Evaluating PDDL for programming production cells: – a case study

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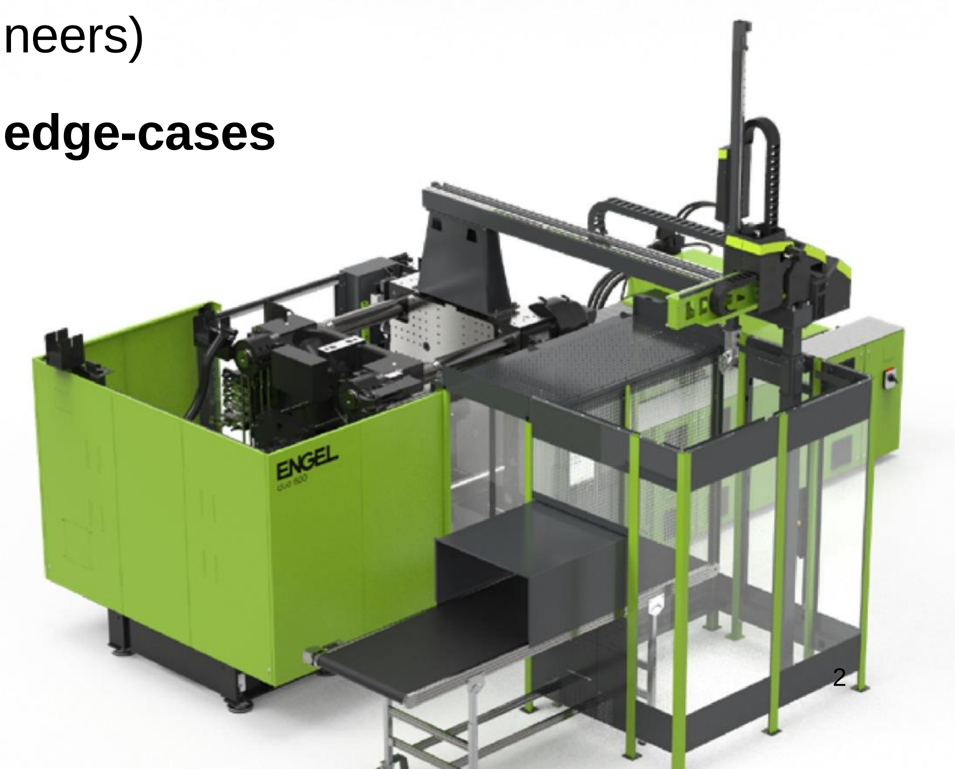
Motivation

Manufacturing companies are required to **quickly/easily adapt** their **production** to changing demands and innovation.

