AUTOMATED CAR WASH WITH PDDL & INDIGOLOG

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ABOUT THE IDEA

The idea for this project is to develop efficient automated car washing facilities that can handle multiple vehicle types, multiple cleaning program while managing resources effectively.

- Different vehicle sizes such as small car, big car, motocycle,.
- Various cleaning programs such as fast, basic, premium with different resource requirements and cost.
- Resource management including water, soap and wax,
- Optimal scheduling to minimize wait times and maximize throughput

The goal is to minimize cleaning time, efficiently allocate resources, and maximize station throughput while ensuring that resource replenishment and scheduling constraints are respected.

THE DOMAIN

•Multiple cleaning stations (fast cleaning station, basic cleaning station, premium cleaning station, interior cleaning station)

•Various vehicle types requiring different cleaning resources

•Limited resources that need to be managed and replenished

•Different cleaning programs with varying cost and resource requirements

THE PREDICATES

•(vehicle_at ?v - vehicle ?s - station)	TRUE if a vehicle is at a certain station
•(free_location ?v – vehicle)	TRUE if a location is free
•(connected ?l1 - location ?l2 - location)	TRUE if locations are connected
•(station-compatibility ?p - program ?s - station)	TRUE if a station is compatible with the program selected
•(has_resources ?s - station ?r - resource)	TRUE if a station has that kind of resources (written general for simplicity)
•(small-car ?v - small_car) / (big-car ?v - big_car) / (moto ?v - moto)	TRUE is the vehicle is the kind specified
•(can-be-refilled ?s - station)	TRUE if the station support the refill
•(vehicle-ready ?v - vehicle ?p - program)	TRUE if the vehicle has been cleaned and ready
•(interior-clean ?v - vehicle)	TRUE if the interior cleaning has be done
•(vehicle-ready-int ?v - vehicle ?p - program)	TRUE if the vehicle is ready with the interior cleaned
•(interior ?s - interior)	TRUE if the station is of kind that can clean the interior

- V = (small car, big car, motocycle)
- S = 1-2-5
- R= (water tank, active soap tank, wax tank)
- P = (fast, basic, premium, moto)
  - fast = water –
  - basic= soap, water
  - premium = soap, water, wax
  - premium with interior = soap, water, wax, interior
  - moto = soap water

THE AVAILABLE ACTION

MOVE

FINISH

FINISH-INTERIOR

INTERIOR-CLEAN

START-PREMIUM-CLEANING

START-BASIC-CLEANING

START-FAST-CLEANING

REFILL-WATER

REFILL-SOAP

REFILL-WAX

THE GENERAL PROBLEM

In the problem file we can make different choices and model whatever we want such as:

- Number of cleaning stations
  - Type of station
- Number of vehicles
  - Type of vehicle
- Available resources
  - Type of resources (water, soap, wax)
- Cleaning program types
  - Fast, Basic, Premium, Interior
- Resource consumption rates
- Cleaning cost

In the Initial State we set:

- Station availability
- Resource levels
- Vehicle positions
- Resource consumption rates
- Cleaning cost parameters for the program

The Goal is to clean all vehicles according to their required programs while:

- Minimizing total cleaning cost
- Optimizing resource usage
- Ensuring efficient station utilization

3 INSTANCES OF THE PROBLEM

PROBLEM 1: Basic Setup

- 1 stations
- 1 vehicles (1 cars)
- Basic resources (water)
- Limited resources: 1 unit of water
- 1 cleaning programs (Fast)
- Goal: Clean all vehicles while ensuring no resource depletion.

PROBLEM 2: Multiple Station Types

- 2 stations
- 2 vehicles (2 cars, 1 motorcycle)
- Extended resources (water, soap, wax)
- Resources include water (0 liters), soap (0 liters), and wax (0 liters).
- 3 cleaning programs (fast, basic, premium)
- Goal: Optimize cleaning while managing resource replenishment.

