



Contribution to the definition of a decision support system for the dynamic maintenance of a fleet of cyber-physical systems

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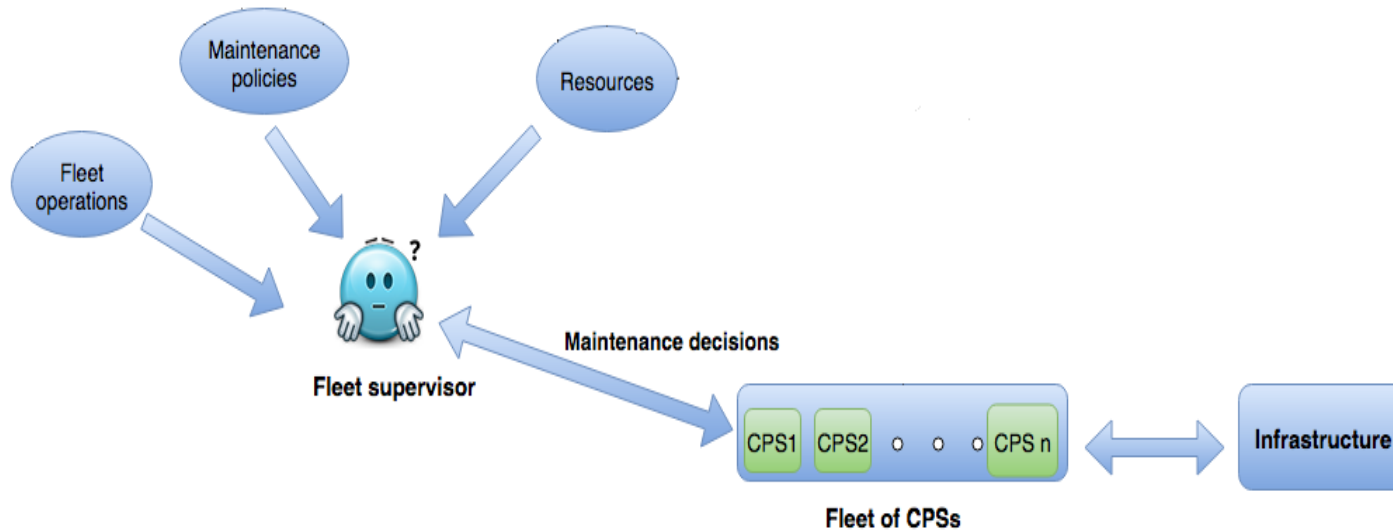
Workshop SuferLab Janvier 2019,
LAMIH UMR CNRS 8201,
à Valenciennes,
le 31 Janvier 2019

Outline

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Motivation and objectives



Objectives:

- Increasing fleet's availability (mission-ready CPSs) [1]
- Increasing fleet's reliability [1]
- Operate in a dynamic environment

Problem formulation



Problem's assumptions

- Fleet's CPSs have acquisition, processing and communication capabilities
- Each CPSs is attached to a specific maintenance depot
- In cases of emergencies a CPS can be repaired in any maintenance depot [2]
- Given fleet size f and the number of depots d , $f \geq d$ [3]
- Mean maintenance time to repair (MMTR) of a CPS is known/can be estimated [4]



Problem formulation



Global variables

i : Index of CPSs ($i = 1 \dots f$), with f the number of CPSs in the fleet

j : Index of maintenance depots ($j = 1 \dots d$), with d the number of maintenance depots

k : Index of skills ($k = 1 \dots K$), with K the number of maintenance teams based on skills per depot

t : Index of time periods ($t = 1 \dots T$), with T the time horizon

h : Index of depot hangars ($h = 1 \dots H$), with H the number of maintenance hangars (tracks) per maintenance depot

