Multi-model Maintenance Scheduling

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Introduction

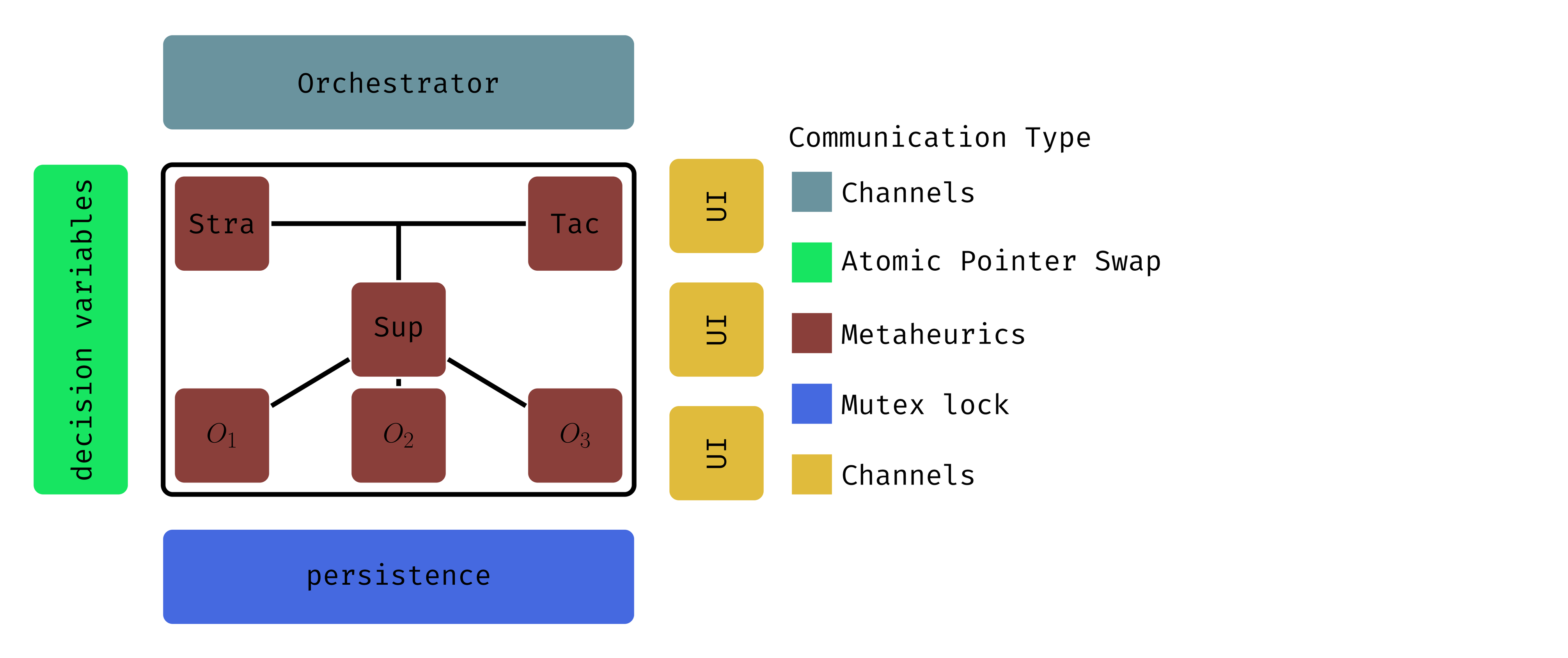
Current Operation Research methods have proven difficult to implement in operational settings. The poster presents a methodology to decompose a large-scale decision process into a series of modules that each represents the decisions taken by each individual stakeholder making up the scheduling process. The maintenance scheduling procees 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

