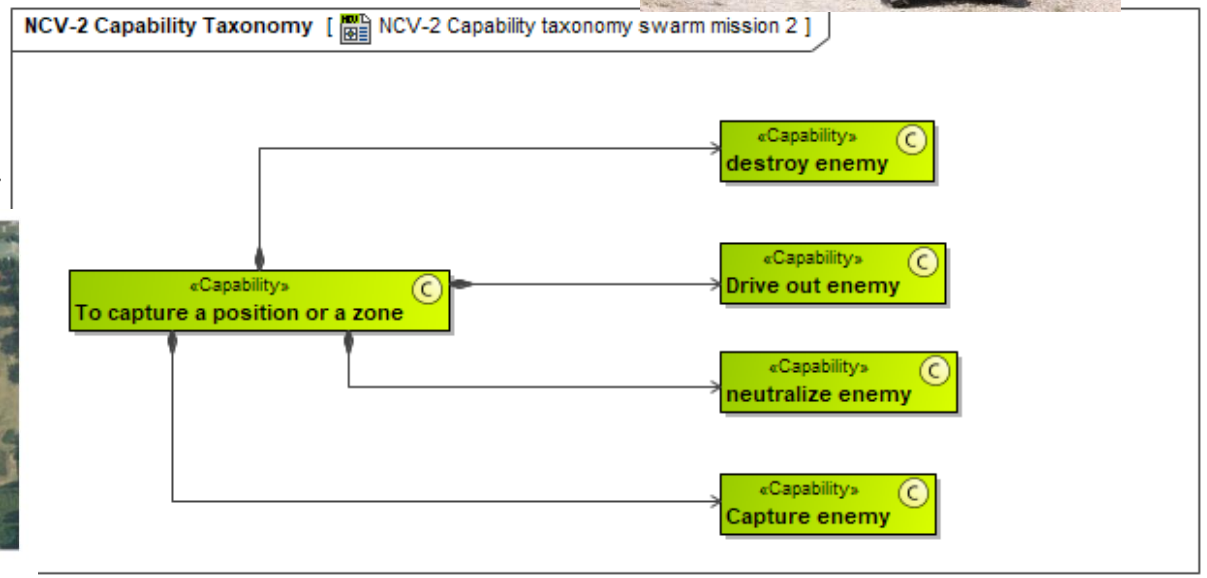
- Robotic challenge – capabilities, constraints – two increments





