Artelys | OPTIMIZATION SOLUTIONS

TOYOTA

Operational scheduling in automotive industry

Scheduling Seminar

5-Nov-24

www.artelys.com

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Artelys in a nutshell

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Artelys is an independent company, created in 2000, specialized in optimization, decision-support, modeling.

2000
CREATION
Arnaud Renaud

15% annual
sustained growth

90 EXPERTS
MSc and PhD

35% of our activity
is dedicated to R&D

SOFTWARE EDITION
Custom software,
off-the-shelf software,
Numerical solvers

SERVICES & CONSULTING
Optimisation,
Data Science
and business expertise

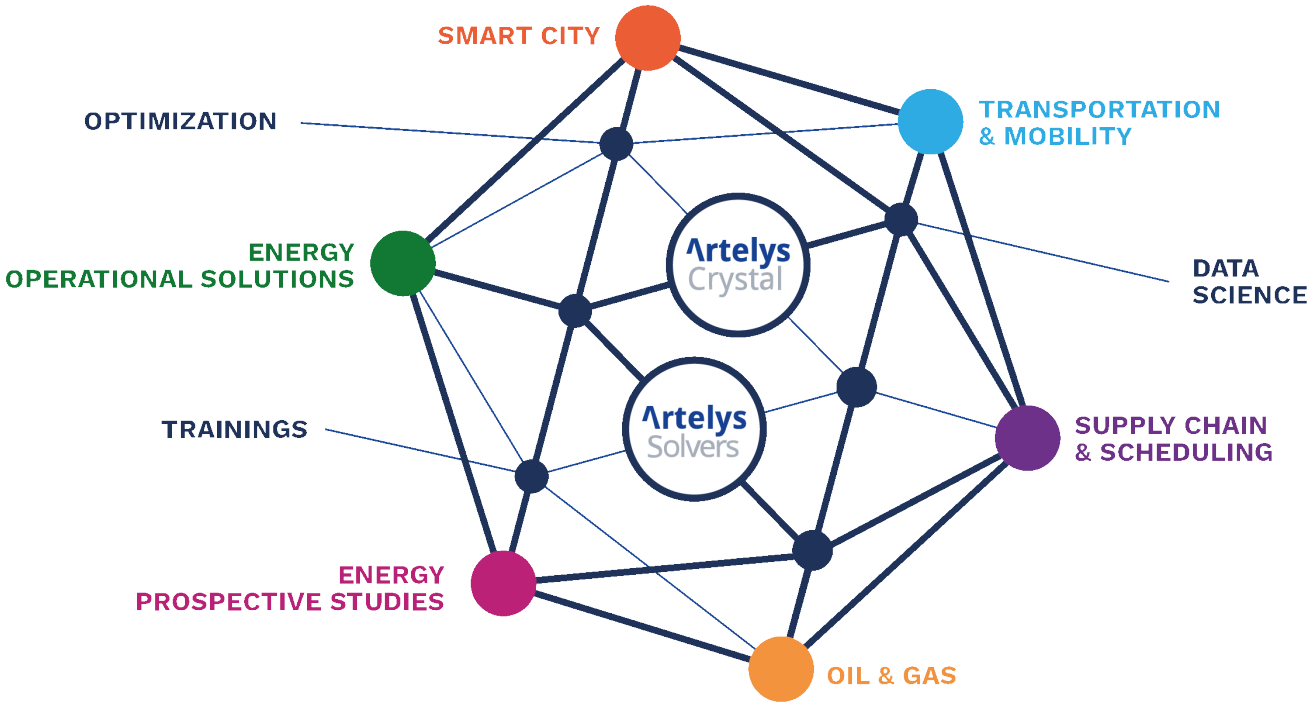
Artelys in a nutshell

Strong skills in Operational Research, Modeling and Decision Support

Recognized know-how in scientific consulting and project management

A business experience of energy, transport and logistics issues

Mastery of methods and tools for numerical optimization and statistical analysis



Numerical optimization tools

Artelys Knitro

- Industry leading solver for very large, difficult quadratic and nonlinear optimization problems (QP, NLP, MINLP)
  - https://github.com/Artelys/knitro-modeling-examples

FICO Xpress Optimization Suite

- High performance linear, quadratic and mixed integer programming solver (LP,MIP,QP)

Artelys Kalis

- Object-oriented environment to model and solve problems with constraint programming

AMPL

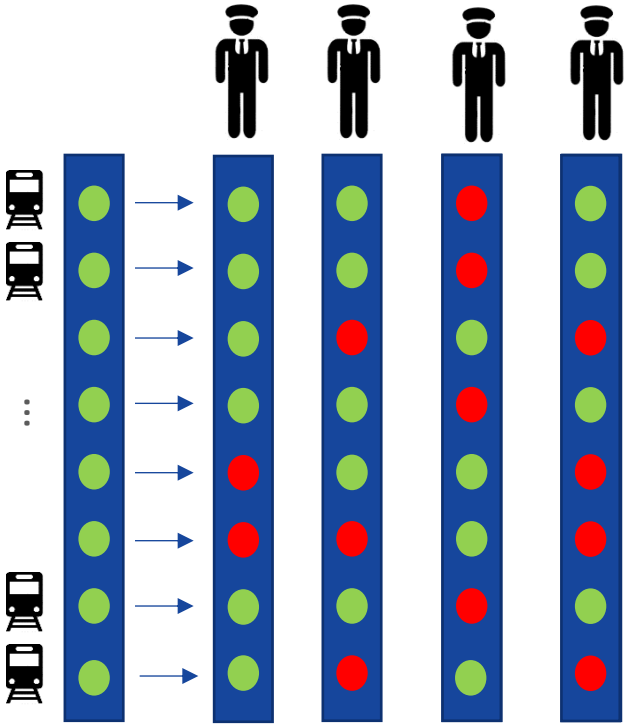
- Comprehensive modeling language for Mathematical Programming