ε : Minimum number of CPSs in a fleet required to complete operations

μ : Fleet availability threshold

$MMTR_i$: Estimated mean maintenance time to recover for a CPS

g_{i_CBM} : CBM gravity indicator of a subsystem in a CPS

M : A positive number



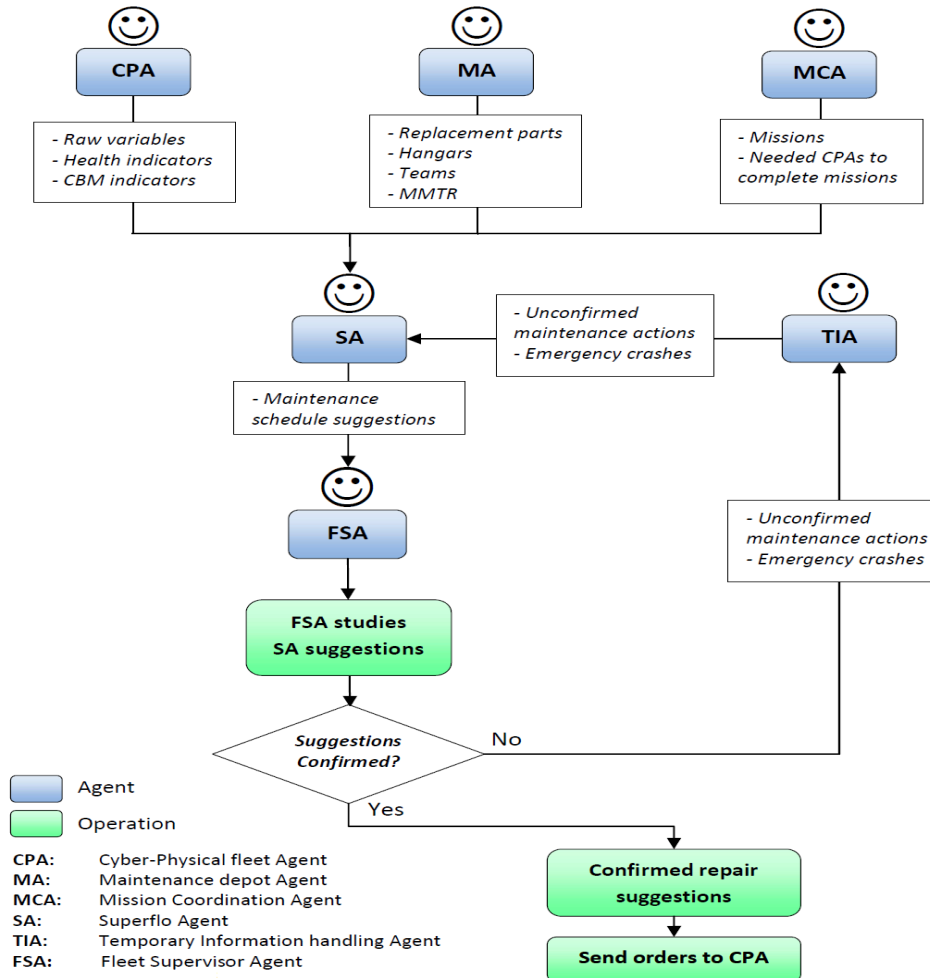
Proposed multi-agent system (MAS)

The agents

- Cyber-physical fleet agents (CPA): *Number (CPA) = f*
- Supervision agent (SA): *Single*
- Fleet supervisor agent (FSA): *Single*
- Maintenance depots agents (MA) : *Number (MA) = d*
- Mission coordination agent (MCA): *Single*
- Temporary information handling agent (TIA): *Single*

Proposed multi-agent system (MAS)

The agents [5]



Agent (Blue box)
Operation (Green box)

CPA: Cyber-Physical fleet Agent
 MA: Maintenance depot Agent
 MCA: Mission Coordination Agent
 SA: Superflo Agent
 TIA: Temporary Information handling Agent
 FSA: Fleet Supervisor Agent

MILP model for validation



MILP decision variables

$$x_{it} = \begin{cases} 1, & \text{if CPS } i \text{ requires no maintenance at time } t \in T \\ 0, & \text{Otherwise} \end{cases}$$

$$y_{it} = \begin{cases} 1, & \text{if CPS } i \text{ is undergoing CBM at time } t \in T \\ 0, & \text{Otherwise} \end{cases}$$

$$z_{it} = \begin{cases} 1, & \text{if CPS } i \text{ is in corrective maintenance} \\ & \text{at time } t \in T \\ 0, & \text{Otherwise} \end{cases}$$



