Pontifical University of Chile
School of Engineering

Master of Science in Engineering

Truck Dispatching Optimization for Open-pit Mining Trucks

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Santiago, Chile, October 2014

Thesis Committee

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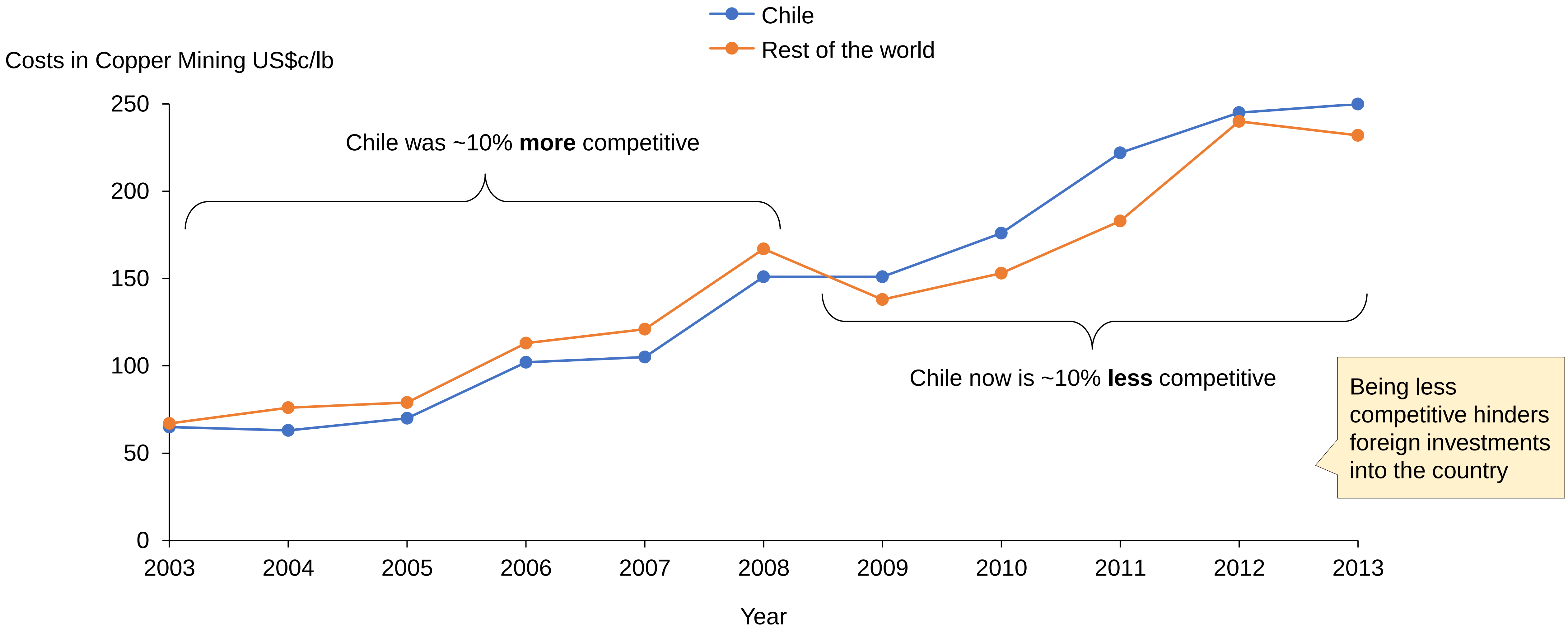
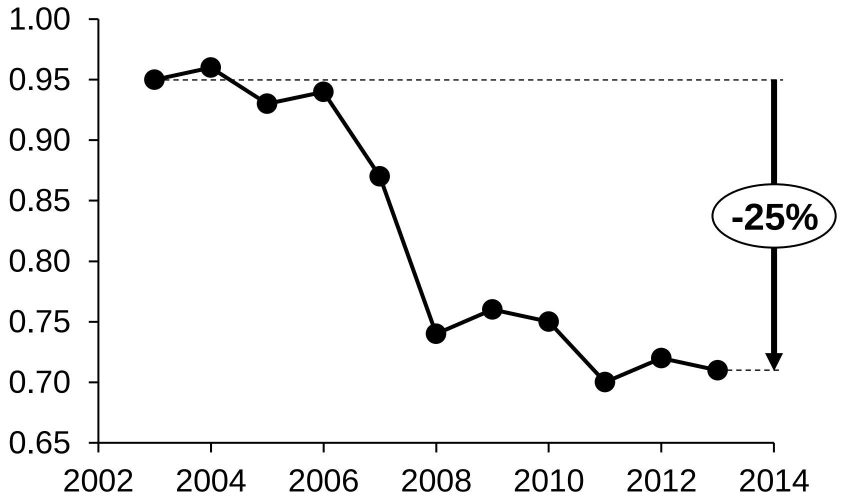
The mining industry has been the engine of the Chilean economy over the last century, but now its contribution is in danger