Example scheduling projects at Artelys

- Maintenance planning for public transit operators (subway, trams)
  - When to apply maintenance tasks on each train ?
    - Satisfy maintenance shop capacities
    - Satisfy min/max travelled distance between each maintenance
    - Satisfy precedence/series constraints for maintenance tasks
    - Satisfy unavailability of trains and maintenance shops
  - Different horizons:
    - Strategic planning (next years)
    - Tactical planning (current year)
    - Operational planning (next 2 weeks)
  - CP + MILP

Example scheduling projects at Artelys

- Shift planning for on-board railway crews
  - Which operator on which train ?
  - Pairing: Generate back-and-forth trips for crews
  - Planning: generate feasible shifts for each operator (sequence of trips)
  - Satisfy work rules and skill requirements
    - min/max trips
    - balance for different types of trips
    - number of overnight stays
  - Maximize train coverage
  - Operational planning for each month
  - CP + MILP



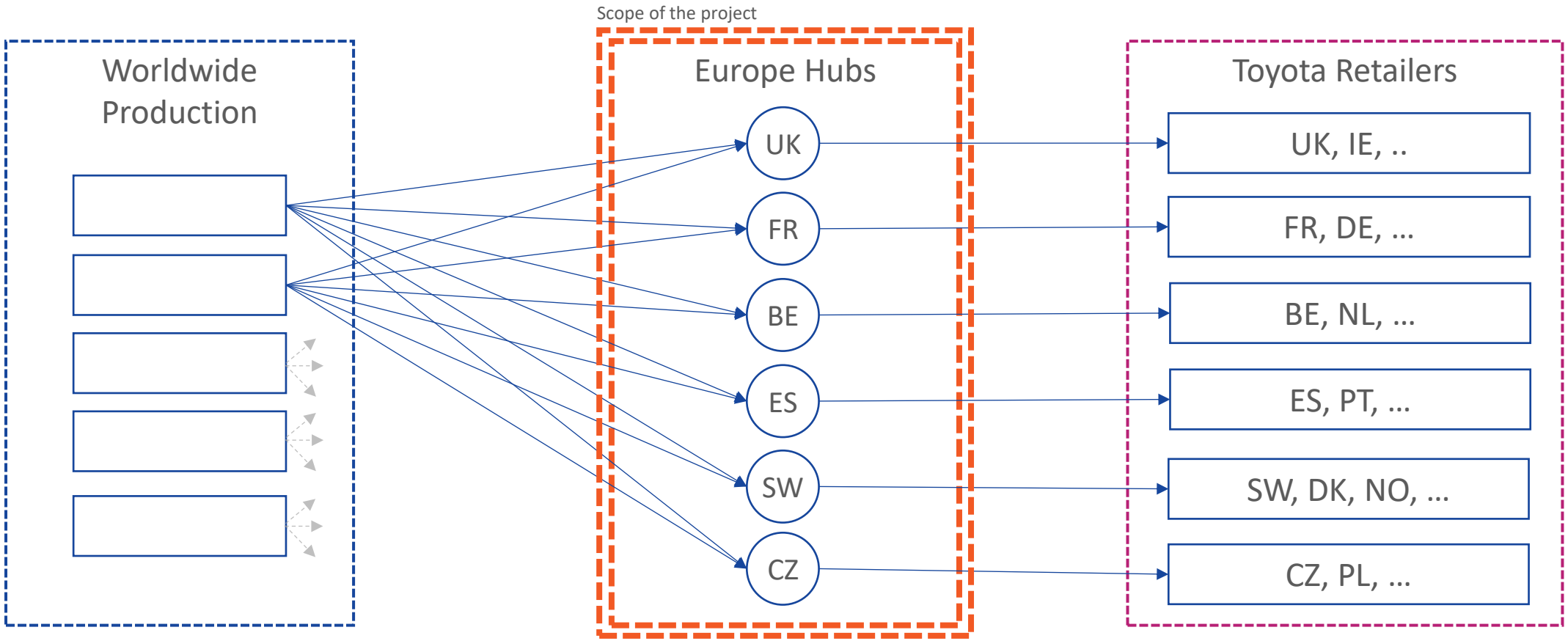
Operational scheduling in automotive industry

