Dynamic sequential decision making for missions and maintenance scheduling for a deteriorating vehicle

E. Robert, C. Bérenguer, K. Bouvard, R. Lesobre, H. Tedie

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Industrial context

Why dynamically scheduling both missions and maintenance operations for a truck ?

Ensure the vehicle availability

Avoid unplanned stops

Fit to the vehicle usage

Adapt to the missions constraints

Schedule at best maintenance time slots

Adapt to disruptions

Improve productivity

Research context

Rescheduling environments

Static
- Deterministic
- Stochastic

Dynamic
- No arrival variability
- Arrival variability
- Process flow variability

Rescheduling strategies

Dynamic
- Dispatching rules
- Control-theoretic

Predictive-reactive
- Periodic rescheduling
- Event-driven rescheduling
- Hybrid rescheduling

Rescheduling methods

Schedule generation
- Nominal schedules
- Robust schedules

Schedule repair
- Right-shift rescheduling
- Partial rescheduling
- Complete regeneration

Problem statement

Activities

Initial missions set: M_1, M_2, M_3, M_4, M_5 … M_n

Preventive maintenance: PM

Problem

$$\max_{\pi} G(\pi) \ \ s.t \ \ \forall k \in [\![1; N_b]\!], \mathbb{P}_f(k) \leq \mathbb{P}_{max}$$

- G: Operating incomes
- π: Schedule
- N_b: Number of blocks composing π
- $\mathbb{P}_f(k)$: Probability to have one failure in block k
- $\mathbb{P}_{max}$: Maximum failure probability

Schedule

Initial schedule:
$(M_2, M_1)(M_5, M_4, M_n) \dots (M_3)$

Information during/ after M_x?

M_{n+1}

Information type:

- Deterioration measurement
- Failure
- New mission(s)

Schedule update

Current schedule kept

Contributions

- **Propose a predictive-reactive approach to jointly schedule missions and maintenance operations**
  - Generation of a schedule evolving over time according to monitoring information and disruptions
  - Maintenance model based on the vehicle deterioration evolution

- **Implement the rescheduling strategy based on a genetic algorithm**
  - Optimization criterion
  - Sequential rescheduling according to the event

- **Comparison between a static scheduling method and the dynamic one**
  - Performance analysis
  - Effect of the rescheduling

Decision criterion

➤ **Dynamic scheduling decision criterion:** $\boldsymbol{C(\pi) = G_m - C_d - C_m}$

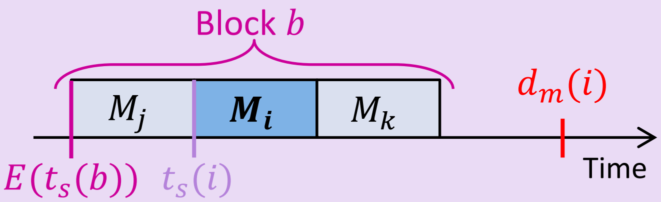
Gains earned when the missions are completed

$$G_m = \sum_{i=1}^{n} g_m(i)$$

$g_m(i)$: gain generated by the mission i

Delay costs

$$C_d = \sum_{i=1}^{n} c_d(i)$$



For M_i : $c_d(i) = t_d(i) C_{ud}$
with $t_d(i) = t_s(i) - d_m(i)$

↕ $E(t_s(b))$

$c_d(i)$: delay cost for mission i
$t_d(i)$: delay time for mission i
$E(t_s(b))$: average beginning time for block b

Maintenance cost

$$C_m = \sum_{b=1}^{N_b} \left(C_0 + C_f \sum_{k=1}^{N_f(b)} \mathbb{P}_f(b,k) \right)$$

N_b: number of blocks
C_0: preventive maintenance cost
C_f: corrective maintenance cost
$N_f(b)$: maximum number of considered failures for block b
$\mathbb{P}_f(b,k)$: probability to exceed the failure threshold L for the k^{th} time in block b

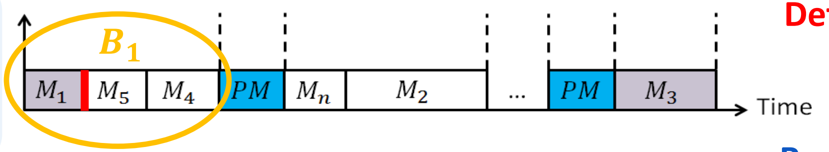
Maintenance model

➢ **Deterioration-threshold failure model** → estimate the maintenance costs associated with failures