$$N_{platforms} \geq N_{pilots}$$

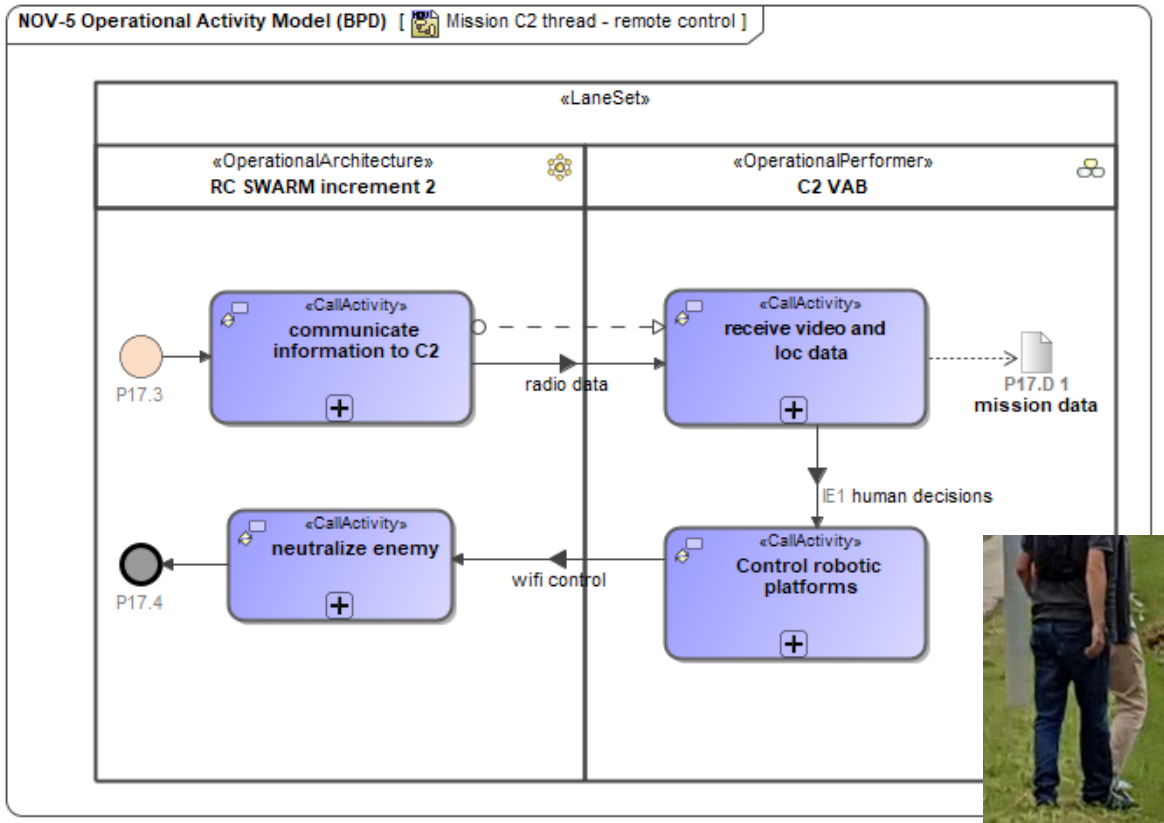
$$N_{platforms} > N_{pilots}$$

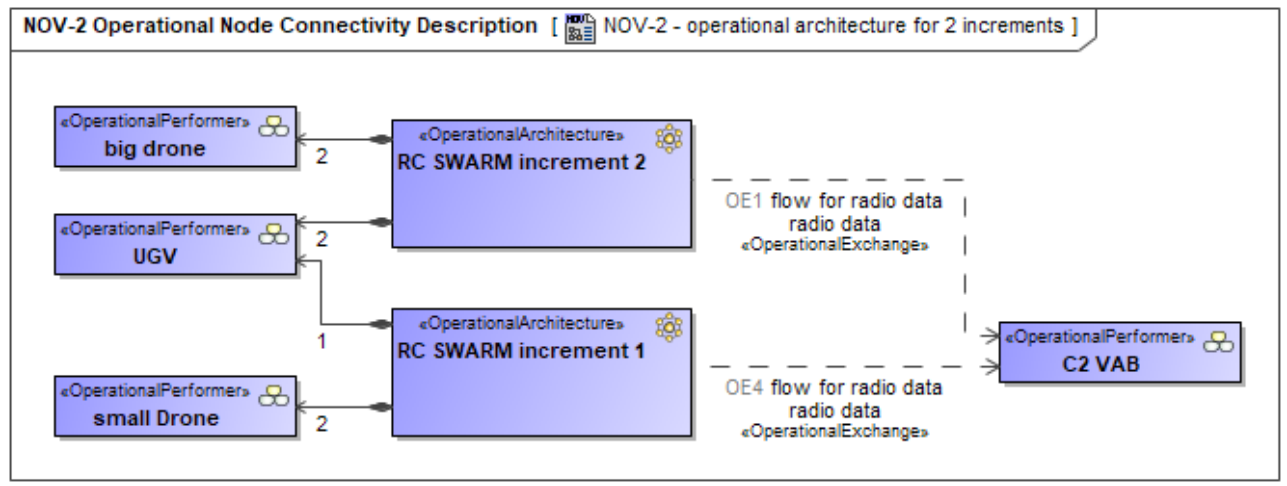


- Trapezoidal terrain of 500 m by 1 km
- Divided into 5 LIMAs
- Check point at each LIMA passage

