Equipment Routing task scheduling with BaPCOD

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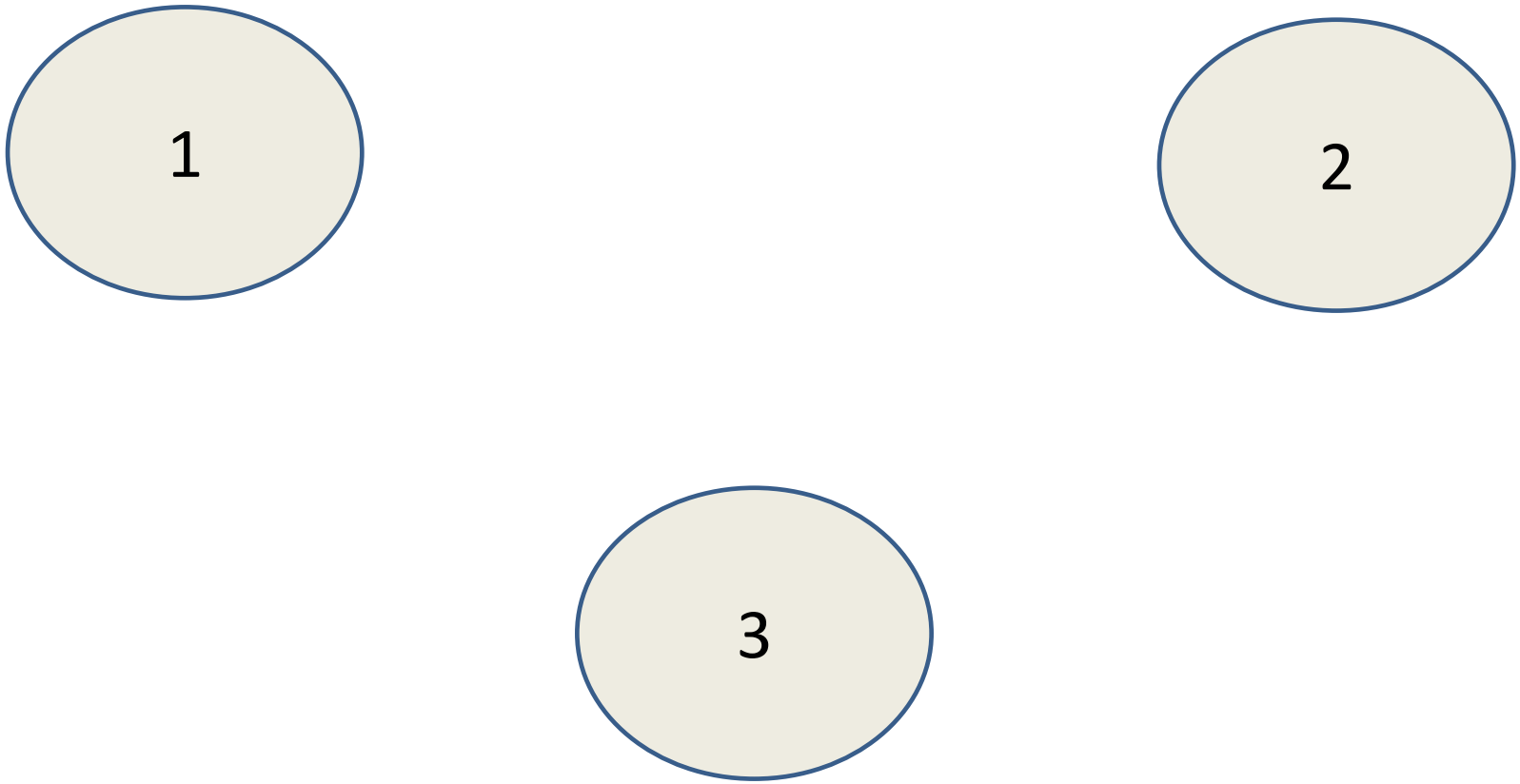
Environment of the Application

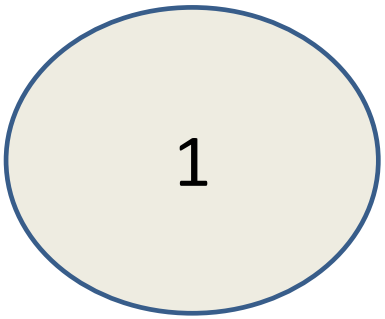
- Port Operations:
  - Shipment: Iron ore, Iron ore pellets
  - Iron ore pellet production
  - Other activities (up to 20%) (Soya, Etanol, Equipment for Fixed Equipment maintenance...)
- Activities:
  - 27 different locations
  - More than 50 types of equipments
  - Around the clock (24/7)

A few Types of Equipments...

