MBSE, PLM, MIP and Robust Optimization for SoS management of SCCOA

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System of systems engineering must be problem driven*

- How SE methodology is implemented for the complex industrial SoS SCCOA?
- How to integrate in a tool stack state-of-the-art method of SE and OR to address a specific problematic?

Agenda

- Context presentation
- Implementation of SE methods and specific tool stack
- RETEX
- Conclusion
SCCOA establishes the Recognized Air Picture 24/7
SCCOA provides tactical control of military flights

**COMMUNICATION**
- Surface-to-air radio system

**SEARCH AND RESCUE**
- Coordination and rescue centre

**CONTROL**
- 4 Control and reporting centres
- 5 Military air traffic control centres embedded in civilian centres
- 24 Military airfield air traffic control centres
SCCOA, the French air Defense system, is a **real** system of systems

- More than 80 systems (radars, telecom artifacts, control and command centers, gateways)
- ... connected to 80 external systems
- More than 150 operational centers
- More than 100 sites
SCCOA's management meets Maier’s criteria

- A lot of stakeholders…
- … many programs…
- … and many decision makers
A permanent issue: SCCOA’s management issues

- Systems can be acquired and/or used independently

- SCCOA’s Project Management (PM) is decomposed into several management decision levels

- SCCOA is interfaced with other military and civilian programs

- Incremental management of SCCOA to face SoS complexity
A transient issue: migration of telecom artifacts

AS IS

C2OPS-LYON-C2-V2.2

Deployment Date = 01-01-2014

Retirement Date = 01-06-2025

Computed_Retirement_Date = 01-09-2020

LEGACY_TECHNO

LOYON

C2OPS-LYON-GTW-C2-V1.0

Deployment Date = 01-09-2020

Bordeaux

C2OPS-LYON-C2-V2.2

Deployment Date = 01-06-2013

RETIREMENT_DATE = 01-01-2023

DER-BORD-RDX-V2.3

TO BE

C2OPS-LYON-C2-V2.2

Deployment Date = 01-09-2020

NICE

C2OPS-LYON-GTW-C2-V1.0

Deployment Date = 01-01-2018

Retirement Date = 01-01-2027

DER-NICE-RAD-V3.1

Bordeaux

DER-BORD-RDX-V2.3

NICE

DER-NICE-RAD-V3.1

Real names have been obfuscated

Issue: no tool is available + schedule uncertainty
MBSE tooling has made recent progress


MBSE enables stakeholders communication with a Domain Specific Ontology on top of NAF*
In common: Decision Support frameworks

SE: structured processes, information and databases. Questions raised in multi-objective optimization

OR: algorithms and tools for complex decision making

Opportunities to couple SE and OR.

State-of-the-art SE/OR: historic heritage of AI techniques (sub-gradients, genetics algorithm, Constraint Programming)

Recent helpful advances in OR (generic design of meta-heuristics, model&run solvers: LocalSolver, MIP, robust optimization)
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When a new problem is met, the tool stack is augmented.

One tool stack to tackle many issues
The stack enables data reuse across tools
A Product Lifecycle Management (PLM) tool is needed to support SoS engineering.

**Single system engineering**

**System engineering:**
Definition of configurations

**PLM**
Definition of spatial & temporal deployment

**System of systems engineering**

**System engineering:**
Definition of configurations

**PLM**
Definition of spatial & temporal deployment

Engineering data flow
An ontology for the management of System of Systems

Main validation effort

Main driver is capture of validated models
An pivot ontology for enabling communication between tools

Defined by problem of interest

Defined by CM
Communication between tools is enabled by Prolog and a CM process

- Communication between tool is a «change management» process
- Input & output formats are tool neutral (n-uplets)
- Correspondence rules* are expressed with the Domain Specific Language of the pivot ontology

*ISO/IEC/IEEE 42010
Mixed Integer Programming (MIP)/ Robust optimization

- PERT scheduling: a polynomial problem
  - Minimizing total completion time (makespan)
  - Only precedence constraints among tasks
  - Implemented in MS Project

- Adding resources constraints, RCPSP, a NP Hard problem.

- Our objectives:
  - Minimizing dismantling dates for SCCOA sites
  - Minimizing financial cost through maintenance costs of obsolete technologies

- Needs for a specific optimization problem
  - MIP: model&run implementation using OPL Cplex
  - Robust optimization extension: considering stochastic delays in project milestones
Plan

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Lessons learnt using MEGA NAF

- MEGA NAF imposed by the DGA for coherence of DGA architecture modelling.

- Automatic generation of chapters of analytical documents ensures consistent documentation.

- Some vigilance points were raised thanks to the NAF SoS model to detect functional and/or temporal discontinuities.

- Generation of a website with selected views and pieces of information:
  - clear success amongst stakeholders of SCCOA.
  - The website gave satisfaction for its ability to capitalize knowledge amongst stakeholders, it was adopted for the training of newcomers in SCCOA.
Surprise ! Prolog (b. 1972) match the needs !

- Input/output format are tools neutral
- Correspondence rules are naturally and concisely written in prolog → Low maintenance
- Prolog is open source,
- Having satisfactory performances with quick developments encouraged us to use Prolog.
Lessons learnt using Mixed Integer Programming

- IBM Cplex for the MIP model & run computations, OPL script for data preprocessing.

- MIP allows to deal with more complex models: resource constraints, financial costs and uncertainty with robust optimization techniques.

- For this case, resolution to optimality is easy with Cplex. Other free and less efficient MIP solvers could be used efficiently.

- Generally, MIP requires some specific expertise in modeling to be efficient, but offers optimality guarantees.

- For discrete optimization problems, we recommend for non experts to use more intuitive modeling frameworks such as LocalSolver or Constraint Programming.
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Conclusions

Methodological conclusions:
- NAF extensions: Calendar database, PLM tool with Prolog
- Interest of Prolog for concision and maintainability
- MIP interest: optimality proof, state-of-the art robust optimization techniques

Industrial conclusions for SCCOA:
- Return on investment of the SE methodology
- Web site export: a powerful tool for communication amongst stakeholders and for training of SCCOA newcomers.
- Innovating methodology for opportunity questions.
- Dismantling old telecom artifacts: planning results presented to the customers and decision makers
Methodological perspectives:
- Generalization of the methodology for other SoS
- Excel for pivot files between SE and OR
- Using more open source software (COIN-OR)
- Multi-objective optimization
- Constraint Programming: efficient for scheduling problems, easier for model&run
- LocalSolver: large scale model&run optimization solver
- Simulation coupled with SE and OR.

Industrial perspectives for SCCOA:
- Preparation of next increment SCCOA 5: architecture design
- Other opportunity and scheduling questions
References

- **System Engineering references**:  

- **Operations Research references**:  
Appendix: MIP model

\[
\begin{align*}
\min_{x, T \geq 0} & \quad \text{Cost} \\
& T^c \\
& T^l \\
& T^l \\
& T^l \\
& T^l \\
& T^l \\
& T^l \\
& T^l \\
& \geq \min(t^l_b, t^l_f) \\
& \geq \delta_d + t(x_{d,t} - x_{d,t-1}) \\
& \leq x_{d,t+1} \\
& \leq 0 \\
& \geq 1 \\
& \leq \eta_{r,t} \\
& \in \{0, 1\}
\end{align*}
\]