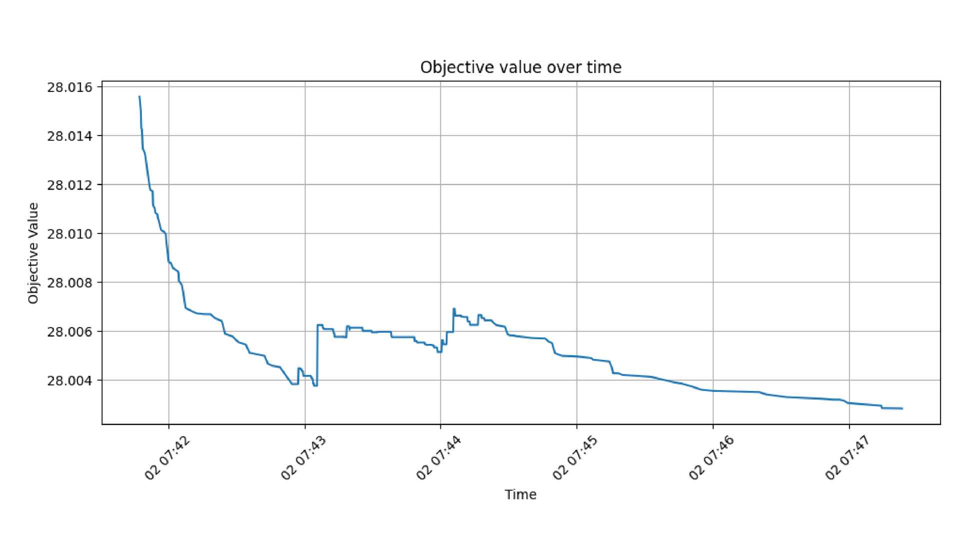


Algorithm: Actor based Large Neighborhood Search

Algorithm 1 Actor-based Large Neighborhood Search

```
Input Q = message queue
Input P = problem instance
Input X = initial schedule
Input S = SharedSolution
repeat
    X^t = clone(X)
    while Q.has_message() do
        P.update(S, m)
        X^t.destruct(S, m)
    end while
    X^t.repair(S)
    if accept(X^t, X) then
        X.update(X^t)
    end if
    if c(X^t) < c(X) then
        X.update(X^t)
        S.atomic_pointer_swap(X)
    end if
    Q.push(m)
until
```

Results



Future Work

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

Methodology

Strategic: Variant of the knapsack problem

Meta variables:

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

Minimize:

$$\sum_{w \in W(\tau)} \sum_{p \in P(\tau)} strategic\_value_{wp}(\tau) \cdot \alpha_{wp}(\tau) + \sum_{p \in P(\tau)} \sum_{r \in R(\tau)} strategic\_penalty \cdot \epsilon_{pr}(\tau) + \sum_{p \in P(\tau)} \sum_{w1 \in W(\tau)} \sum_{w2 \in W(\tau)} clustering\_value_{w1,w2} \cdot \alpha_{w1p}(\tau) \cdot \alpha_{w2p}(\tau) \tag{4}$$

Subject to:

$$\sum_{w \in W(\tau)} work\_order\_work_{wr} \cdot \alpha_{wp}(\tau) \leq resource_{pr}(\tau, \beta(\tau)) + \epsilon_{pr}(\tau) \quad \forall p \in P(\tau) \quad \forall r \in R(\tau) \tag{5}$$
$$\sum_{w \in W(\tau)} \alpha_{wp}(\tau) = 1 \quad \forall p \in P(\tau) \tag{6}$$
$$\alpha_{wp}(\tau) = 0 \quad \forall (w,p) \in exclude(\tau) \tag{7}$$
$$\alpha_{wp}(\tau) = 1 \quad \forall (w,p) \in include(\tau) \tag{8}$$
$$\alpha_{wp}(\tau) \in \{0,1\} \quad \forall w \in W(\tau) \quad \forall p \in P(\tau) \tag{9}$$
$$\epsilon_{pr}(\tau) \in \mathbb{R}^+ \quad \forall p \in P(\tau) \quad \forall r \in R(\tau) \tag{10}$$

Tactical: Variant of the project scheduling problem

Meta variables:

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

Minimize:

$$\sum_{o \in O(\tau,\alpha(\tau))} \sum_{d \in D(\tau)} tactical\_value_{do}(\tau) \cdot \beta_{do}(\tau) + \sum_{r \in R(\tau)} \sum_{d \in D(\tau)} tactical\_penalty \cdot \mu_{rd}(\tau) \tag{14}$$