MILP model for validation



MILP objective function and constraints

Objective function:

$$\text{Maximize: } \sum_{i=1}^f w_i g_{i_CBM} \quad (1)$$

- 15 Constraints



MILP model for validation

Validation results

Instances					Number of CPAs available for missions		Number of CPAs available for CBM	
f	ϵ	f_1	f_2	f_3	MAS	MILP	MAS	MILP
7	3	3	3	1	3	3	1	7
10	5	2	6	2	5	3	1	10
• • • • •								
65	21	10	45	10	21	34	65	21

MAS under perturbations

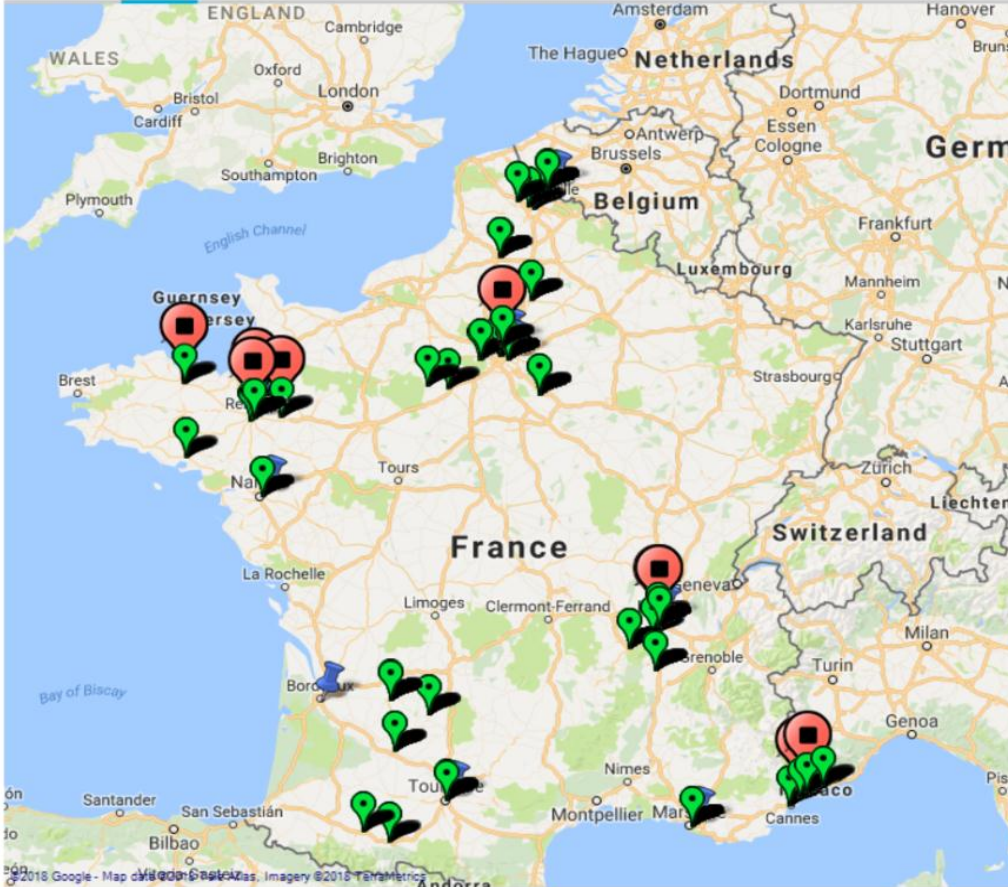


Before perturbation							Perturbations	After perturbation						
Instances					CPAs Available	CPAs for CBM	CPAs breakdown	Instances					CPAs Available	CPAs for CBM
f	ϵ	f_1	f_2	f_3				f	ϵ	f_1	f_2	f_3		
7	3	3	3	1	3	3	1	7	3	2	3	2	3	2
10	5	2	6	2	5	3	1	10	5	2	5	3	5	2
							•							
							•							
							•							
							•							
							•							
							•							
							•							
							•							
65	21	10	45	10	21	34	5	65	21	5	45	15	21	29

Industrial implementations



La flotte R2N Geoloc Groupement trains Etat de santé Classement par gravité Systèmes Planning



09:32:41

File Help



I'm Superflo. Can I help you?