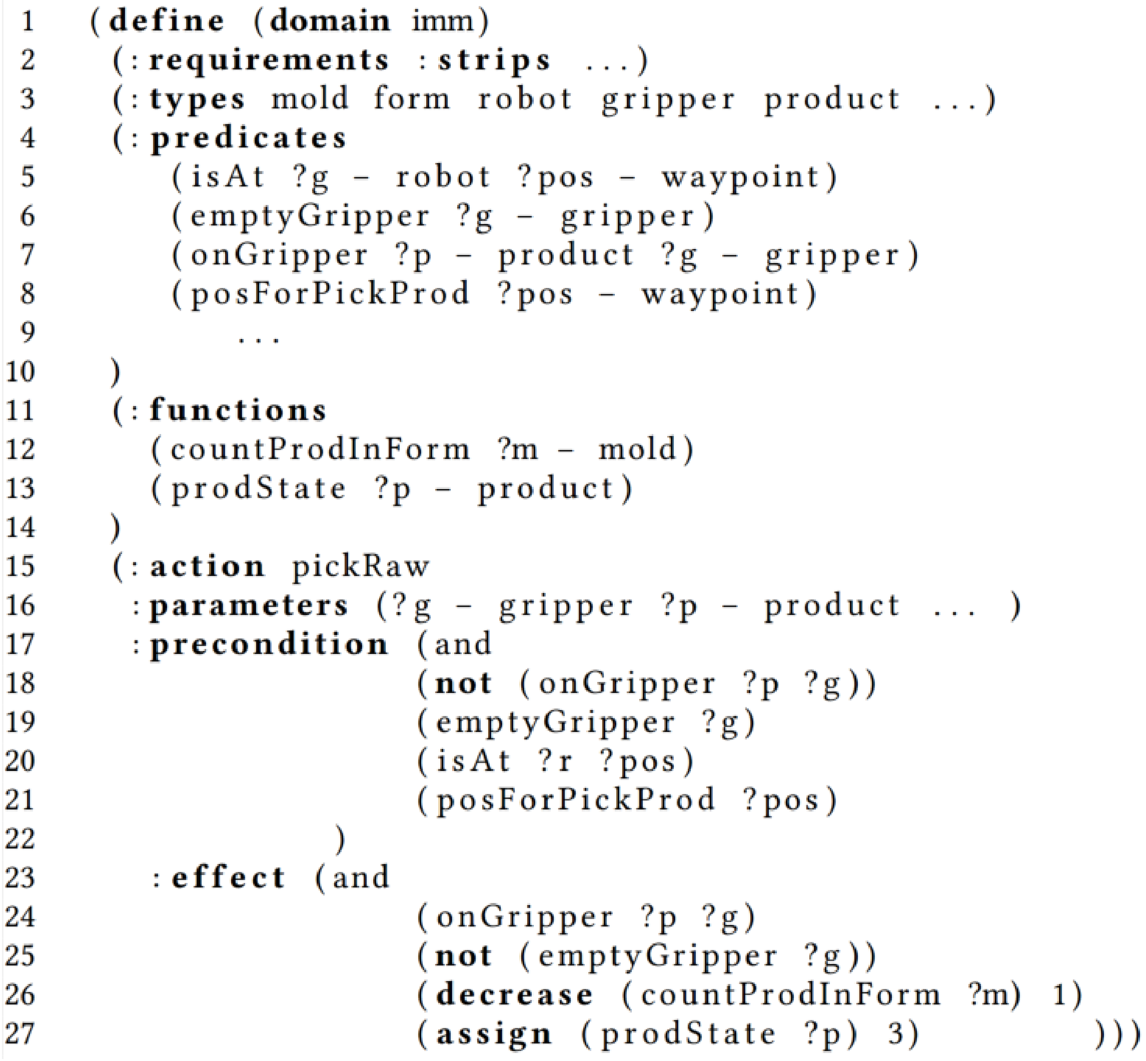
- Need to **frequently reprogram robots** and machines on the shop floor
- Involves defining the **interaction with other shop floor participants** (robots/machines/humans).
- (Re)programming is often done **by end-users** (e.g., domain engineers)
- Complex interactions/sequences require **extensive handling of edge-cases**
  - Hard to get right
  - Hard to understand
  - Hard to reuse