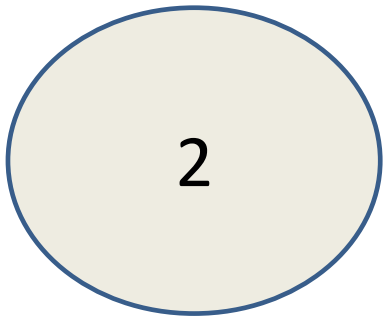
Given a set of locations,



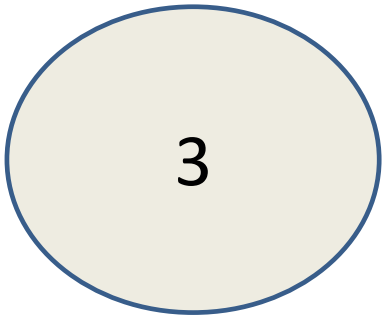
Given a set of locations, a set of tasks to be performed,



T1 = { E1, E3}
T2 = { E2, E3, E4}

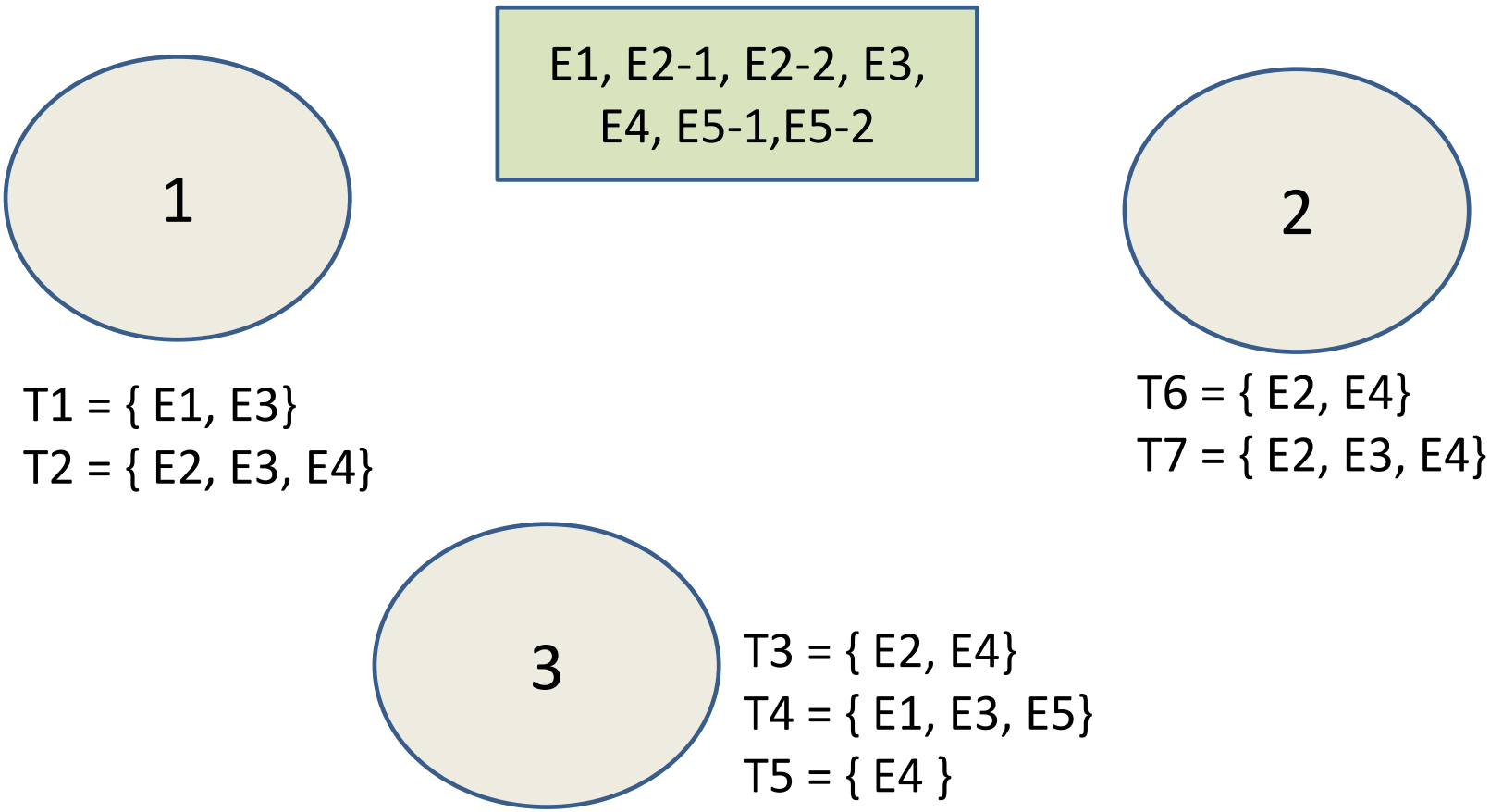