Subject to:

$$\sum_{o \in O(\tau,\alpha(\tau))} work_o(\tau) \cdot \beta_{do}(\tau) \leq tactical\_resource_{dr}(\tau) + \mu_{rd}(\tau) \forall d \in D(\tau) \quad \forall r \in R(\tau) \tag{15}$$
$$\sum_{d=earliest\_start_o(\tau)}^{latest\_finish_o(\tau)} \sigma_{do}(\tau) = duration_o(\tau) \quad \forall o \in O(\tau, \alpha(\tau)) \tag{16}$$
$$\sum_{d^* \in D_{duration_o(\tau)}(\tau)} \sigma_{d^*o}(\tau) = duration_o(\tau) \cdot \eta_{do}(\tau) \quad \forall o \in O(\tau,\alpha(\tau)) \quad \forall d \in D(\tau) \tag{17}$$
$$\sum_{o \in O(\tau,\alpha(\tau))} \eta_{do}(\tau) = 1, \quad \forall d \in D(\tau)$$
$$\sum_{d \in D(\tau)} d \cdot \sigma_{do1}(\tau) + \Delta_o(\tau) = \sum_{d \in D(\tau)} d \cdot \sigma_{do2}(\tau) \quad \forall (o1, o2) \in finish\_start_{o1,o2} \tag{18}$$
$$\sum_{d \in D(\tau)} d \cdot \sigma_{do1}(\tau) = \sum_{d \in D(\tau)} d \cdot \sigma_{do2}(\tau) \quad \forall (o1, o2) \in start\_start_{o1,o2} \tag{19}$$
$$\beta_{do}(\tau) \leq number_o(\tau) \cdot operating\_time_o \quad \forall d \in D(\tau) \quad \forall o \in O(\tau,\alpha(\tau)) \tag{20}$$
$$\beta_{do}(\tau) \in \mathbb{R} \quad \forall d \in D(\tau) \quad \forall o \in O(\tau,\alpha(\tau)) \tag{21}$$
$$\mu_{rd}(\tau) \in \mathbb{R} \quad \forall r \in R(\tau) \quad \forall d \in D(\tau) \tag{22}$$
$$\sigma_{do}(\tau) \in \{0,1\} \quad \forall d \in D(\tau) \quad \forall o \in O(\tau,\alpha(\tau)) \tag{23}$$
$$\eta_{do}(\tau) \in \{0,1\} \quad \forall d \in D(\tau) \quad \forall o \in O(\tau,\alpha(\tau)) \tag{24}$$
$$\Delta_o(\tau) \in \{0,1\} \quad \forall o \in O(\tau,\alpha(\tau)) \tag{25}$$

Supervisor: Varient of the assignment problem

Meta variables:

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

Maximize:

$$\sum_{a \in A(\tau,\alpha(\tau))} \sum_{t \in T(\tau)} supervisor\_value_{at}(\tau, \lambda_t(\tau), \Lambda_t(\tau)) \cdot \gamma_{at}(\tau) \tag{30}$$

Subject to:

$$\sum_{a \in A_o(\tau,\alpha(\tau))} \rho_a(\tau) = work_o(\tau) \quad \forall o \in O(\tau,\alpha(\tau)) \tag{31}$$
$$\sum_{t \in T(\tau)} \sum_{a \in A_o(\tau,\alpha(\tau))} \gamma_{at}(\tau) = \phi_o(\tau) \cdot number_o(\tau) \quad \forall o \in O(\tau,\alpha(\tau)) \tag{32}$$
$$\sum_{o \in O_w(\tau,\alpha(\tau))} \phi_o(\tau) = |O_w(\tau,\alpha(\tau))| \quad \forall w \in W(\tau,\alpha(\tau)) \tag{33}$$
$$\sum_{a \in A_o(\tau,\alpha(\tau))} \gamma_{at}(\tau) \leq 1 \quad \forall o \in O(\tau,\alpha(\tau)) \quad \forall t \in T(\tau) \tag{34}$$
$$\gamma_{at}(\tau) \leq feasible_{at}(\theta(\tau)) \quad \forall o \in O(\tau,\alpha(\tau)) \quad \forall t \in T(\tau) \tag{35}$$
$$\gamma_{at}(\tau) \in \{0,1\} \quad \forall o \in O(\tau,\alpha(\tau)) \quad \forall t \in T(\tau) \tag{36}$$
$$\rho_a(\tau) \in [lower\_activity\_work_a(\tau), work_a(\tau)] \quad \forall a \in A(\tau,\alpha(\tau)) \tag{37}$$