$Gamma\ process: X \sim Ga(\alpha_i, \beta_i)$

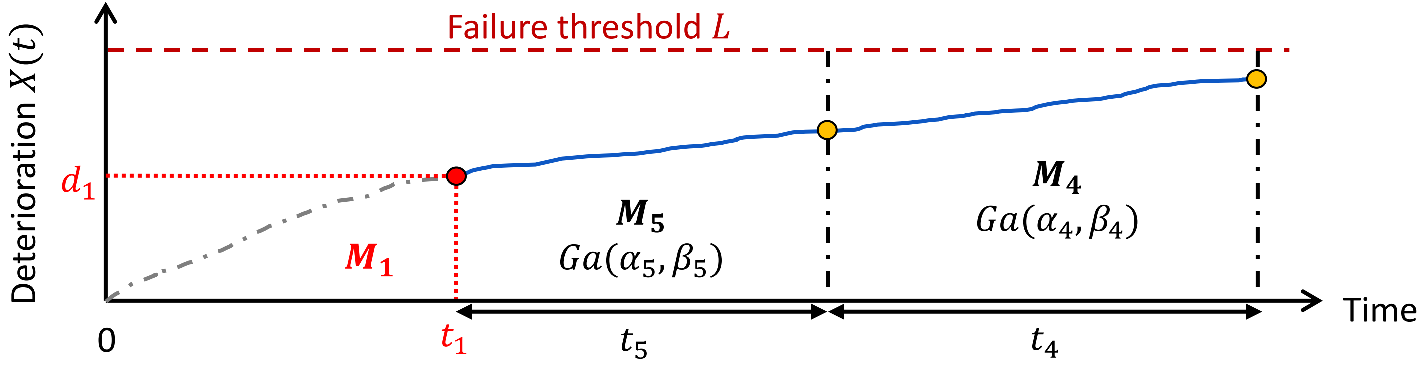
$X(t_d) = \boldsymbol{L} \rightarrow failure$

Mission



Deterioration level after M_1: d_1

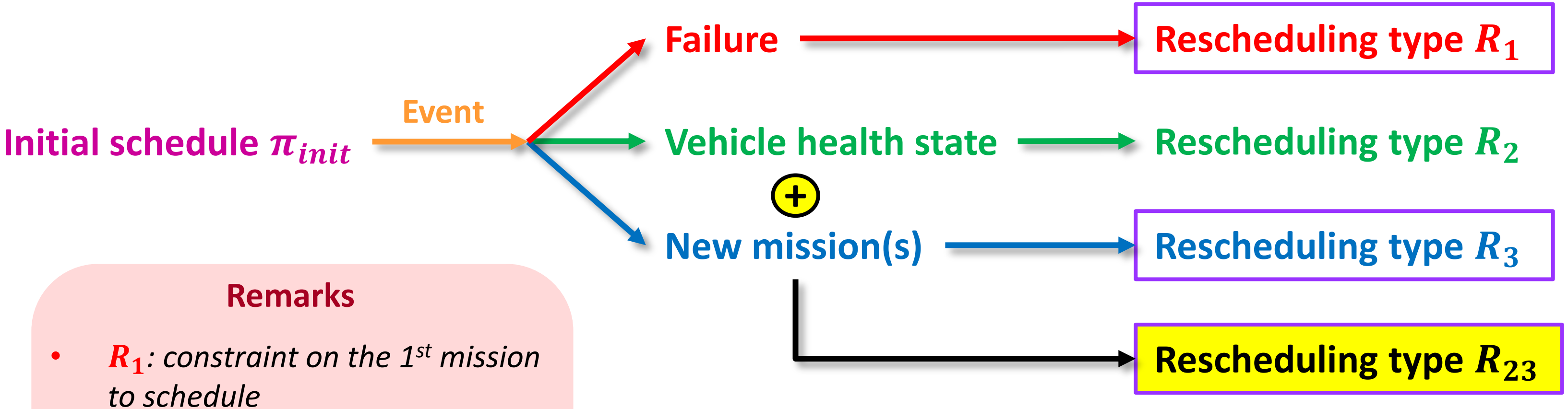
Remaining missions in B_1: M_5, M_4



Equivalent Gamma process with the remaining missions → estimate the probability to exceed the threshold $L - d_1$