Context

Context

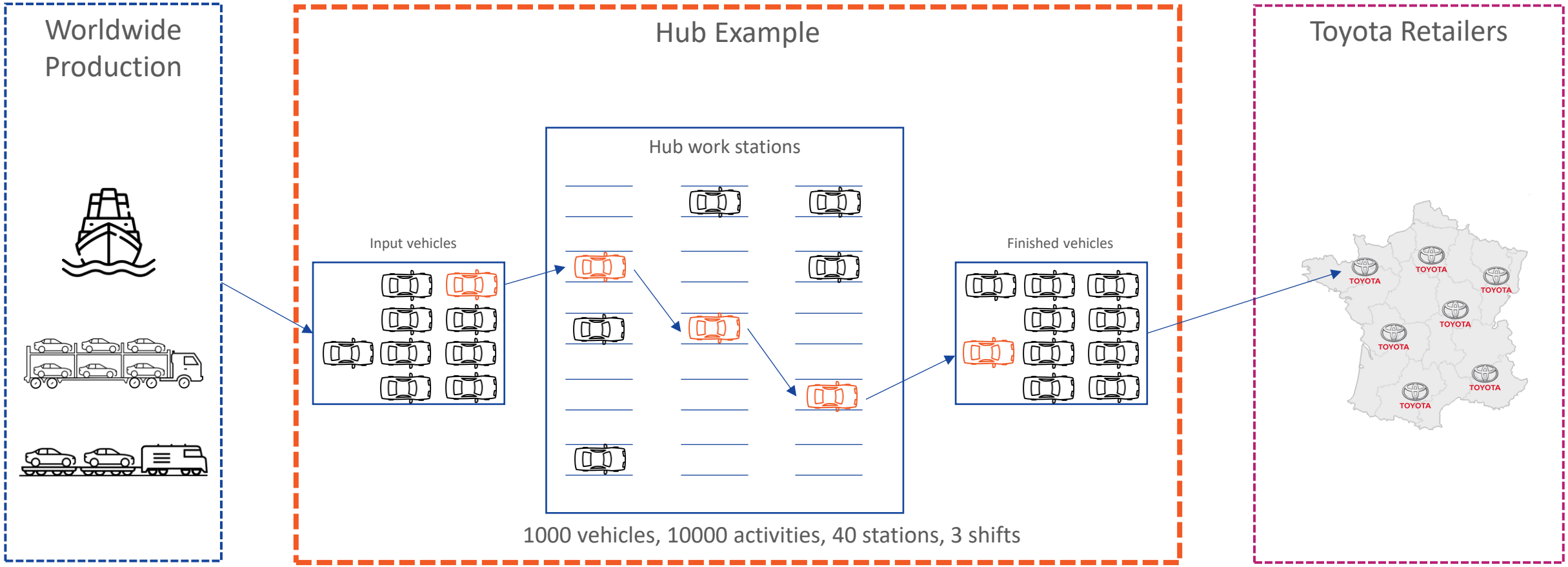
Toyota Motors Europe (TME) operations:

- **Hubs** receive produced vehicles and finalize them with Post-Production Options (PPO) before final retailers delivery



Context

One hub example



Context

- One hub example

Optimization problem

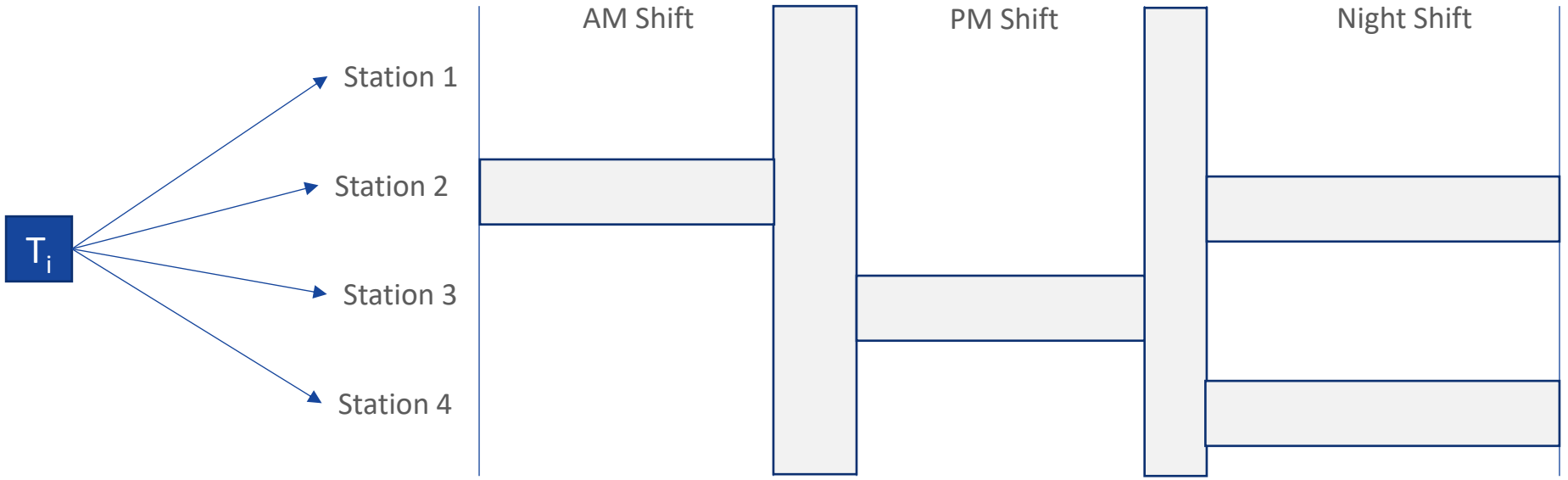
Hard constraints

Disjunctive resources

- A station can execute at most one task at a time
- At most one task executed at a time on a vehicle