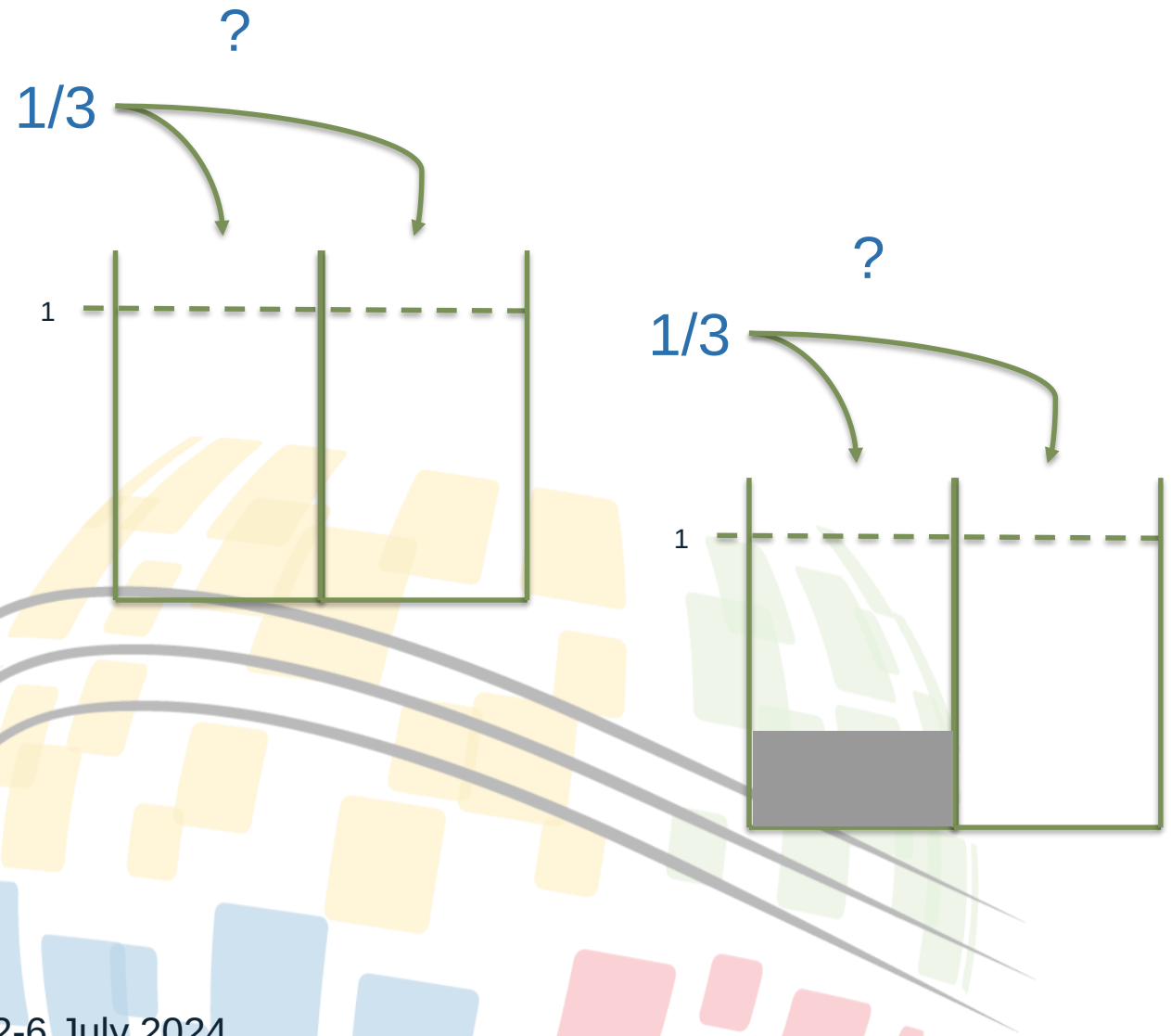
1. Experimentation

- Results & model

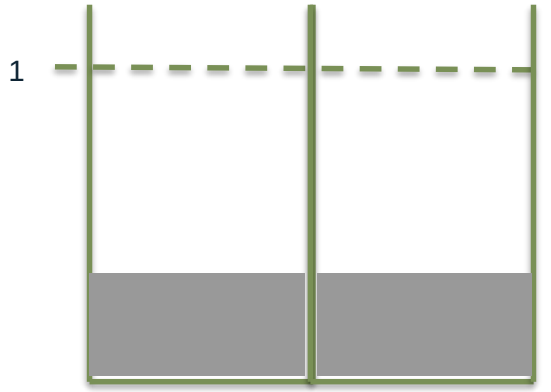




2. Adding artefact to MBSE from fielded experience, the Engineering Leakage Problem (ELP): an online problem

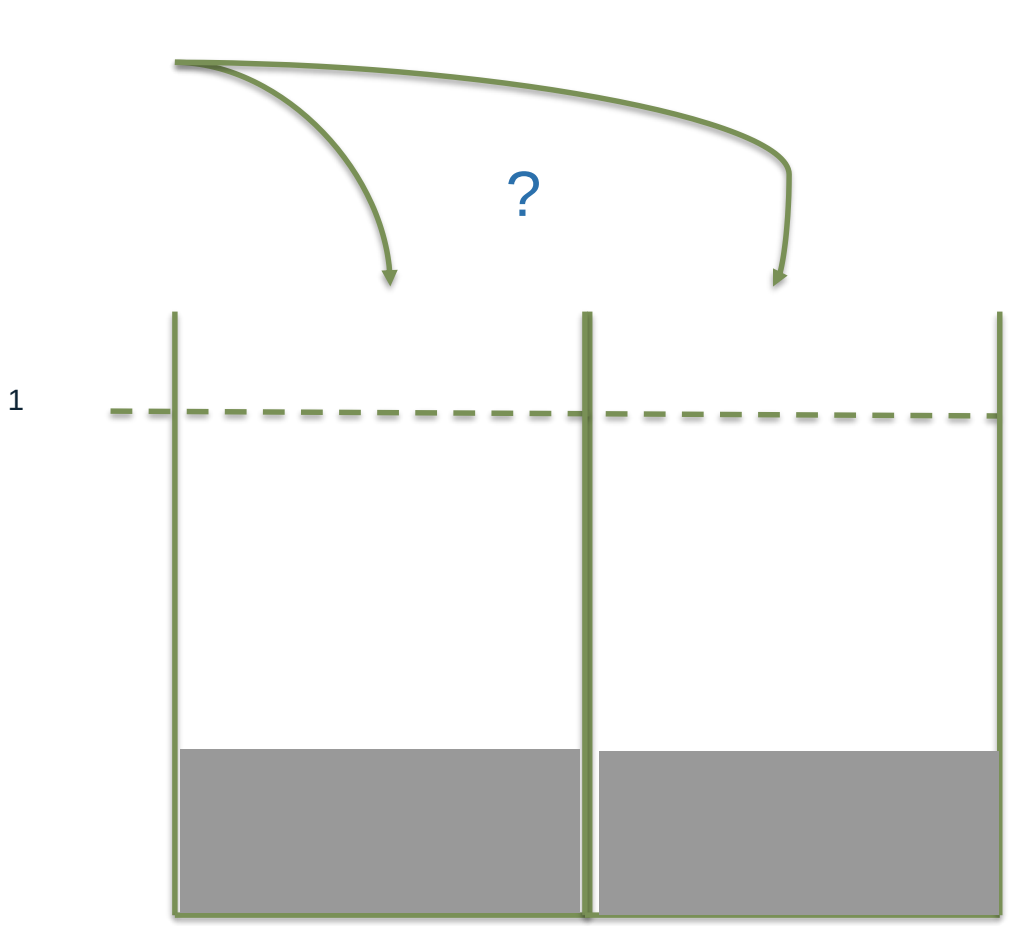


Fill in all cups with <Q,R,T> constraints as close as possible to 1



2. Adding artefact to MBSE from fielded experience, the Engineering Leakage Problem (ELP): an online problem

- “if I had known problem”



2. Adding artefacts to MBSE from fielded experience, the Engineering Leakage Problem (ELP), an online problem

How does it apply to systems engineering?