Dynamic sequential method

Based on a **genetic algorithm**



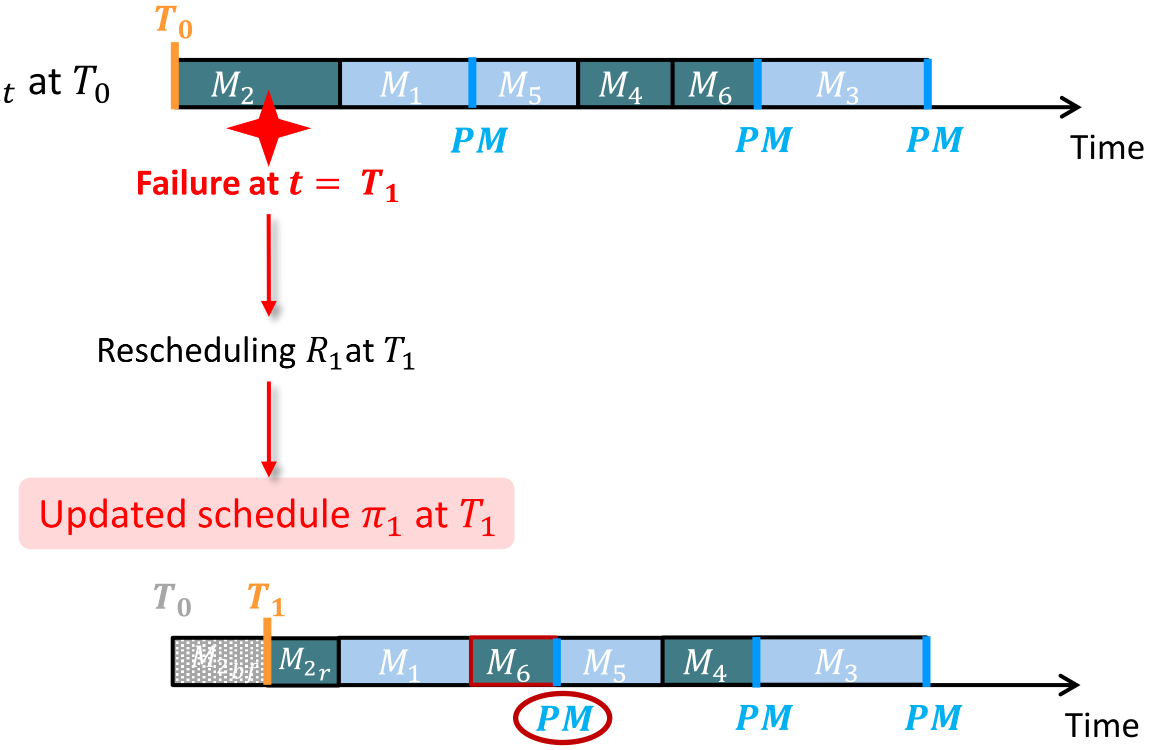
Remarks

- R_1: *constraint on the 1st mission to schedule*
- R_2: *constraint on the 1st mission block to fill in*
- R_3: *add new missions in the missions batch*