T6 = { E2, E4}
T7 = { E2, E3, E4}

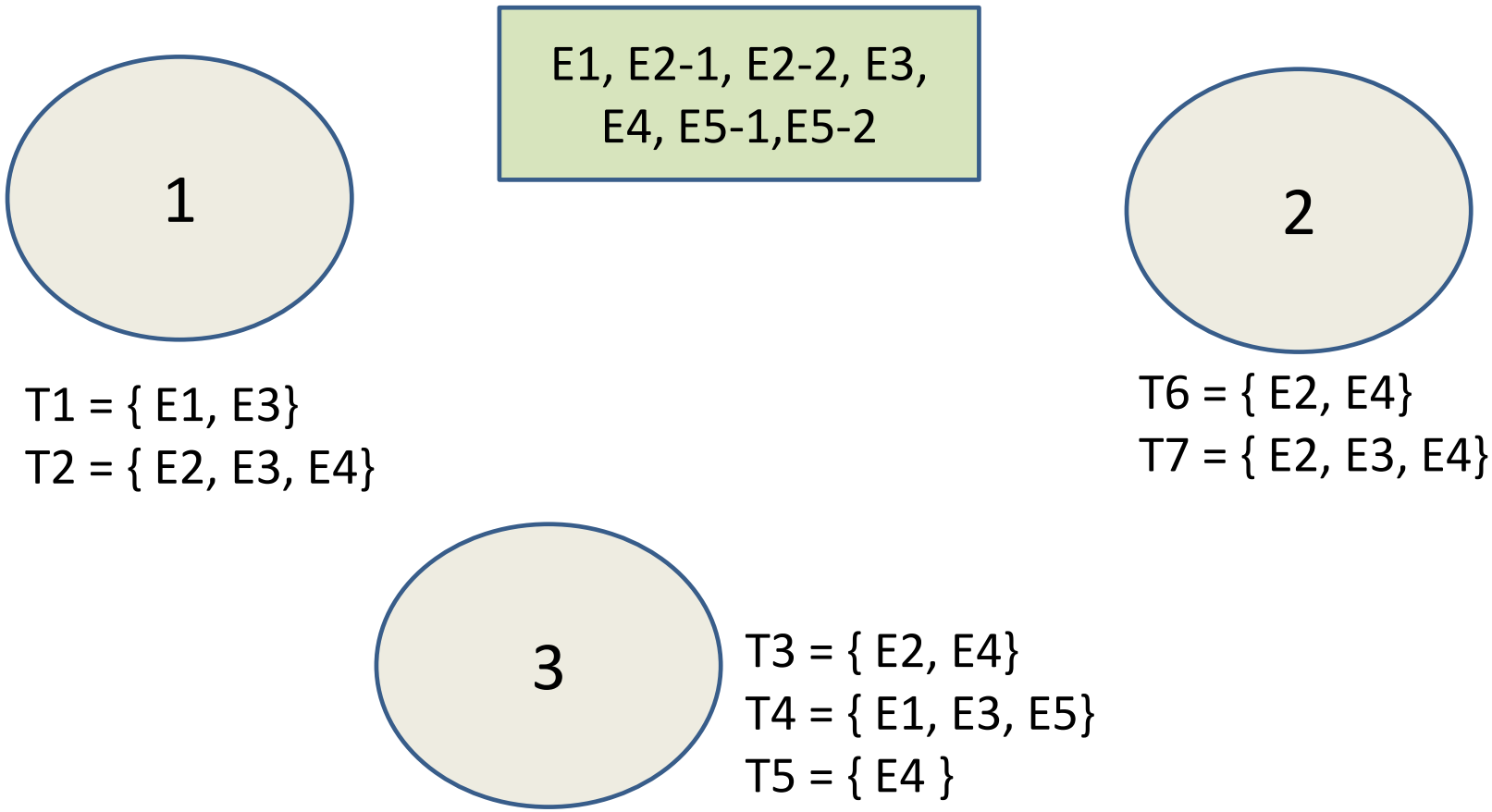


T3 = { E2, E4}
T4 = { E1, E3, E5}
T5 = { E4 }

Given a set of locations, a set of tasks to be performed, a set of equipments of different types,