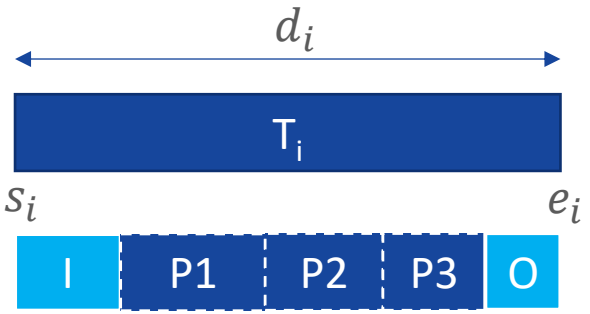
Hard constraints

- Disjunctive resources
  - A station can execute at most one task at a time
  - At most one task executed at a time on a vehicle
- Tasks can be assigned to several stations
- Tasks can be performed only during specific shifts



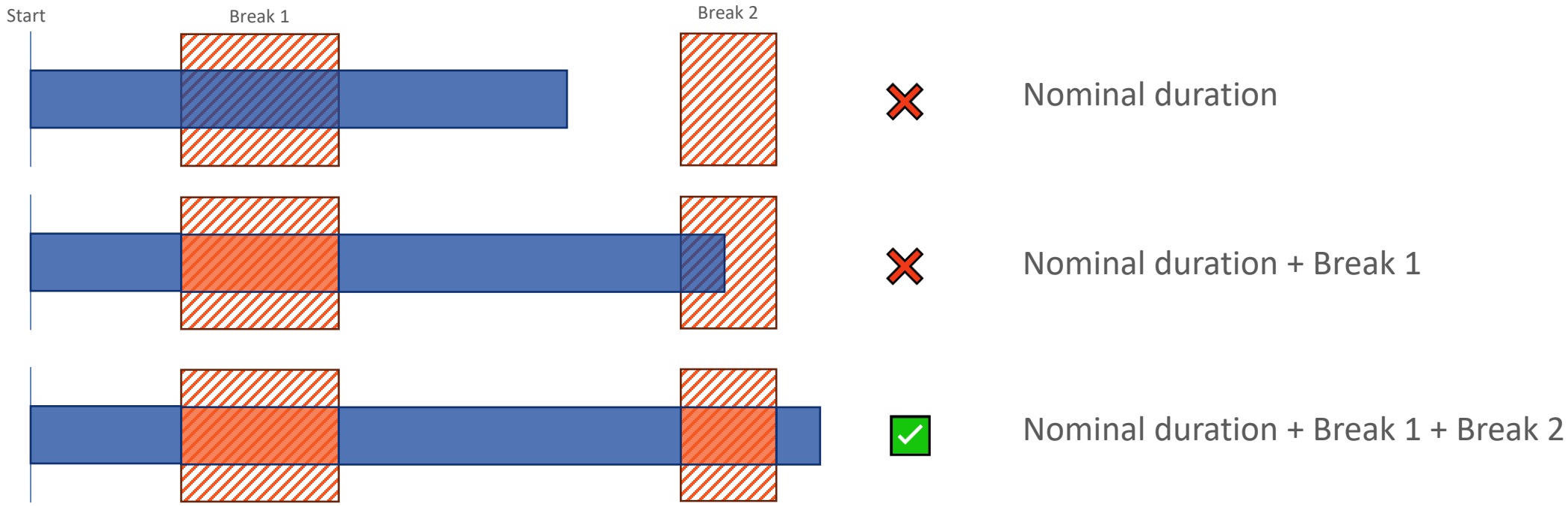
Hard constraints

- Disjunctive resources
  - A station can execute at most one task at a time
  - At most one task executed at a time on a vehicle
- Tasks can be assigned to several stations
- Tasks can be performed only during specific shifts
- Task duration is variable:
  - Nominal duration: PPOs of a vehicle are **aggregated** into tasks based on business rules
  - Operator's skills / Number of operators
  - **In/out times** for parking trips varying for stations/shifts
  - Stations have **hard-breaks** and **soft-breaks** and work during a **shift**



Hard constraints

- Task duration is variable:
  - **Soft-breaks**
    - Breaks are specific to each station/shift (cannot pre-process them)
    - Cannot be dealt with hard breaks
    - Duration of task depends fully on the start time of the task (must not branch on duration variables)