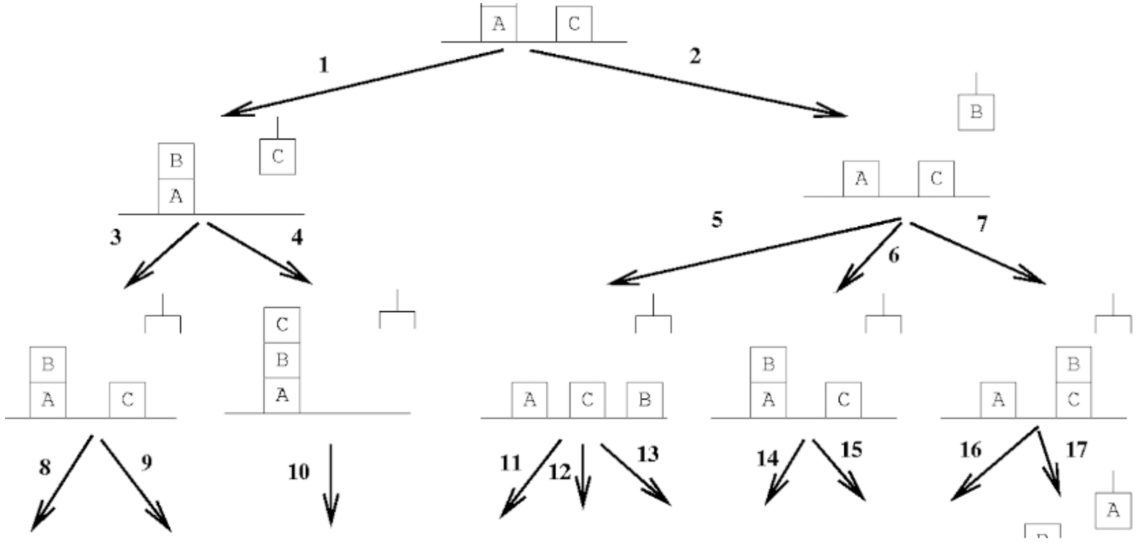
PROBLEM 3: Full System

- 5 stations
- 7 vehicles (all types)
- Complete resource management
- Large but constrained resources: each station has their level of resources
- All cleaning programs
- Added interior clenaing
- Maintenance and scheduling
- Goal: Optimize cleaning while managing resource replenishment.

The planner

To solve the numerical planning problem, we have decided to use ENHSP-20 (Expressive Numeric Heuristic Search Planner) which is a PDDL automated planning system that supports both Classical and Numeric Planning (PDDL2.1).

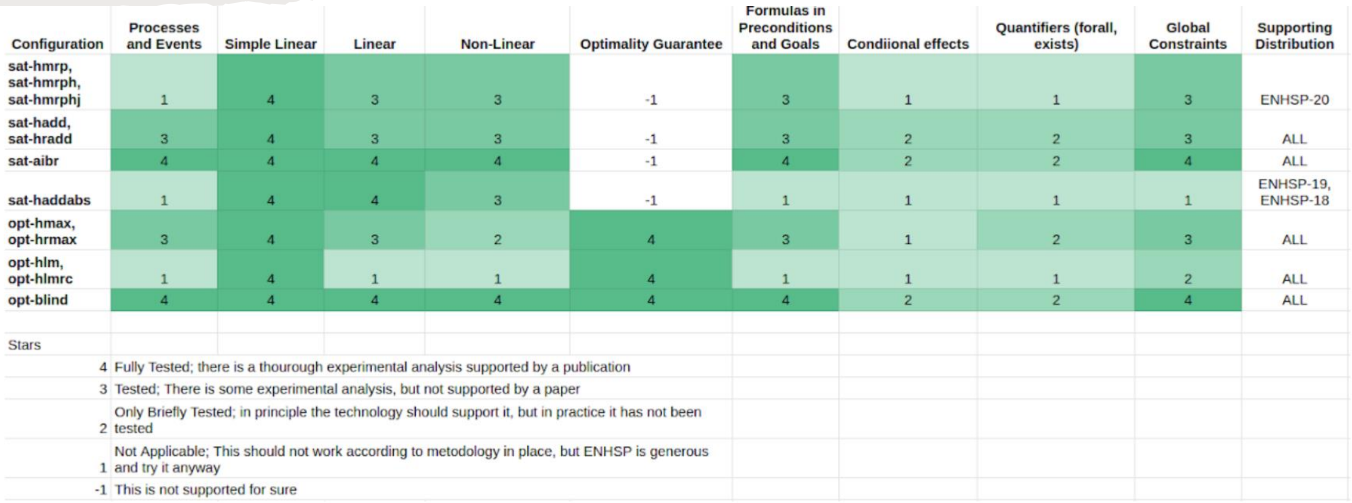
ENHSP transforms the PDDL descriptions into a graph-search problem where nodes represent states visited by the planner. The planner is guided by a heuristic function to explore only those nodes whose associated state is reachable from the init and get the planner closer to the goals.



THE HEURISTICS AVAILABLE

Different configurations tested:

- **sat-hmrp: GBF with MRP heuristic**
- **sat-hadd: GBF with HADD heuristic**
- **opt-hmax: A* with numeric heuristics for optimization scenarios (only some problem available)**



Configuration	Processes and Events	Simple Linear	Linear	Non-Linear	Optimality Guarantee	Formulas in Preconditions and Goals	Condiional effects	Quantifiers (forall, exists)	Global Constraints	Supporting Distribution
sat-hmrp, sat-hmrph, sat-hmrphj	1	4	3	3	-1	3	1	1	3	ENHSP-20
sat-hadd, sat-hradd	3	4	3	3	-1	3	2	2	3	ALL
sat-aibr	4	4	4	4	-1	4	2	2	4	ALL
sat-haddabs	1	4	4	3	-1	1	1	1	1	ENHSP-19, ENHSP-18
opt-hmax, opt-hrmax	3	4	3	2	4	3	1	2	3	ALL
opt-hlm, opt-hlmrc	1	4	1	1	4	1	1	1	2	ALL
opt-blind	4	4	4	4	4	4	2	2	4	ALL