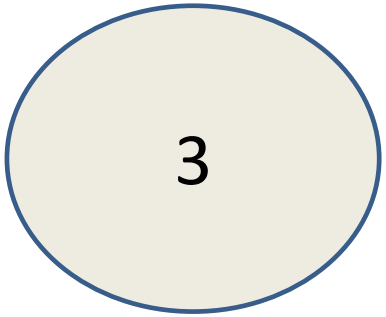


Given a set of locations, a set of tasks to be performed, a set of equipments of different types, ROUTE the equipments to execute the Tasks in such a way that:



Given a set of locations, a set of tasks to be performed, a set of equipments of different types, ROUTE the equipments to execute the Tasks in such a way that:

- A task is only executed when all required equipments are available for all its duration;
- A task may be executed in one of possible (2 to 4) shifts;



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Given a set of locations, a set of tasks to be performed, a set of equipments of different types, ROUTE the equipments to execute the Tasks in such a way that:

- A task is only executed when all required equipments are available for all its duration;
- A task may be executed in one of possible (2 to 4) shifts;

and the (Weighted) sum of performed Tasks is Maximized.

More details on the Tasks

- Time Windows:
  - Usually a Task should be execute during a given shift, but tighter time windows may occur
  - Tasks may have alternative time windows:
    - It is common to have task that may be performed in a shift on any of selected weekdays
    - For instance: morning shift, Monday, Wednesday or Friday; night shift, Saturday or Sunday
- Planning is done on Fridays for the next week (Sun-Sat)
  - There are performed more than 500 sub-tasks every week
  - (A Task with 3 equipments has 3 sub-tasks)
  - Re-planing may be done everyday
- There are owned and hired equipments

BaPCOD: Objectives and Development Context

- Main Objective: Arrive at a wider use of BaPCOD
- Development environment:
  - A company that develops corporative planning systems
    - Currently over 40 (tailored) solvers inside 16 systems that are used daily/weekly by over 12 large companies: Continuous Maintenance is an Issue.
    - 6 new solvers developed in 2011, the team is now just more than 30 OR (skilled programmer) professionals.
    - Overall, 1 (one) is a column generation solver. Can BaPCOD improve this number?
- Productivity is The Issue.

- $a \in A$: type of equipment
- $d^a \in D$: demand d asking for equipament type a
- Given $d_1^a, d_2^a \in D$, $f_{d_1^a d_2^a} = TUse_{d_1^a} + TDisp_{d_1^a d_2^a}$.

Variables

- $x_{e^a, d^a, i}$: Binary. One for demand d for type a equipment e starts at instant i
- y_d^s: Binary. One when demand d is serviced in shift s.

MIP Formulation

$$max \sum_{e^a \in E} \sum_{d^a \in D} \sum_{i \in tw_{d^a}} x_{e^a,d^a,i}$$

$$\sum_{e^a \in E} \sum_{i \in tw_{d^a}} x_{e^a,d^a,i} = y_d^s, \forall d^a \in D, \forall s \in Shifts(d^a), \forall a \in Types(d)$$

$$x_{e^a,d_1^a,i} + \sum_{j \in tw_{d_2^a} : i \leq j < i + f_{d_1^a d_2^a}} x_{e^a,d_2^a,j} \leq 1, \forall e^a \in E, d_1^a, d_2^a \in D, i \in tw_{d_1^a}$$

$$\sum_{s \in Shifts(d^a)} y_d^s \leq 1, \forall d^a in D$$

$$x_{e^a,d^a,i} \in \{0,1\}, \forall e^a \in E, d^a \in D, i \in tw_{d^a}$$

$$y_d^s \in \{0,1\}, \forall d^a \in D, \forall s \in Shifts(d^a)$$

Path Formulation

$$max \sum_{r_a \in \Omega} c_{r_a} \lambda_{r_a}$$

$$(\beta_{d^a}) : \sum_{r_a \in \Omega} \sum_{i \in tw_{d^a}} q_{r_a}^{d^a,i} \lambda_{r_a} = y_d^s, \forall d^a \in D, \forall s \in Shifts(d^a)$$

$$(\alpha_a) : \sum_{r_a \in \Omega} \lambda_{r_a} \leq K_a, \forall a \in A$$

$$\sum_{s \in Shifts(d^a)} y_d^s \leq 1, \forall d^a \in D$$

$$\lambda_{r_a} \in \{0,1\}, \forall r_a \in \Omega$$

- K_a: quantity of equipments of type a.
- r_a: a route for equipment a, $r_a \Omega_a$
- λ_{r_a}: Binary variable associated with route r_a
- $q_{r_a}^{d^a,i}$: 1 if route r_a serves (sub)demand d^a starting at instant i. Zero otherwise.
- c_{r_a}: cost of route r_a
- $c_{r_a} = \sum_{d^a \in D} \sum_{i \in tw_{d^a}} q_{r_a}^{d^a,i}$.