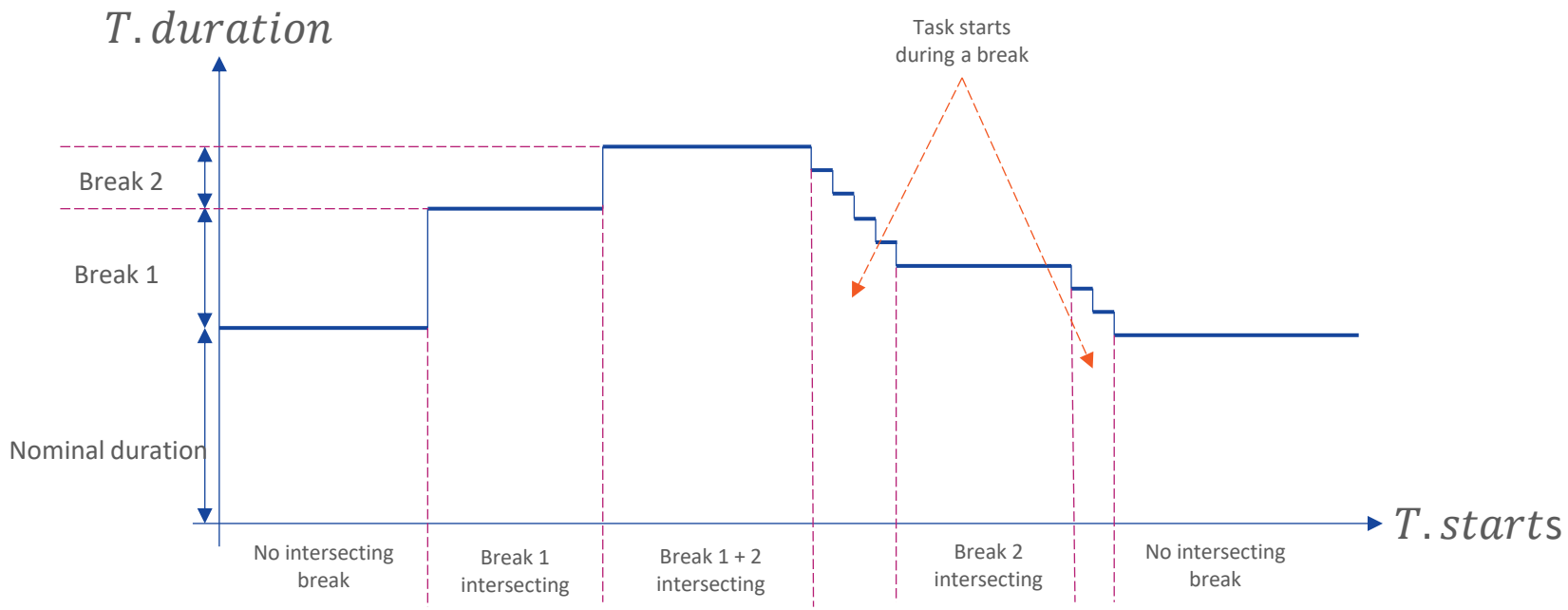


Hard constraints

Task duration is variable:

Soft-breaks

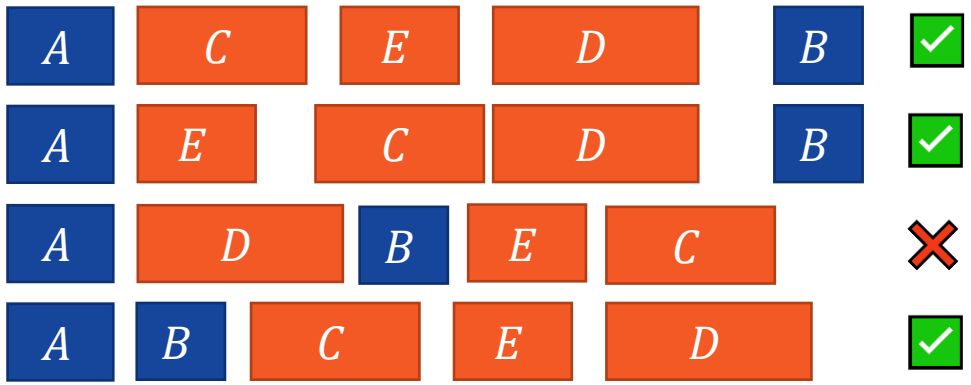
- Breaks are specific to each station/shift (cannot pre-process them)
- Cannot be dealt with hard breaks
- Duration of task depends fully on the start time of the task (must not branch on duration variables)
  - "Start based duration" global constraint



Hard constraints

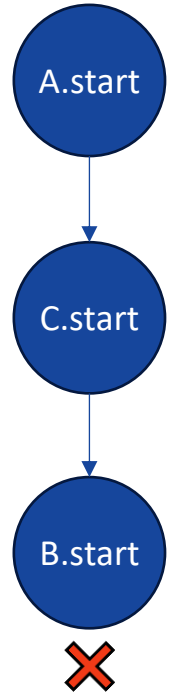
Precedence and sequence constraints:

- Precedence constraints:
  - Task A must be done **before** Task B
- Sequence constraints:
  - Task C, D, E must be done without any other task **in-between them**



- **High-level rule-based definition:**
  - ***-A-*-[C-E-D]-*-B-***
  - **User does not generate the precedence matrix by himself**