Research Questions

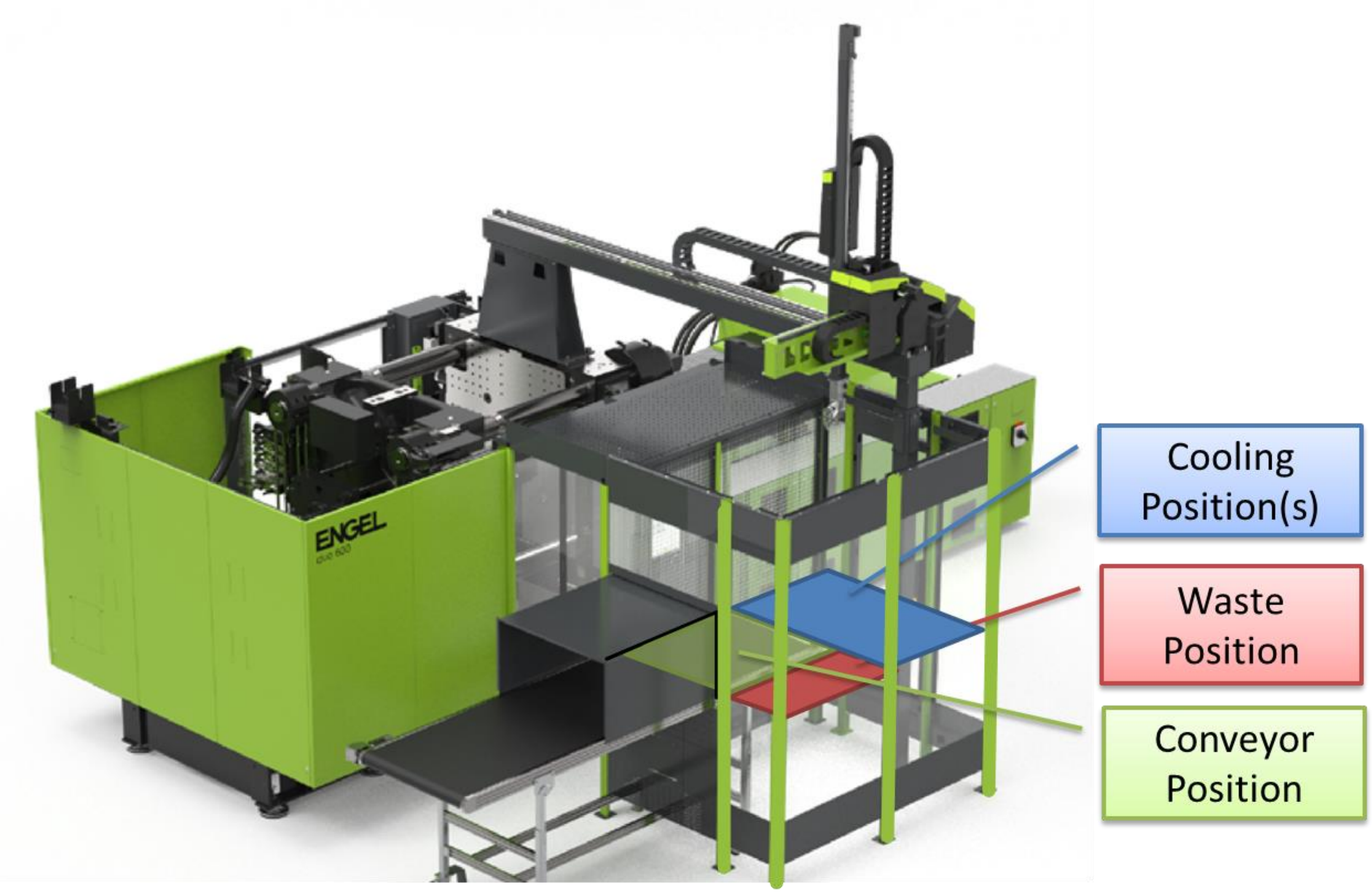
- How can we enable engineers to focus on their domain knowledge and limit detailed implementation work?
  - Engineers have detailed product know-how
  - Are aware of production stages, goals
  - Pre and post conditions of production steps

- Are planning languages such as PDDL and/or HDDL practical to this end?
  - RQ1: To create efficient production sequences?
  - RQ2: How easy are they to be extended for changing production scenarios?



```
(define (domain imm)
  (:requirements :strips ...)
  (:types mold form robot gripper product ...)
  (:predicates
     (isAt ?g - robot ?pos - waypoint)
     (emptyGripper ?g - gripper)
     (onGripper ?p - product ?g - gripper)
     (posForPickProd ?pos - waypoint)
        ...
  )
  (:functions
    (countProdInForm ?m - mold)
    (prodState ?p - product)
  )
  (:action pickRaw
   :parameters (?g - gripper ?p - product ... )
   :precondition (and
                 (not (onGripper ?p ?g))
                 (emptyGripper ?g)
                 (isAt ?r ?pos)
                 (posForPickProd ?pos)
             )
    :effect (and
                 (onGripper ?p ?g)
                 (not (emptyGripper ?g))
                 (decrease (countProdInForm ?m) 1)
                 (assign (prodState ?p) 3)         )))
```

Case Study: multi-stage molding



- Multi-stage sequence C:
  - Pick solidified part
  - Place for cooling
  - Take cooled insertion component
  - (Pick solidified final part from previous run)
  - (Pick solidified intermediary part from previous run)
  - Insert component into mold
  - Place solidified final part
- Complexity due to distinction between initial and subsequent runs, failures of picking/placing, and restarting from previous run in unknown state: multiple cooling locations, two mold forms, amount of grippers

Results – Support for adaptation

3 modeling variants: PDDL+ for time-aware sequences, PDDL cost for some optimization, HDDL for hierarchical task structuring

	PDDL+ based	PDDL cost based	HDDL based
Structure:	10 actions, 3 proc., 6 events	11 actions	11 actions, 10 tasks, 23 methods
LoC:	~300	~205	~490
Structure	12 actions, 4 proc. , 7 events	14 actions	14 actions, 12 tasks, 29 methods
LoC:	~365	~280	~660
New/diff LoC	65/15	70/20	170/80

