

Multi-model Maintenance Scheduling

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Introduction

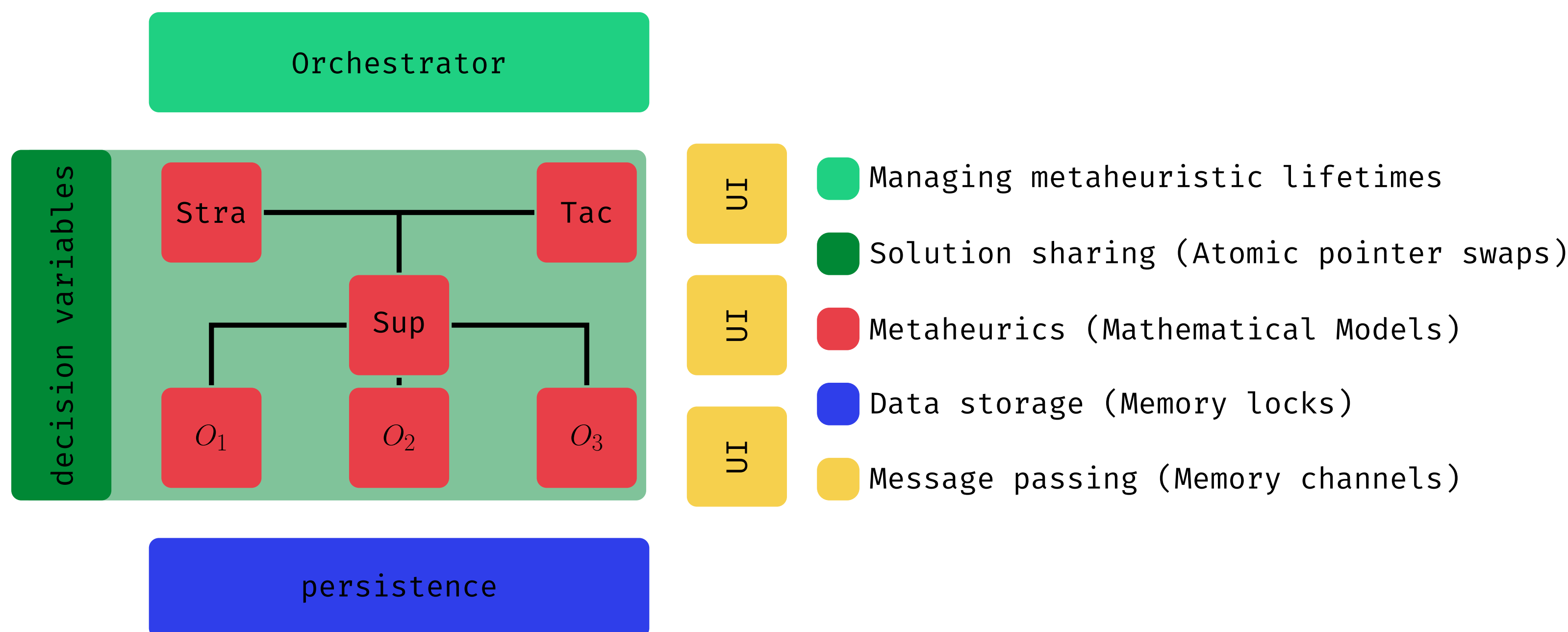
Current Operation Research methods have proven difficult to implement in operational settings. The poster presents a methodology to decompose a large-scale decision process into a series of modules that each represents the decisions taken by each individual stakeholder making up the scheduling process. The maintenance scheduling process in its most general form is composed of a Scheduler, a set of Supervisors, and groups of technicians that are lead by the supervisors. It is generally believed that maintenance efficiency can be increased by up to 35% (Palmer 2019) by having a well organized maintenance scheduling system in place. This project will provide an implementable architecture that is able to model and optimize this system through the use of real-time optimization and user interactions.