Mandatory rescheduling

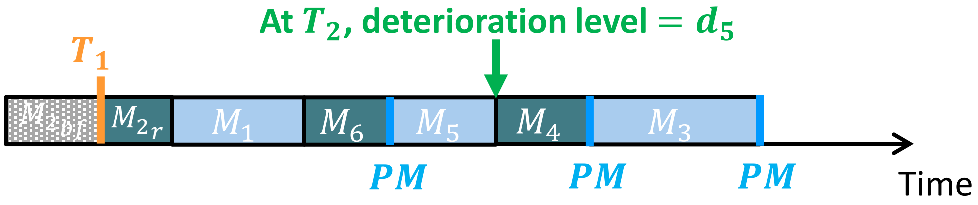
Dynamic sequential method

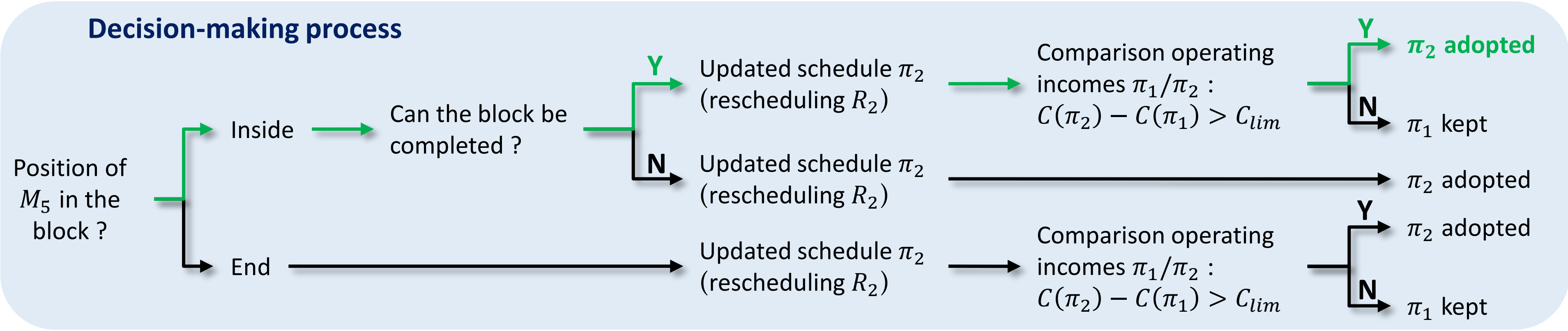
- Initial schedule π_{init} at T_0



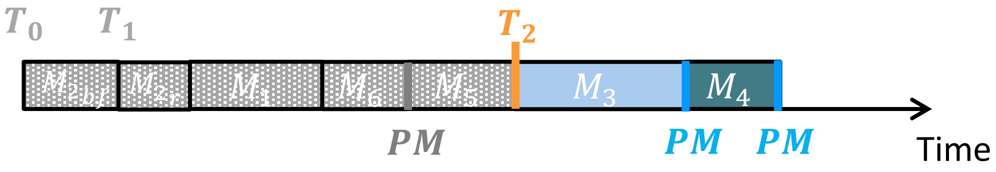
Dynamic sequential method

- Schedule π_1 at T_1





Updated schedule π_2 at T_2



Numerical example: framework

Mission → $(\boldsymbol{t_m}, \boldsymbol{\alpha_m}, \boldsymbol{\beta_m}, \mathbb{P}_m, \boldsymbol{g_m}, \boldsymbol{d_m})$

$\forall m, g_m = 5000$

18 missions → 6 available at T_0

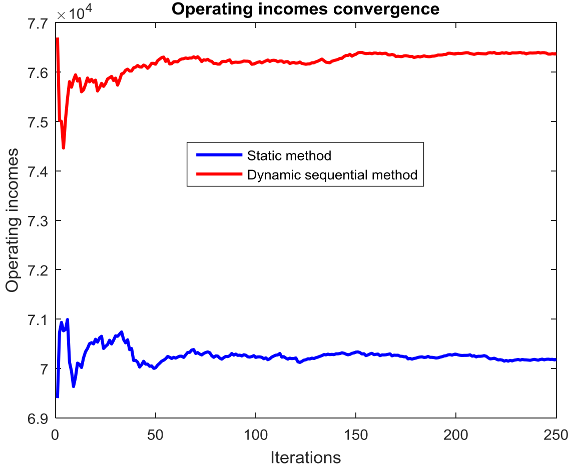
Parameters	Values
C_{ud}: *unitary penalty cost for delay*	50
C_0: *preventive maintenance cost*	1000
d_p: *preventive maintenance duration*	2
C_f: *corrective maintenance cost*	3000
d_c: *corrective maintenance duration*	4
L: *failure threshold*	100%
$\mathbb{P}_{max}$: *maximum failure probability*	0.1

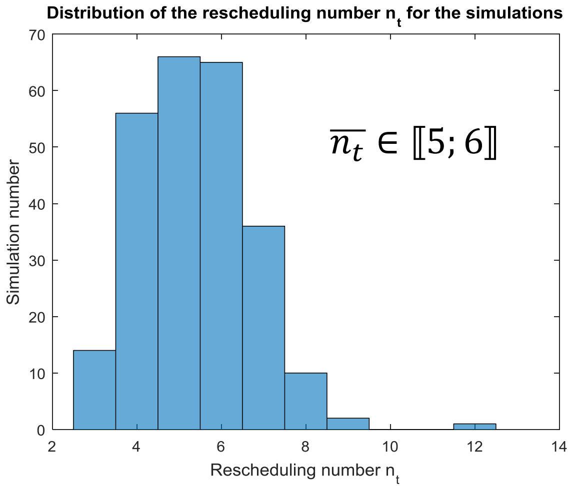
- t_m: duration
- (α_m, β_m): deterioration process parameters
- $\mathbb{P}_m$: failure probability
- g_m: gain
- d_m: starting deadline