Each iteration over fielded tests in IVVQ may be seen as an online problem: it forces the engineers to reconsider original constraints.

“Systems thinking is voracious. Mathematics are required to observe facts when negligence strikes back”

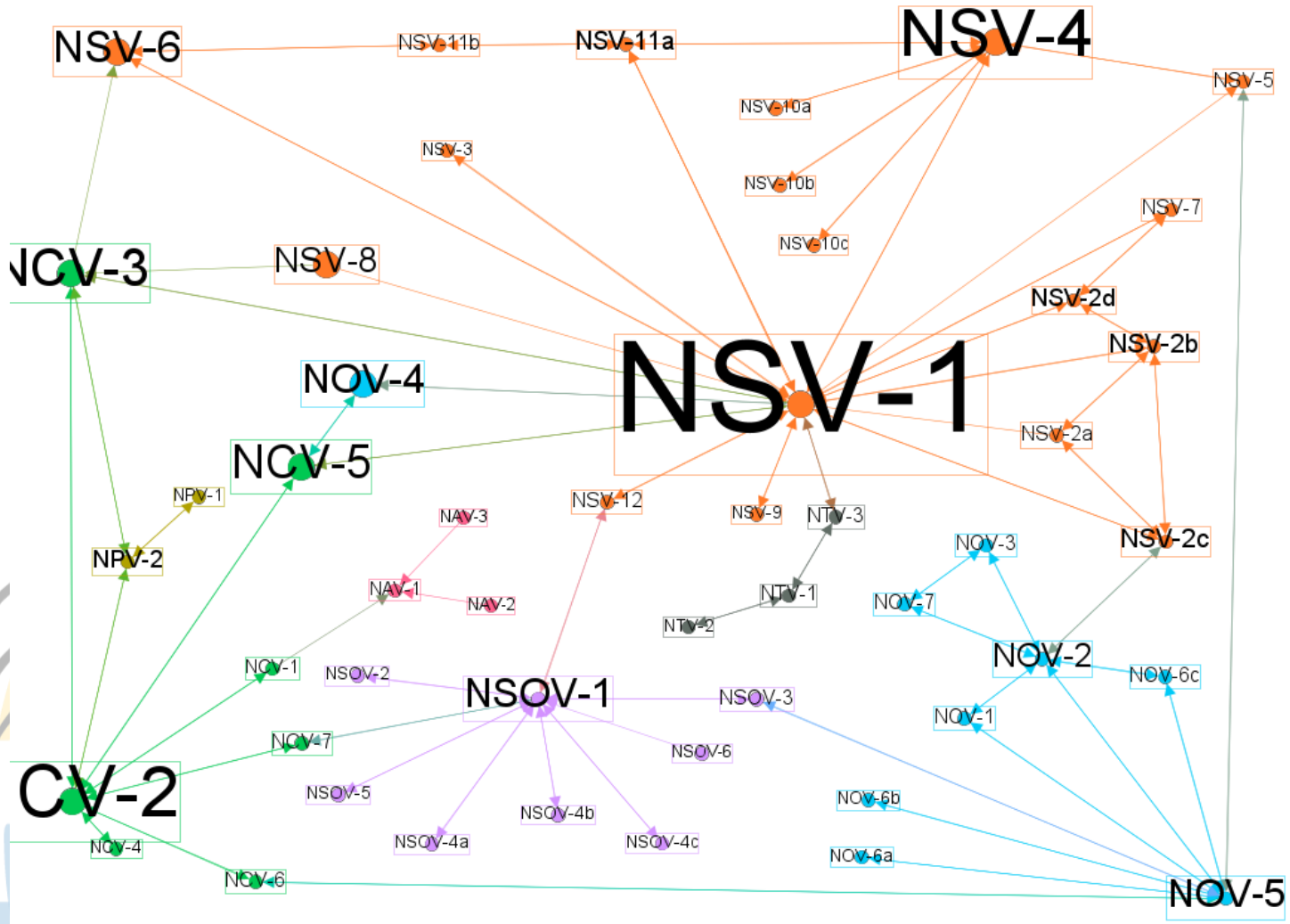
3. Mathematical formulation of systems engineering for the next challenges