Operational: Variant of the sequencing problem

Meta variables:

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

Maximize:

$$\sum_{a \in A(\tau,\gamma_t(\tau))} \sum_{k \in K(\gamma(\tau))} \delta_{ak}(\tau) \tag{42}$$

Subject to:

$$\sum_{k \in K(\gamma(\tau))} \delta_{ak}(\tau) \cdot \pi_{ak}(\tau) = activity\_work_a(\tau, \rho(\tau)) \cdot \theta \quad (\tau) \forall a \in A(\tau, \gamma_t(\tau)) \tag{43}$$
$$\lambda_{a21}(\tau) \geq \Lambda_{a1last(a1)}(\tau) + preparation_{a1,a2} \quad \forall a1 \in A(\tau,\gamma_t(\tau)) \quad \forall a2 \in A(\tau,\gamma_t(\tau)) \tag{44}$$
$$\lambda_{ak}(\tau) \geq \Lambda_{ak-1}(\tau) - constraint\_limit \cdot (2 - \pi_{ak}(\tau) + \pi_{ak-1}(\tau)) \quad \forall a \in A(\tau,\gamma_t(\tau)) \quad \forall k \in K(\gamma(\tau)) \tag{45}$$
$$\delta_{ak}(\tau) = \Lambda_{ak}(\tau) - \lambda_{ak}(\tau) \quad \forall a \in A(\tau,\gamma_t(\tau)) \quad \forall k \in K(\gamma(\tau)) \tag{46}$$
$$\lambda_{ak}(\tau) \geq event_{ie} + duration_{ie} - constraint\_limit \cdot (1 - \omega_{akie}(\tau)) \quad \forall a \in A(\tau,\gamma_t(\tau)) \quad \forall k \in K(\gamma(\tau)) \quad \forall i \in I(\tau) \quad \forall e \in E(\tau) \tag{47}$$
$$\Lambda_{ak}(\tau) \leq event_{ie} + constraint\_limit \cdot \omega_{akie}(\tau) \quad \forall a \in A(\tau,\gamma_t(\tau)) \quad \forall k \in K(\gamma(\tau)) \quad \forall i \in I(\tau) \quad \forall e \in E(\tau) \tag{48}$$
$$\lambda_{a1}(\tau) \geq time\_window\_start_a(\beta(\tau)) \quad \forall a \in A(\tau,\gamma_t(\tau)) \tag{49}$$
$$\Lambda_{alast(a)}(\tau) \leq time\_window\_finish_a(\beta(\tau)) \quad \forall a \in A(\tau,\gamma_t(\tau)) \tag{50}$$
$$\pi_{ak}(\tau) \in \{0,1\} \quad \forall a \in A(\tau,\gamma_t(\tau)) \quad \forall k \in K(\gamma(\tau)) \tag{51}$$
$$\lambda_{ak}(\tau) \in [availability\_start(\tau), availability\_finish(\tau)] \quad \forall a \in A(\tau,\gamma_t(\tau)) \quad \forall k \in K(\gamma(\tau)) \tag{52}$$
$$\Lambda_{ak}(\tau) \in [availability\_start(\tau), availability\_finish(\tau)] \quad \forall a \in A(\tau,\gamma_t(\tau)) \quad \forall k \in K(\gamma(\tau)) \tag{53}$$
$$\delta_{ak}(\tau) \in [0, work_{a\_to\_o(a)}(\tau)] \quad \forall a \in A(\tau,\gamma_t(\tau)) \quad \forall k \in K(\gamma(\tau)) \tag{54}$$
$$\omega_{akie}(\tau) \in \{0,1\} \quad \forall a \in A(\tau,\gamma_t(\tau)) \quad \forall k \in K(\gamma(\tau)) \quad \forall i \in I(\tau) \quad \forall e \in E(\tau) \tag{55}$$
$$\theta_a(\tau) \in \{0,1\} \quad \forall a \in A(\tau,\gamma_t(\tau)) \tag{56}$$

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