Branching

- Branches are on the aggregated variables $x_{d^a,i}$
- Adding constraint $\sum_{r_a \in \Omega} q_{r_a}^{d^a,i} \lambda_{r_a} = 0$ or $\sum_{r_a \in \Omega} q_{r_a}^{d^a,i} \lambda_{r_a} = 1$.
- Let $\mu_{d^a,i}$ be the dual variable associated to the above constraint.

Path Reduced Cost

- $\bar{c}_{r_a} = c_{r_a} - \sum_{d^a \in D} \sum_{i \in tw_{d^a}} q_{r_a}^{d^a,i} \beta_{d^a} - \sum_{d^a \in D} \sum_{i \in tw_{d^a}} q_{r_a}^{d^a,i} \mu_{d^a,i} - \alpha_a$
- $\bar{c}_{r_a} = \sum_{d^a \in D} \sum_{i \in tw_{d^a}} q_{r_a}^{d^a,i} (1 - \beta_{d^a} - \mu_{d^a,i}) - \alpha_a$

Column Generation Subproblem sp_a

$$min \sum_{d^a \in D} \sum_{i \in tw_{d^a}} (1 - \beta_{d^a} - \mu_{d^a,i}) X_{d^a,i}$$

$$X_{d_1^a,i} + \sum_{j \in tw_{d_2^a} : i \leq j < i + f_{d_1^a d_2^a}} X_{d_2^a,j} \leq 1, \forall d_1^a, d_2^a \in D, i \in tw_{d_1^a}$$

$$X_{d^a,i} \in \{0,1\}, \forall d^a \in D, i \in tw_{d^a}$$

Dynamic Programming

- Shortest Path Problem with Time-Windows – SPPTW
- Complexity $O(n^2 t)$, with n the number of sub demands for equipment a. and horizon t

Tested Algorithms

- CPLEX on the "compact" formulation.
  - Upper and Lower bounds.
- Non-elementary route (no branching) on BaPCOD
  - Upper bound (relaxation)
- Elementary route on BaPCOD - Diving heuristic
  - Lower bound (feasible solution)
- Elementary route on BaPCOD - Set Partitionning heuristic
  - About 20000 routes.
  - Lower bound (feasible solution)

Instance Generation

- The intent was to find close to real instances that are difficult for CPLEX to solve.
- Those instances should not be too large to fit into CPLEX (below 100000 constraints for a AMD 3500, 789 MHz, with 1GB RAM)
- Tasks (demands) had 1, 2 or 3 subtasks. I.e., required up to 3 different equipments.
- Tasks could be executed on 2 or 3 different shifts (50% probability each).
- Number of locations was the real ones.
- Traveling times where obtained by randomly distributing over a square and computing the Euclidean distances. These where further normalized so that the largest displacement was as long as the real one.

Table Columns

- ND1, ND2 and ND3: number of tasks with 1, 2, and 3 subtasks(different equipments), respectively.
- LOC: number of locations
- NTY: number of types of equipments
- NTO: total number of equipments
- QRT: Non-elementary path Upper bound
- SPP: Set Partitioning Heuristic (BaPCOD)
- DIV: Diving heuristic
- CPL: CPLEX 12.1 best feasible or optimal.

Algorithmic Improvements

- Improve branching strategies
  - The non-elementary route bounding looks strong.
  - Good primal solutions may be found consistently.
- Test and Tune BaPCOD Primal Heuristics
  - We are at the beginning of the tests.

Optimization Problem Evolution

- Other Objective Functions
  - Users have pointed out their intention to care more about costs
  - This include hiring cost of equipment
  - Total fuel used, etc.
- Operators
  - For now they are considered in a post-processing, since they operate with teams of operators for each equipment.
  - This will not be true for too long.
- Instance Size and Centralized Planning
  - Today the planning is divided in groups of equipments (and there are already 500 a week)
  - In the future, it will be only one planning group, (sub)demands will be over 1000 a week.

Questions ?

Merci Bien!!