Results – Support for adaptation

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3 modeling variants: PDDL+ for time-aware sequences, PDDL cost for some optimization, HDDL for hierarchical task structuring

	PDDL+ based	PDDL cost based	HDDL based
Structure:	10 actions, 2 proc., 6 events	11 actions	11 actions, 10 tasks, 2[illegible] methods
LoC:	~300	~205	~490
Structure	12 actions[illegible]	14 actions	14 actions, 12 tasks, 29 methods
LoC:	~[illegible]	[illegible]	~660
New/diff LoC	65/15	70/20	170/80

Similar actions/predicates across the variants

Same type and extent of adaptation across the variants

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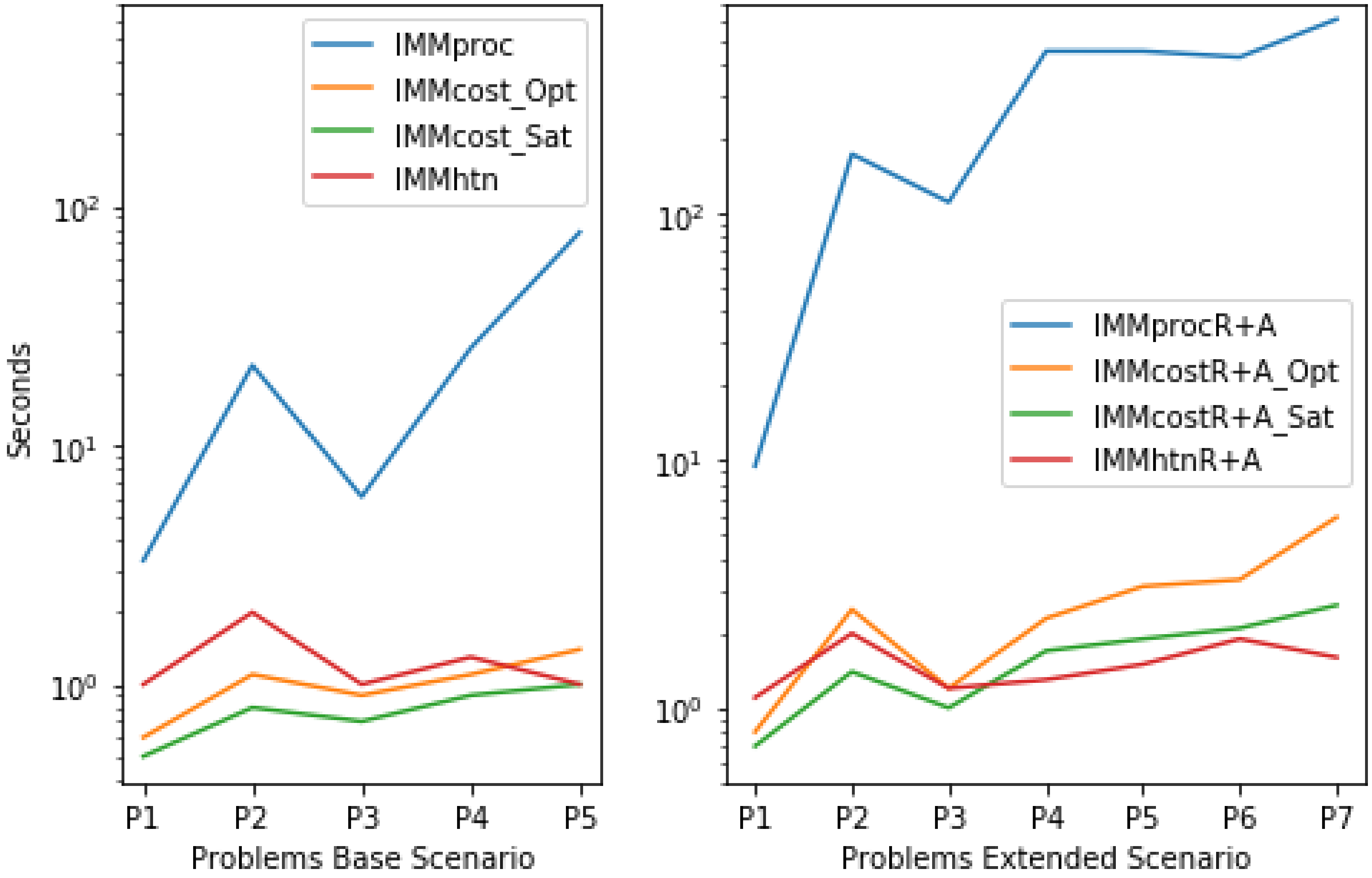
Results - Performance

Problem scenarios with increasing product instances and starting conditions.