Research Questions

1. How to create modular algorithm components that can solve well defined decision problems while also integrating into a larger decision making process?
2. What approaches can be used to implement a real-time scheduling system that coordinates multiple agents, each utilizing different mathematical models and metaheuristics?
3. In what ways can metaheuristics be integrated into existing scheduling workflows and business IT infrastructures, such as ERP systems, to address complex operational problems involving multiple stakeholders?
4. How to model a scheduling process where each decision affects the process itself?

Solution Method

Modular Scheduling System Architecture

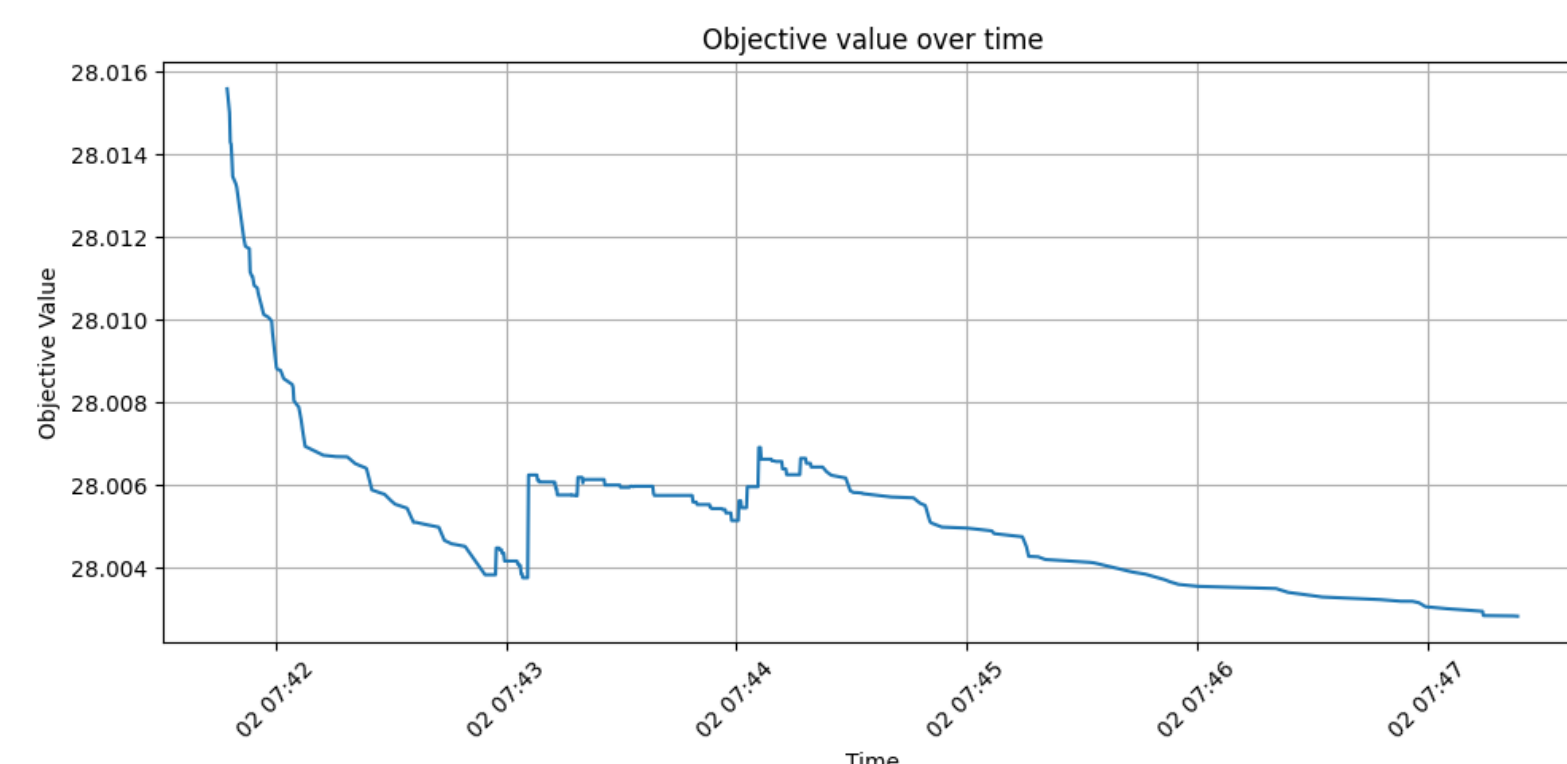


Algorithm: Actor based Large Neighborhood Search

Algorithm 1 Actor-based Large Neighborhood Search

```
1: Input  $Q$  = message queue
2: Input  $P$  = problem instance
3: Input  $X$  = initial schedule
4: Input  $S$  = SharedSolution
5: repeat
6:    $X^t = \text{clone}(X)$ 
7:   while  $Q.\text{has\_message}()$  do
8:      $P.\text{update}(S, m)$ 
9:      $X^t.\text{destruct}(S, m)$ 
10:  end while
11:   $X^t.\text{repair}(S)$ 
12:  if  $\text{accept}(X^t, X)$  then
13:     $X.\text{update}(X^t)$ 
14:  end if
15:  if  $c(X^t) < c(X)$  then
16:     $X.\text{update}(X^t)$ 
17:     $S.\text{atomic\_pointer\_swap}(X)$ 
18:  end if
19:   $Q.\text{push}(m)$ 
20: until
```

Results



Future Work

1. Validate effectiveness user-inputs into the Scheduling Application with case company