Impact on tree search

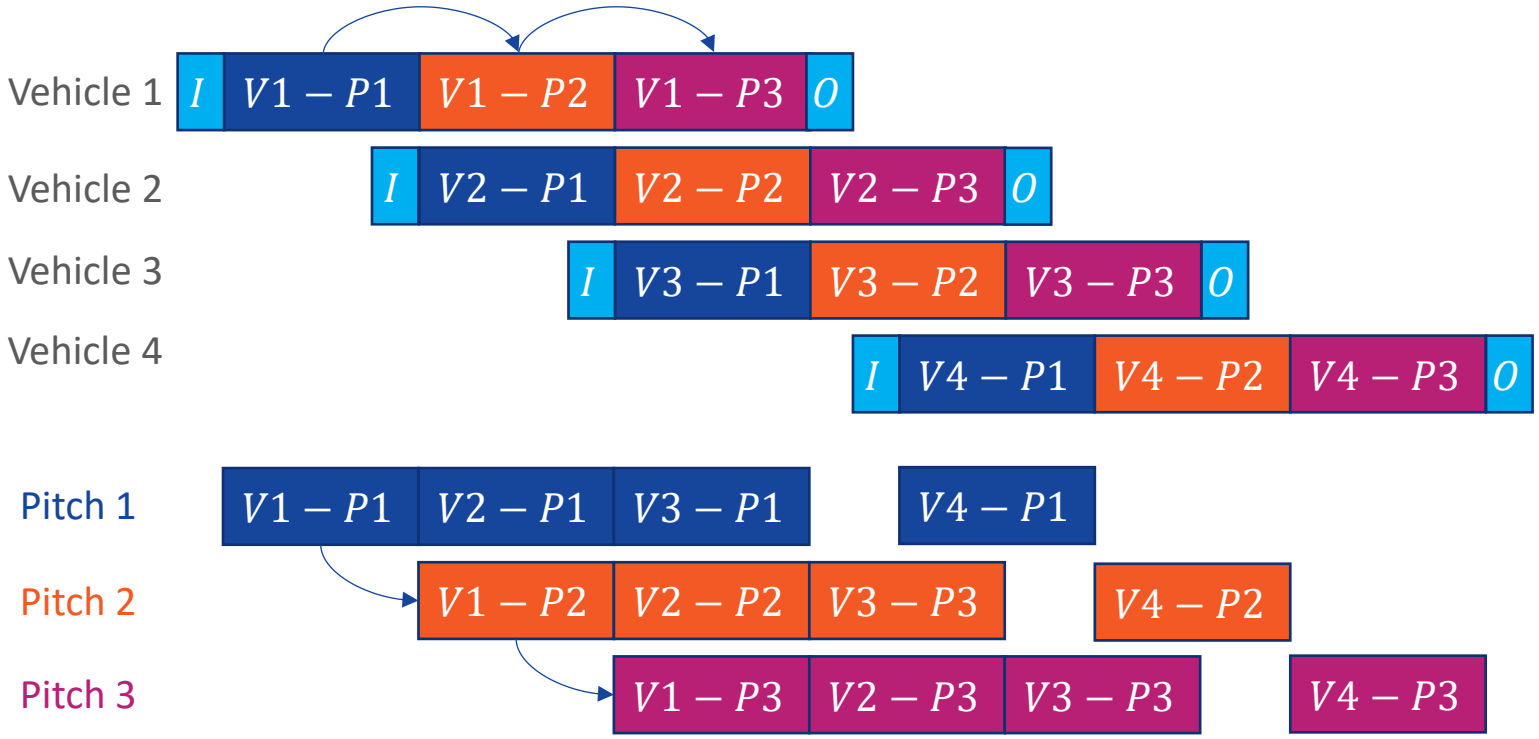


"No good" choice

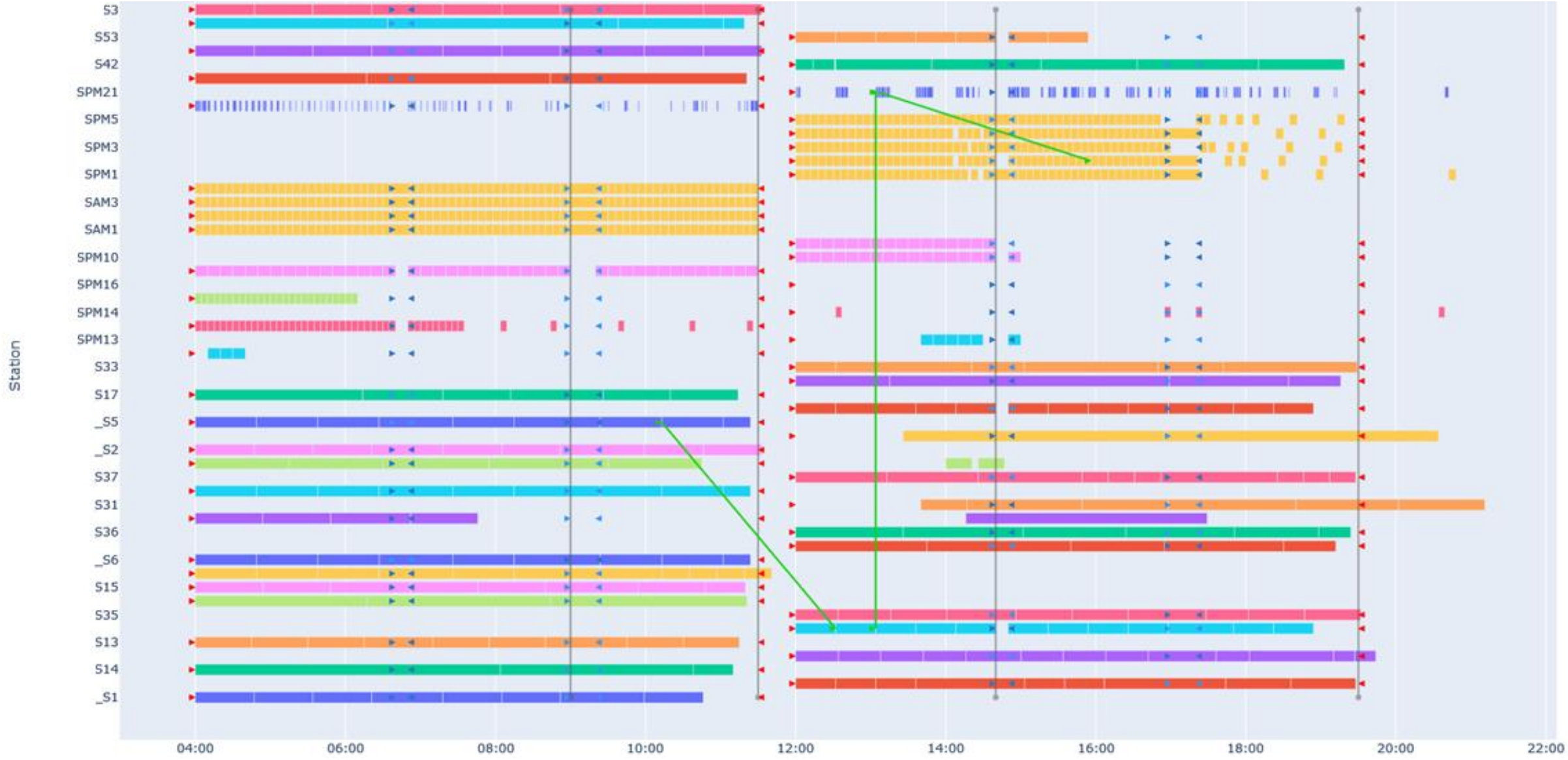
Hard constraints

Conveyors

- The vehicle must pass through n pitches
- 1 pitch takes a fixed number of seconds (e.g. 100 seconds)
- This is not a resource of capacity n
- Once in the conveyor, the vehicle must go through all pitches
- I/O times only applied to vehicle resources
- Breaks applied on all pitches



Example visualization



Soft-constraints

Multi-objective

- Maximize the number of tasks planned within shifts
- Maximize the number of vehicles ending before their cutoff time

Deadline constraints

- Minimize vehicles time span (minutes)
- Minimize shifts durations (minutes)

Workshop efficiency

- Minimize successive complex tasks on stations
- Minimize successive different family tasks

Stations efficiency

Soft-constraints

Multi-objective

- Maximize the number of tasks planned within shifts — 0.5%
- Maximize the number of vehicles ending before their cutoff date — 10%
- Minimize successive complex tasks on stations — 20%
- Minimize successive different family tasks — 20%
- Minimize shifts durations (minutes) — 20%
- Minimize vehicles span times (minutes) — 20%

Goal-programming method:

- Ranking + Equivalency tolerance
- Two solutions comparison:
  - ↳ Solution 1 is better