- Status
- Priority
- R2N
- NAT

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Industrial implementations



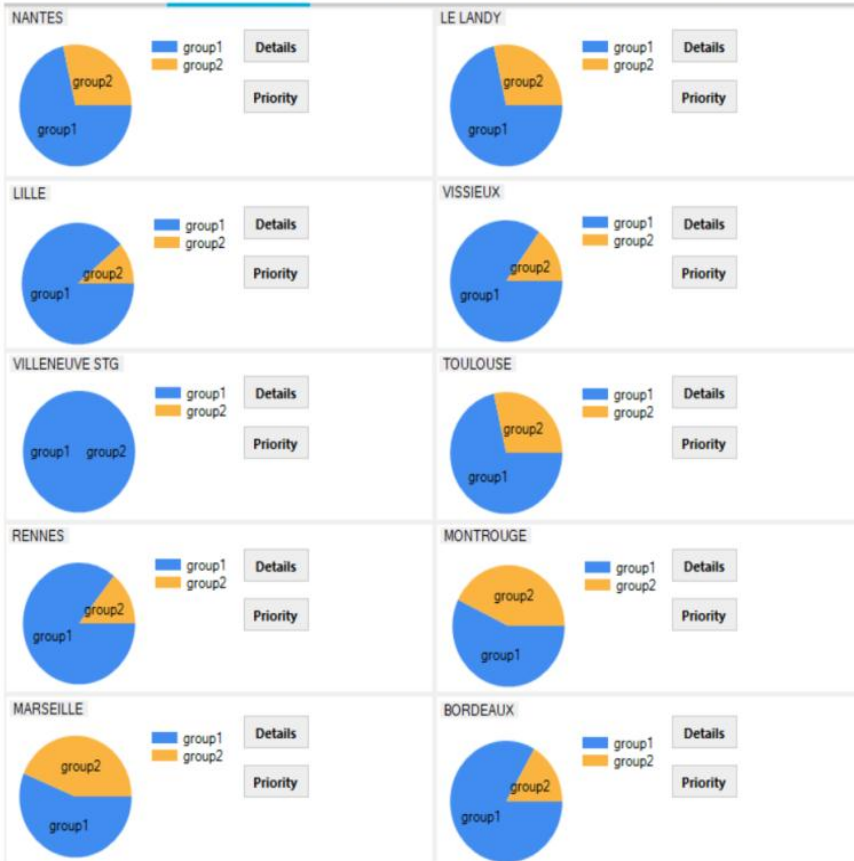
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La flotte R2N Geoloc Groupement trains Etat de santé Classement par gravité Systèmes Planning



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Trains	Prior	Faults	Opt_Ind
R118C	200	2	202
R036L	100	1	101
R027L	0	1	1
R004L	0	0	0
R016L	0	0	0
R029L	0	0	0
R035L	0	0	0
R050L	0	0	0
R056L	0	0	0
R061L	0	0	0
R067L	0	0	0
R068C	0	0	0
R074C	0	0	0
R080C	0	0	0
R086C	0	0	0
R114C	0	0	0
R119C	0	0	0
R122L	0	0	0
R126L	0	0	0
R128L	0	0	0
R129L	0	0	0

Conclusion



- The proposed MAS model:
 - Effective – Validated by MILP model
 - Reactive – Capable of handling uncertainties

Conclusion



- Industrial implementation challenges:
 - Missing industrial data (e.g. CBM indicators)
 - Highly heterogeneous data
- Outcomes:
 - Initiation of CBM project (machine learning)

References

- [1] S. Dožić, A. Jelović, M. Kalić, and M. Čangalović, 'Variable Neighborhood Search to solve an airline fleet sizing and fleet assignment problem', *Transp. Res. Procedia*, vol. 37, pp. 258–265, 2019.
- [2] Q. Feng, Y. Chen, B. Sun, and S. Li, 'An Optimization Method for Condition Based Maintenance of Aircraft Fleet Considering Prognostics Uncertainty', *Sci. World J.*, vol. 2014, pp. 1–8, 2014.
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- [5] J. Mbuli, T. Chargui, D. Trentesaux, A. Bekrar and T. Dailly, 'A multi- agent system for the reactive planning of the maintenance of a fleet of mobile cyber-physical systems', *Computers in Industry*, 2019.