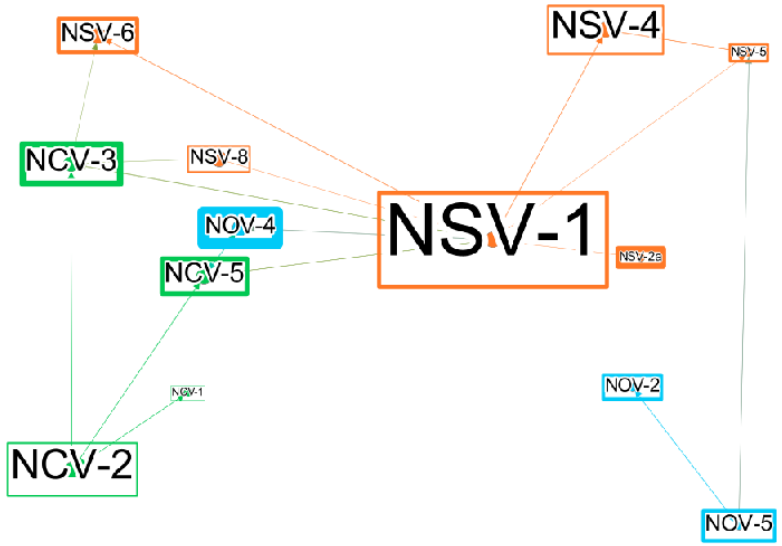
- Example: Refreshing feed from video through WIFI

- The next increment will most likely include communication, even at a higher level as we aim at robots autonomy

- Three problems most likely to be observed:
  1. Our own architecture jams the performance, because of system placement and unnoticed interactions between subsystems
  2. As always, COTS are unreliable. The platform does not perform as it should in our environment,
  3. The client changes requirements for collaborative behavior, and our choices for CPU and comm become obsolete.

3. Mathematical formulation of systems engineering for the next challenges





Pb1. What happens when a new view is necessary?

3. Mathematical formulation of systems engineering for the next challenges

- Adds the view in iself, with its own complexity level, its interaction
- Adds the links with existing views
- Adds consequences over the whole views
- Selection of the necessary shared artefacts with this view
- Most of the times, the architecture framework does not include the required view eg. Mechanical, electromagnetic, terrain topology, forces, finite elements, electrical power consumption

- Adding a view creates an exponential set of questions

Selection of an optimal subgraph in a graph: well known to applied mathematics specialist. Heuristics to get approximate solutions.

3. Mathematical formulation for three problems

- Pb2. Caracterization of behaviour of COTS, platforms or any system element in realistic environnment.
  - Required topology of the terrain,
  - Required hygrometry/dust resistance,
  - Required dynamic characterization (MINES, cannon schock…)

- Possibility to establish a link with technico-operational simulation

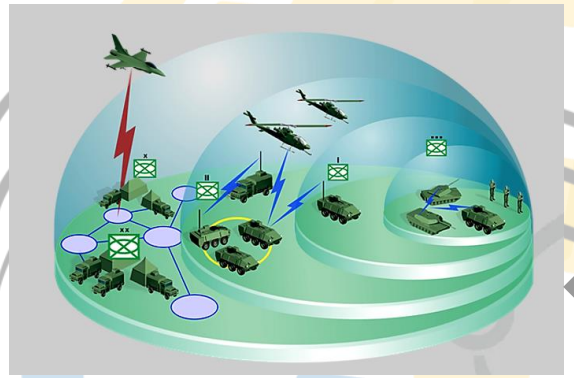


Image credits. MASA SWORD. SWORD | MASA Group (masasim.com)

Simulation is required, but theoretical problem associated to it does not present heuristics !