Objective	Sense	Solution 1	Solution 2	Gap
NB_PPOS_PLANNED_IN_SHIFTS	MAX	980	979	-0.1%
NB_VEHICLE_BEFORE_CUTOFF	MAX	430	434	+9%
NB_SUCCESSIVE_COMPLEX	MIN	10	10	0%
NB_MODEL_PPOS_CHANGES	MIN	80	150	+87%
TOTAL_SHIFTS_DURATION	MIN	960	1050	
TOTAL_VEHICLE_SPAN_TIME	MIN	50000	40000	

Resolution & Results

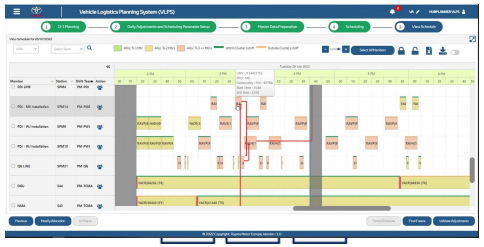
Resolution

VLPS Scheduler Service

- **Optimize a daily scheduling plan** taking into account operational constraints
- Fully integrated as a **stateless microservice** with TME's Vehicle Logistics Planning System

Vehicle Logistics Planning System (VLPS)

- Web hosted Software
- Gantt diagram to visualize/modify the solution



Inputs

- Daily allocation: vehicles, tasks
- Hub resources: stations, shifts

Outputs

- Tasks start/end dates
- Tasks allocated station
- KPIs

Scheduler Service

- Optimization with hard and soft constraints
- Modes:
  - Simple optimization
  - Checker
  - Re-optimization

ARTELYS KALIS™
Constraint Programming Library

Resolution

- Optimization technologies
  - Artelys-Kalis
  - Modelling with FICO Xpress-Mosel
    - Easy to update the model for a specification update
  - Short running times
    - 10000+ activities
    - 1s timestep
    - 5 minutes time limit
- Remote computing
  - Multiple users can call the service simultaneously
  - Horizontal scaling