Stars	
4	Fully Tested; there is a thourough experimental analysis supported by a publication
3	Tested; There is some experimental analysis, but not supported by a paper
2	Only Briefly Tested; in principle the technology should support it, but in practice it has not been tested
1	Not Applicable; This should not work according to metodology in place, but ENHSP is generous and try it anyway
-1	This is not supported for sure

The chosen metric to be minimized is a combination of:

- **Total cleaning cost**
- **Resource refill cost**
- **Number of move**

To run the planner with different configuration:

```
enshp -o <domain_file> -f <problem_file> -planner <configuration>
```

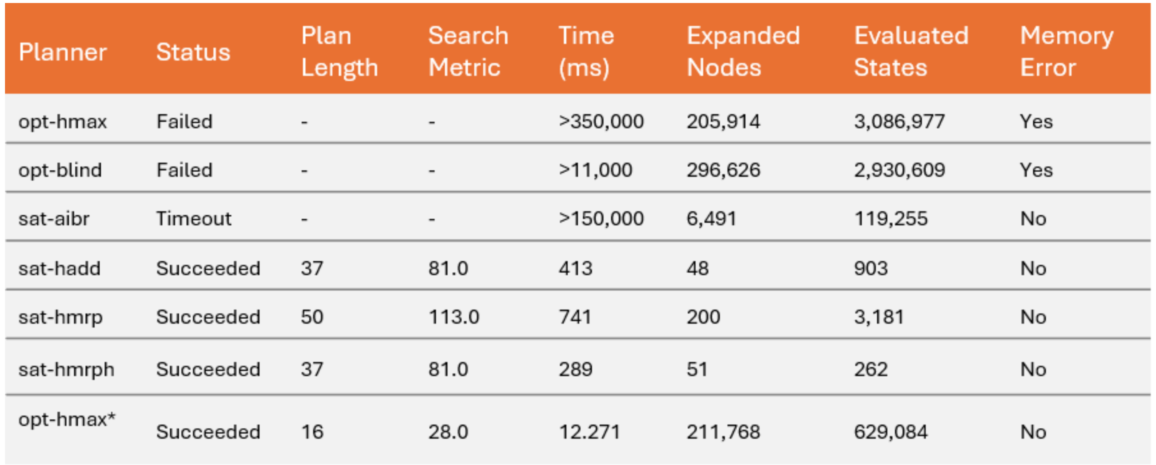
RESULTS

The results demonstrate that for this problem, satisficing planners with sophisticated heuristics (particularly sat-hmrph) performed best.

The results are correlated all to the latest and more complex planning problem.

The optimal planners, while theoretically capable of finding the best possible solution, were impractical due to memory constraints. This suggests that for similar complex planning problems, using satisficing planners with well-designed heuristics might be the most practical approach.

*The last row represent the second problem implementation



Planner	Status	Plan Length	Search Metric	Time (ms)	Expanded Nodes	Evaluated States	Memory Error
opt-hmax	Failed	-	-	>350,000	205,914	3,086,977	Yes
opt-blind	Failed	-	-	>11,000	296,626	2,930,609	Yes
sat-aibr	Timeout	-	-	>150,000	6,491	119,255	No
sat-hadd	Succeeded	37	81.0	413	48	903	No
sat-hmrp	Succeeded	50	113.0	741	200	3,181	No
sat-hmrph	Succeeded	37	81.0	289	51	262	No
opt-hmax*	Succeeded	16	28.0	12.271	211,768	629,084	No

REASONING TAKS WITH INDIGOLOG

Scenario

DIFFERENT STATIONS

DIFFERENT CARS

RESOURCES

Run with:

```
swipl config.pl examples/carwash_sim/main.pl
```

Main differences with PDDL

Boolean resource

Automatic multiple car and station handling

Exogenous action handling:

- New car
- Station failure

The Avaible Fluents / Predicates

stn(N)

car_waiting(M)

station_free(N)

resources(N)

The Avaible Actions

start_wash(M,N)

finish_wash(M,N)

reload_resources(N)

Reasoning task with indigolog

Three main controllers:

1. Dumb controllers:
   - Fixed
   - Not fixed
2. Smart Controller
3. Reactive Controller

Reasoning task with indigolog

Checks if is it possible to 2 consecutive washes in the same station

- indigolog(test_execution1).

Checks if resources are empty after a 2 consecutive washes in the same station with only 1 reload

- indigolog([test_execution2,?(resources(2))]).

Checks if after a cycle of wash, the car is still waiting

- indigolog([test_execution3,?(neg(car_waiting(1)))]).

Thanks for the attention