2. Assess effectiveness of modular meta-heuristics with atomic pointer swaps to share state

Methodology

Strategic: Variant of the knapsack problem

Meta variables:

- $s \in S$ (1)
- $\beta(\tau)$ (2)
- $\tau \in [0, \infty]$ (3)

Maximize:

$$\sum_{u \in W(\tau)} \sum_{p \in P(\tau)} \text{strategic_value}_{up}(\tau) \cdot \alpha_{up}(\tau) - \sum_{p \in P(\tau)} \sum_{r \in R(\tau)} \text{strategic_penalty} \cdot \epsilon_{pr}(\tau) + \sum_{p \in P(\tau)} \sum_{w \in W(\tau)} \sum_{u \in U(\tau)} \text{clustering_value}_{w1, w2} \cdot \alpha_{w1p}(\tau) \cdot \alpha_{w2p}(\tau)$$

(4)

Subject to:

- $\sum_{u \in W(\tau)} \text{work_order_work}_{up} \cdot \alpha_{up}(\tau) \leq \text{resource}_{pr}(\tau, \beta(\tau)) + \epsilon_{pr}(\tau) \quad \forall p \in P(\tau) \quad \forall r \in R(\tau)$ (5)
- $\sum_{u \in W(\tau)} \alpha_{up}(\tau) = 1 \quad \forall p \in P(\tau)$ (6)
- $\alpha_{up}(\tau) = 0 \quad \forall (u, p) \in \text{exclude}(\tau)$ (7)
- $\alpha_{up}(\tau) = 1 \quad \forall (u, p) \in \text{include}(\tau)$ (8)
- $\alpha_{up}(\tau) \in \{0, 1\} \quad \forall u \in W(\tau) \quad \forall p \in P(\tau)$ (9)
- $\epsilon_{pr}(\tau) \in \mathbb{R}^+ \quad \forall p \in P(\tau) \quad \forall r \in R(\tau)$ (10)

Tactical: Variant of the project scheduling problem

Meta variables:

- $s \in S$ (11)
- $\alpha(\tau)$ (12)
- $\tau \in [0, \infty]$ (13)

Minimize:

$$\sum_{o \in O(\tau, \alpha(\tau))} \sum_{d \in D(\tau)} \text{tactical_value}_{do}(\tau) \cdot \beta_{do}(\tau) + \sum_{r \in R(\tau)} \sum_{d \in D(\tau)} \text{tactical_penalty} \cdot \mu_{rd}(\tau)$$

(14)

Subject to:

- $\sum_{o \in O(\tau, \alpha(\tau))} \text{work}_{do}(\tau) \cdot \beta_{do}(\tau) \leq \text{tactical_resource}_{dr}(\tau) + \mu_{rd}(\tau) \quad \forall d \in D(\tau) \quad \forall r \in R(\tau)$ (15)
- $\sum_{d \in D(\tau)} \sigma_{do}(\tau) = \text{duration}_d(\tau) \quad \forall o \in O(\tau, \alpha(\tau))$ (16)
- $d = \text{earliest_start}_d(\tau) \quad \sigma_{pd}(\tau) = \text{duration}_d(\tau) \cdot \eta_{dp}(\tau) \quad \forall o \in O(\tau, \alpha(\tau)) \quad \forall d \in D(\tau)$ (17)
- $d \in D(\tau) \quad \eta_{dp}(\tau) = 1, \quad \forall d \in D(\tau)$ (18)
- $\sum_{o \in O(\tau, \alpha(\tau))} d \cdot \sigma_{do}(\tau) + \Delta_o(\tau) = \sum_{d \in D(\tau)} d \cdot \sigma_{do}(\tau) \quad \forall (o1, o2) \in \text{finish_start}_{o1, o2}$ (19)
- $\sum_{d \in D(\tau)} d \cdot \sigma_{do}(\tau) = \sum_{d \in D(\tau)} d \cdot \sigma_{do}(\tau) \quad \forall (o1, o2) \in \text{start_start}_{o1, o2}$ (20)
- $\beta_{do}(\tau) \leq \text{number}_d(\tau) \cdot \text{operating_time}_o \quad \forall d \in D(\tau) \quad \forall o \in O(\tau, \alpha(\tau))$ (21)
- $\beta_{do}(\tau) \in \mathbb{R} \quad \forall d \in D(\tau) \quad \forall o \in O(\tau, \alpha(\tau))$ (22)
- $\mu_{rd}(\tau) \in \mathbb{R} \quad \forall r \in R(\tau) \quad \forall d \in D(\tau)$ (23)
- $\sigma_{do}(\tau) \in \{0, 1\} \quad \forall d \in D(\tau) \quad \forall o \in O(\tau, \alpha(\tau))$ (24)
- $\eta_{dp}(\tau) \in \{0, 1\} \quad \forall d \in D(\tau) \quad \forall o \in O(\tau, \alpha(\tau))$ (25)
- $\Delta_o(\tau) \in \{0, 1\} \quad \forall o \in O(\tau, \alpha(\tau))$ (26)

Supervisor: Variant of the assignment problem

Meta variables:

- $z \in Z$ (26)
- $\alpha(\tau)$ (27)
- $\theta(\tau)$ (28)
- $\tau \in [0, \infty]$ (29)

Maximize:

$$\sum_{a \in A(\tau, \alpha(\tau))} \sum_{t \in T(\tau)} \text{supervisor_value}_{at}(\tau, \lambda_t(\tau), \gamma_t(\tau)) \cdot \gamma_{at}(\tau)$$

(30)

Subject to:

- $\sum_{a \in A(\tau, \alpha(\tau))} \rho_{at}(\tau) = \text{work}_{at}(\tau) \quad \forall a \in A(\tau, \alpha(\tau))$ (31)
- $\sum_{t \in T(\tau)} \sum_{a \in A(\tau, \alpha(\tau))} \gamma_{at}(\tau) = \phi_a(\tau) \cdot \text{number}_a(\tau) \quad \forall a \in A(\tau, \alpha(\tau))$ (32)
- $\sum_{a \in A(\tau, \alpha(\tau))} \phi_a(\tau) = |O_w(\tau, \alpha(\tau))| \quad \forall w \in W(\tau, \alpha(\tau))$ (33)
- $\sum_{a \in A(\tau, \alpha(\tau))} \gamma_{at}(\tau) \leq 1 \quad \forall a \in A(\tau, \alpha(\tau)) \quad \forall t \in T(\tau)$ (34)
- $\gamma_{at}(\tau) \leq \text{feasible}_{at}(\theta(\tau)) \quad \forall a \in A(\tau, \alpha(\tau)) \quad \forall t \in T(\tau)$ (35)
- $\gamma_{at}(\tau) \in \{0, 1\} \quad \forall a \in A(\tau, \alpha(\tau)) \quad \forall t \in T(\tau)$ (36)
- $\rho_{at}(\tau) \in [\text{lower_activity_work}_{at}(\tau), \text{work}_{at}(\tau)] \quad \forall a \in A(\tau, \alpha(\tau))$ (37)