ARTELYS KALIS™

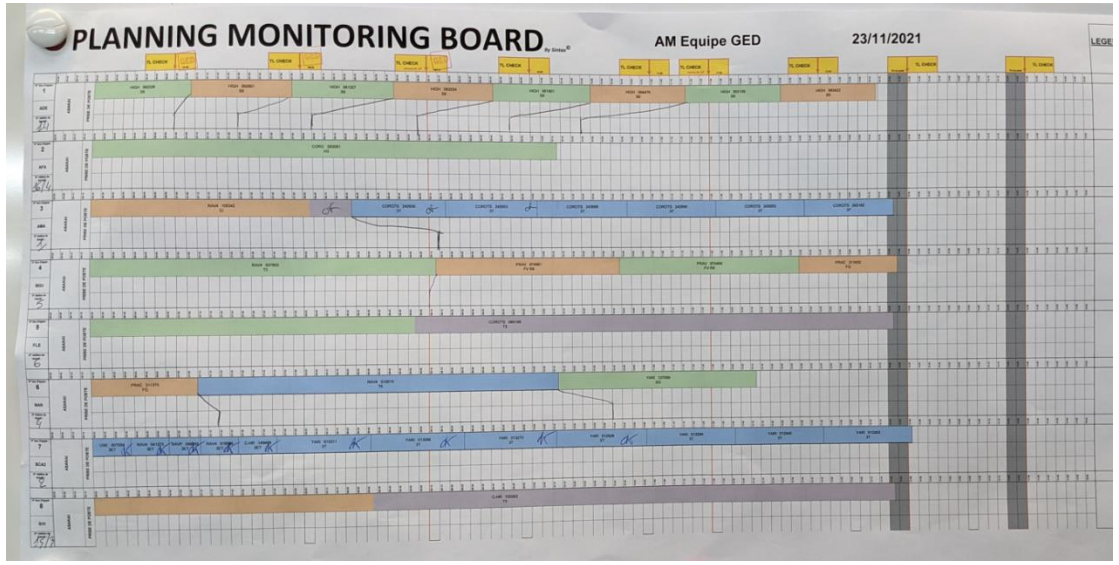
Constraint Programming Library

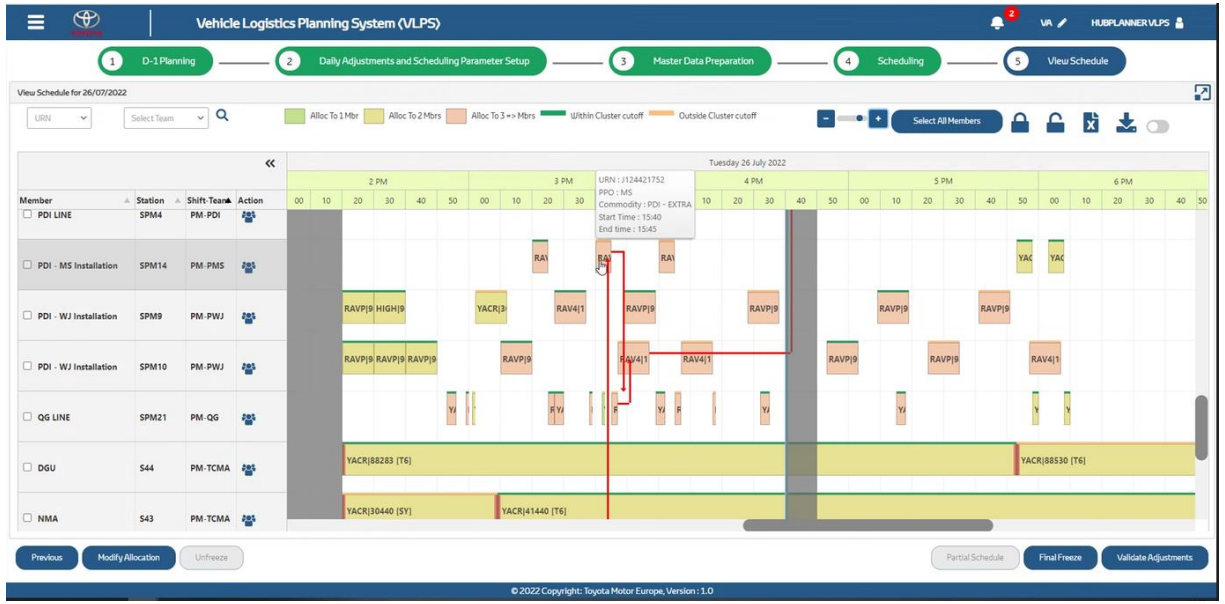
On the use of constraint programming

- MILP would **fail**
  - Too many binary variables
  - Bad overall relaxation
  - Good to get bounds on sub-models
- CP
  - Interval variables are essential
  - Customized search is still required to achieve operational performance
  - Expertise on the CP solver is still important
    - What global constraint to use ? There is no common API for CP Solvers
    - What propagation level is enough ?
    - Where is the time spent at each node ?

Results

- Producing daily production plans on European hubs
- Before:
  - Excel sheets
  - Gantt charts printed on paper
  - 3h
  - Reduced scope
- After:
  - Web-based application
  - 100% digital, allowing management in real-time
  - 20 minutes
  - Improved planning quality





Q&A