Systems engineering

4. Upscaling from platforms to swarm of platforms

- Pb3. Obsolescence of objectives, constraints, any issue directed by the client or operators on field

- Emergence will not be contained to linear growth, calling for hyper-exponential growth to select architectures as much as we aim at growing the number of platforms performing capabilities

- IVVQ major on system-of-systems such as collaborative combat is not a standard yet

If we have a precise idea of how much IVVQ costs and length, it means that architecture is set already

4. Facing ELPs with appropriate means $< \max(Q), \min(R), \min(T) >$

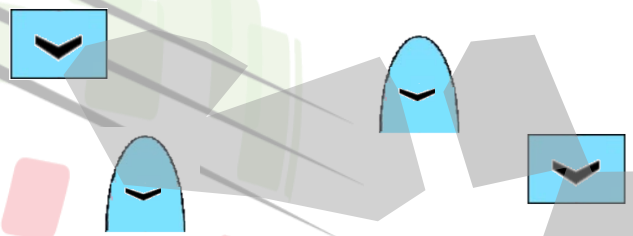
- Complexity assessment of our problems: NP-Hard, NP-complete, unsolved

Pb1.

Finding minimal subgraph in a graph, with Q, R and T constraints.
Close to a Travellers Salesman Problem (TSP), with
- multi-objective
- Multidisciplinary
- Heterogeneous « travelling » means
- Online changing constraints

Pb2.

Equivalent to finding minimal granularity for systems models with Q, R T constraints.
Close to a bin-packing problem, with
- multi-objective
- Multidisciplinarity
- Arbitrarily changing environment



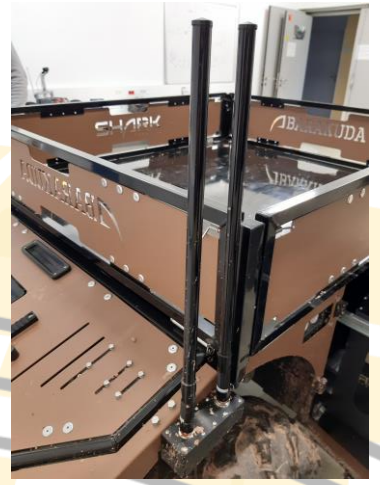
Pb3.

Equivalent to look for minimal costs for systems with Q,R,T constraints.
Close to knapsack problem, with
- multi-objective
- Multidisciplinarity
- Online changing capabilities
- Arbitrary ennemy behaviour
- Online reconfiguration of robotic platform purpose

4. Facing ELPs with appropriate means

HUMS as a new goal for machine learning – really ?

Consistent data requires placement of sensors on systems: 3D topology of system not included yet in AF, as well as the complexity of the problem in 3D (NP-Hard)



IVVQ ? Standardization of IVVQ means for collaborative robots on battlefield systems category and closing the gap with simulation

4. Facing ELPs with appropriate means

1. Simulation gives a chance to fight back environnment, topology, controls
2. Optimization gives a chance to fight back exponential delays and costs while ensuring quality in terms of performance
3. Systems engineering gives a chance to fight back on meaning of values, constants, constraints and objectives

Blind spots are still to be faced using digital continuity, and seamless workflows are mandatory to swim across collaborative combat complexity.

Trusted authority for <Q,R,T> constraints is a mathematical question.

5. Conclusions – Systems engineering swarms

1. COTS-Based Swarm IVVQ is an open question. Cumulative effect of swarm combined uncertainty
2. Theoretical complexity of operational scenarii have to be assessed on the impact on IVVQ complexity has to be defined
3. Mandatory to integrate Monitoring units on the systems to introduce feedback to systems engineering
4. New avenue of research on machine learning from field – propose modification of models from field observations

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