Models for optimal sequences (i.e., considering time) don’t scale.



Discussion and Conclusions

RQ1: feasible but not practical yet

- HDDL/PDDL require tracking each product individually → need to obtain a cyclic plan for continuous production (without constant replanning)
- Difficult transition from start-up to continuous phase
- Planning duration is not practical for efficient (i.e., time aware) sequences
- HDDL solver is sensitive to problem order
- Perhaps process mining (BPM community) can bring some inspiration here

RQ2: advanced engineering support needed

- Changes have cascading effects (not just adding of code),
  - limiting impact/scoping difficult to achieve
  - difficult to understand what is impacted
  - HDDL: Difficult to understand applicable constraints in each step
- Support for testing: wrong logic, wrong test setup, solver limits?
- Support for deadlock detection

Thanks for your attention. Questions?

Supporting Online Material: https://figshare.com/s/8315f52edb597fb7836a

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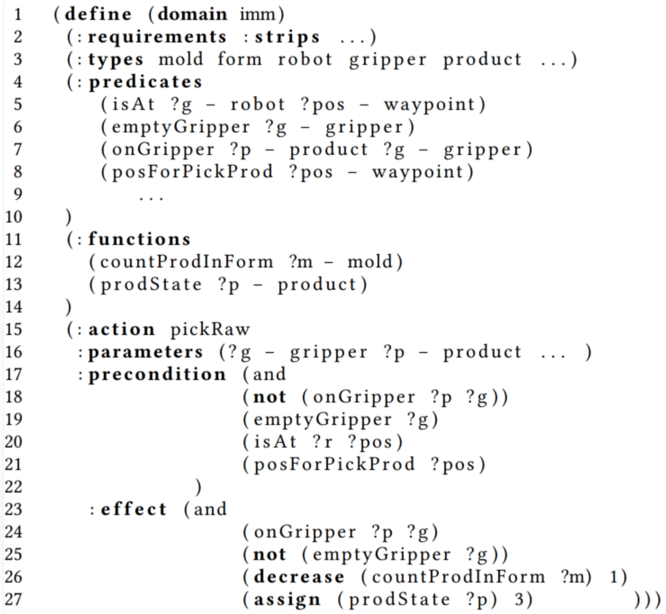

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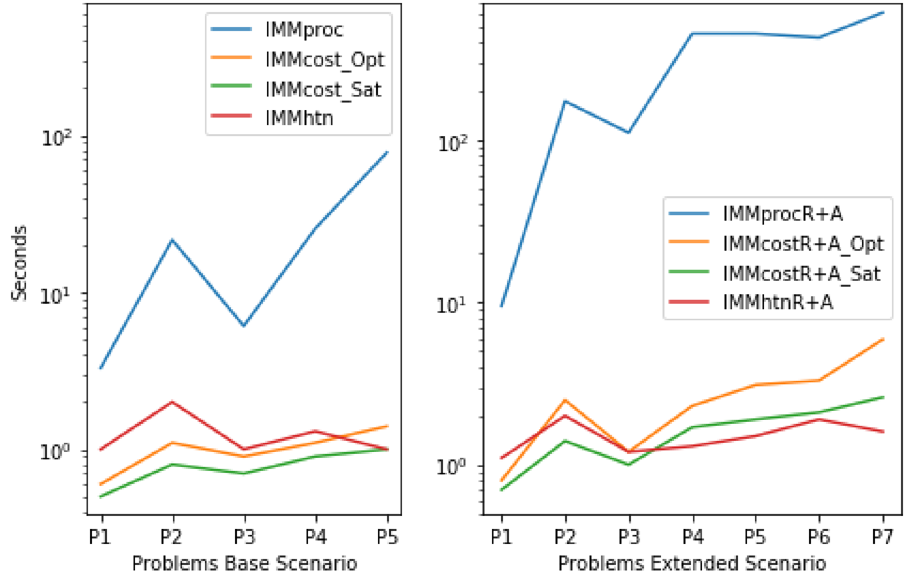

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