Operational: Variant of the sequencing problem

Meta variables:

- $t \in T(\tau)$ (38)
- $\alpha(\tau)$ (39)
- $\gamma(\tau)$ (40)
- $\tau \in [0, \infty]$ (41)

Maximize:

$$\sum_{a \in A(\tau, \gamma(\tau))} \sum_{k \in K(\gamma(\tau))} \delta_{ak}(\tau)$$

(42)

Subject to:

- $\sum_{k \in K(\gamma(\tau))} \delta_{ak}(\tau) \cdot \pi_{ak}(\tau) = \text{activity_work}_{ak}(\tau, p(\tau)) \cdot \theta \quad (\tau) \forall a \in A(\tau, \gamma(\tau))$ (43)
- $\lambda_{a21}(\tau) \geq \lambda_{a1}(\tau) + \text{preparation}_{a1, a2} \quad \forall a1 \in A(\tau, \gamma(\tau)) \quad \forall a2 \in A(\tau, \gamma(\tau))$ (44)
- $\lambda_{ak}(\tau) \geq \lambda_{ak-1}(\tau) - \text{constraint_limit} \cdot (2 - \pi_{ak}(\tau) + \pi_{ak-1}(\tau))$ (45)
- $\forall a \in A(\tau, \gamma(\tau)) \quad \forall k \in K(\gamma(\tau))$ (46)
- $\delta_{ak}(\tau) = \lambda_{ak}(\tau) - \lambda_{ak}(\tau) \quad \forall a \in A(\tau, \gamma(\tau)) \quad \forall k \in K(\gamma(\tau))$ (47)
- $\lambda_{ak}(\tau) \geq \text{event}_{ak} + \text{constraint_limit} \cdot (1 - \omega_{ak}(\tau))$ (48)
- $\forall a \in A(\tau, \gamma(\tau)) \quad \forall k \in K(\gamma(\tau)) \quad \forall i \in I(\tau) \quad \forall e \in E(\tau)$ (49)
- $\lambda_{a1}(\tau) \leq \text{time_window_start}_{a1}(\beta(\tau)) \quad \forall a \in A(\tau, \gamma(\tau))$ (50)
- $\lambda_{a1}(\tau) \leq \text{time_window_finish}_{a1}(\beta(\tau)) \quad \forall a \in A(\tau, \gamma(\tau))$ (51)
- $\pi_{ak}(\tau) \in \{0, 1\} \quad \forall a \in A(\tau, \gamma(\tau)) \quad \forall k \in K(\gamma(\tau))$ (52)
- $\lambda_{ak}(\tau) \in [\text{availability_start}(\tau), \text{availability_finish}(\tau)]$ (53)
- $\forall a \in A(\tau, \gamma(\tau)) \quad \forall k \in K(\gamma(\tau))$ (54)
- $\delta_{ak}(\tau) \in [0, \text{work}_{ak, \text{op}, a}(\tau)] \quad \forall a \in A(\tau, \gamma(\tau)) \quad \forall k \in K(\gamma(\tau))$ (55)
- $\omega_{ak}(\tau) \in \{0, 1\} \quad \forall a \in A(\tau, \gamma(\tau)) \quad \forall k \in K(\gamma(\tau)) \quad \forall i \in I(\tau) \quad \forall e \in E(\tau)$ (56)
- $\theta_a(\tau) \in \{0, 1\} \quad \forall a \in A(\tau, \gamma(\tau))$ (56)



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