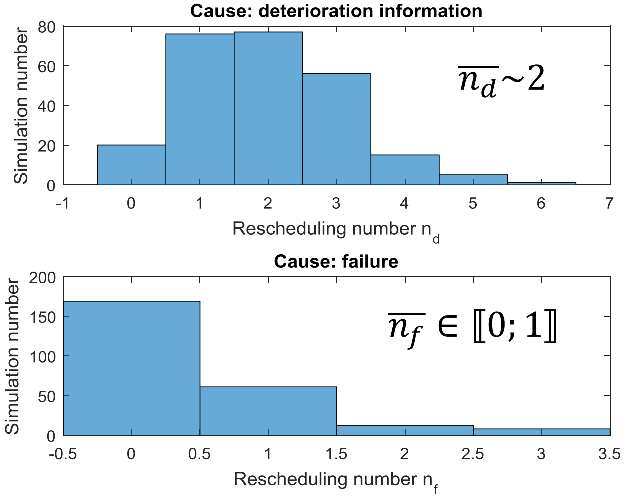
Scenario

- ***New missions:*** *4 missions added after missions 1,3,5*
- ***Deterioration measures:*** *after missions 1,2,5,6,8,10,12,13,14,17,18*
- ***Monte-Carlo simulations***
- ***Comparison*** *dynamic sequential method VS "static" scheduling method*

Performance analysis







Method	Dynamic sequential	Static
Operating incomes	76370	70180
Number of blocks	9	13
Computation time	50s	10s

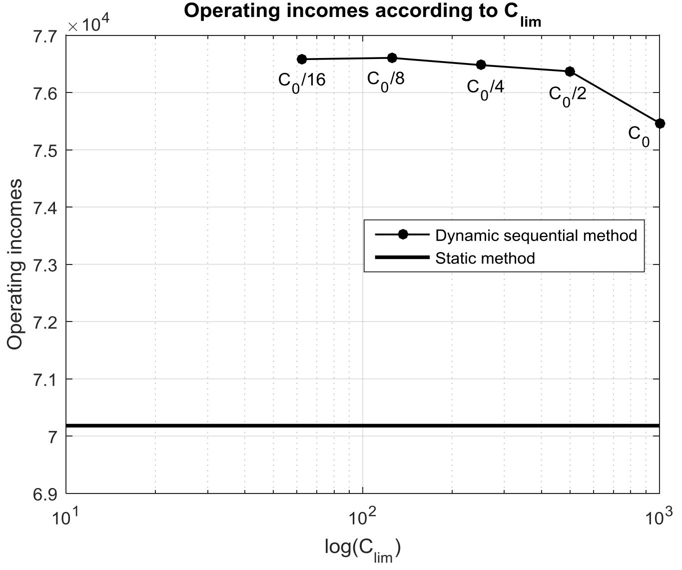
$$n_t = n_f + n_d + n_m + n_{md}$$

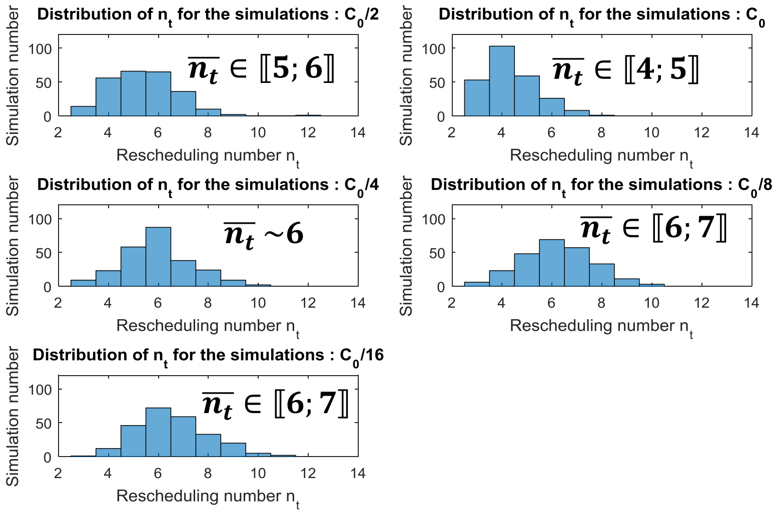
$n_m = 1$, $n_{md} = 2$

Monitoring information → Rescheduling → Benefits generated by the dynamic sequential $\sim 8,8\%$

Rescheduling flexibility

When vehicle health state available → Rescheduling limit condition C_{lim}





Rescheduling effect in the operating incomes through the delay costs to limit disruptions

Conclusion

- **Predictive-reactive rescheduling strategy to schedule missions and maintenance operations**
  - Schedule evolving over time according to available monitoring information
  - Maintenance model based on deterioration-threshold failure model

- **Decision-making process**
  - Optimization criterion → balance between the gains, the delay costs and the maintenance costs

- **Comparison dynamic sequential and “static” methods**
  - Increase of the operating incomes $\sim 8.8\%$ at the expense of the computation time
  - Better fit to the vehicle health state
  - Rescheduling limit condition → avoid too many rescheduling

⚠ The cost necessary to retrieve the monitoring information is not considered

Next step: Develop a similar method for a fleet of vehicles

Thank you for your attention.

Questions ?