Source: Annual Report of Chilean Mining Council (2014)

Chilean mining now is less competitive than the rest of the world due to internal and external factors

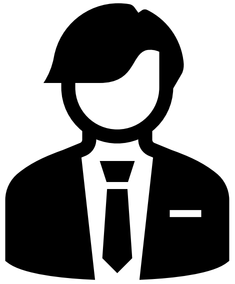
Average copper ore grade extracted in Chile (%)



As deposits advance, their ore grade diminishes over time

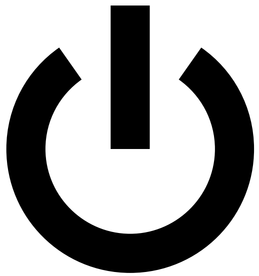
There has been an increase in the cost of important resources

Human



Water

Electricity



One of the measures proposed by the Chilean Ministry of Mining is to use technology to increase productivity[1]

- Within operational expenses, up to **65%** of the costs are related to the processes of loading and transportation.
- A little improvement of productivity can lead to enormous economic benefits!

The focus of this research is to improve the productivity of the **truck dispatching problem**

(1) Source: Annual Report of Chilean Mining Council (2014)

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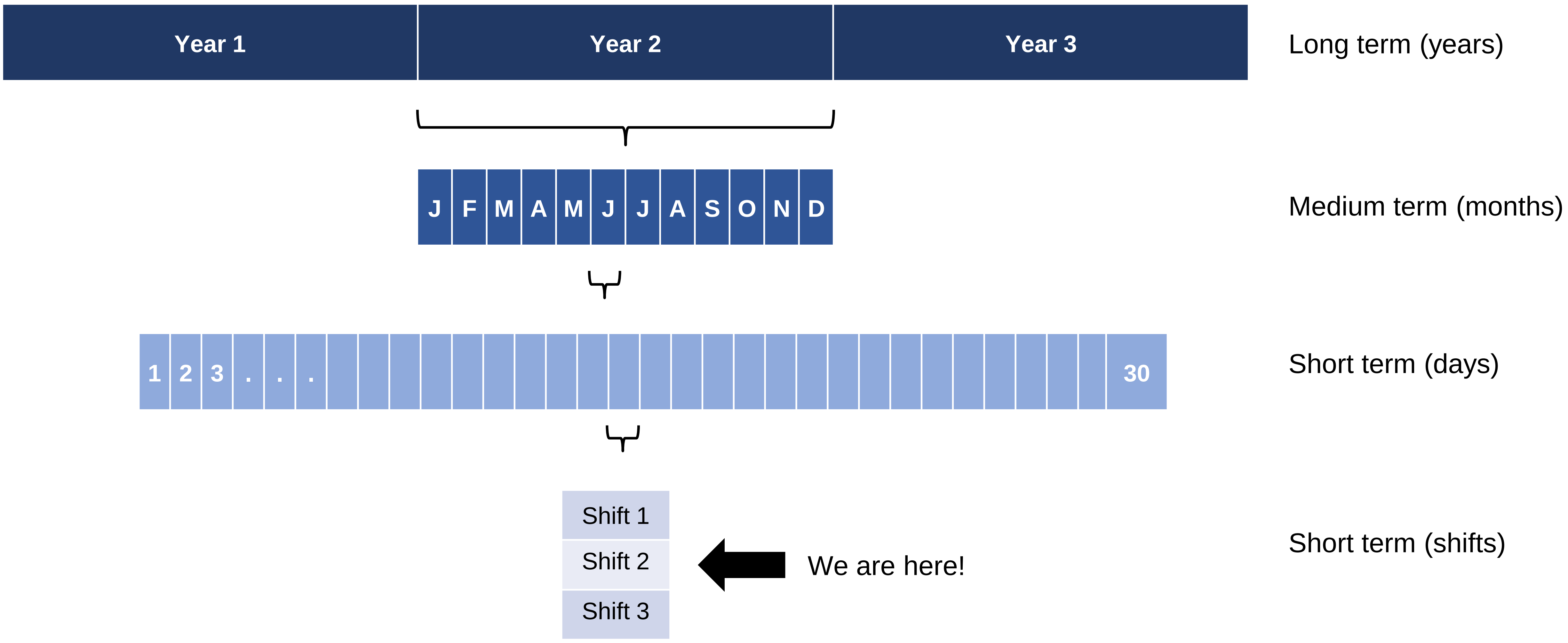
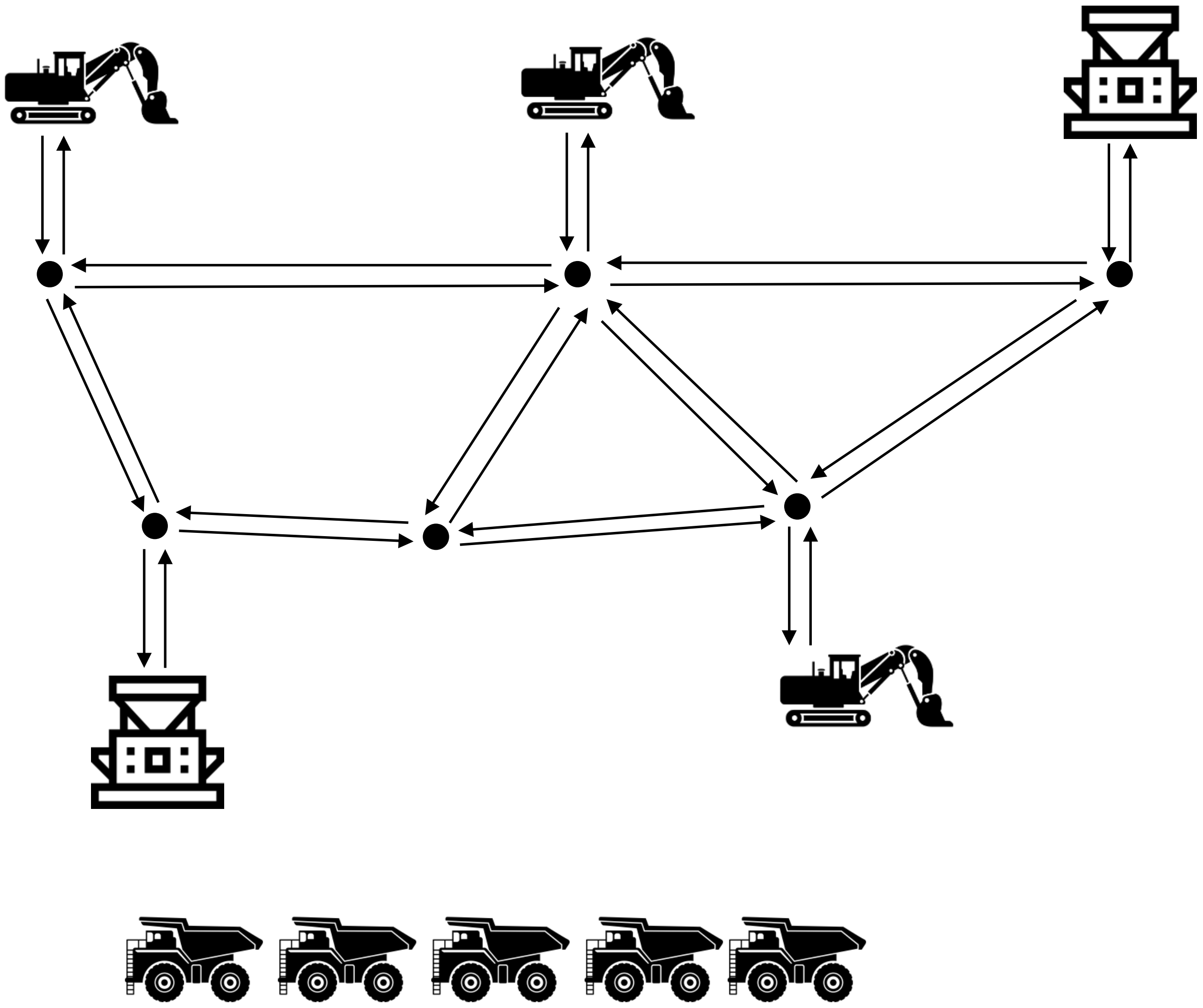
The exploitation of a mine has long, medium and short-term plans. The truck dispatching problem occurs at the shift-level



The truck dispatching problem has competing objectives and operational constraints to meet



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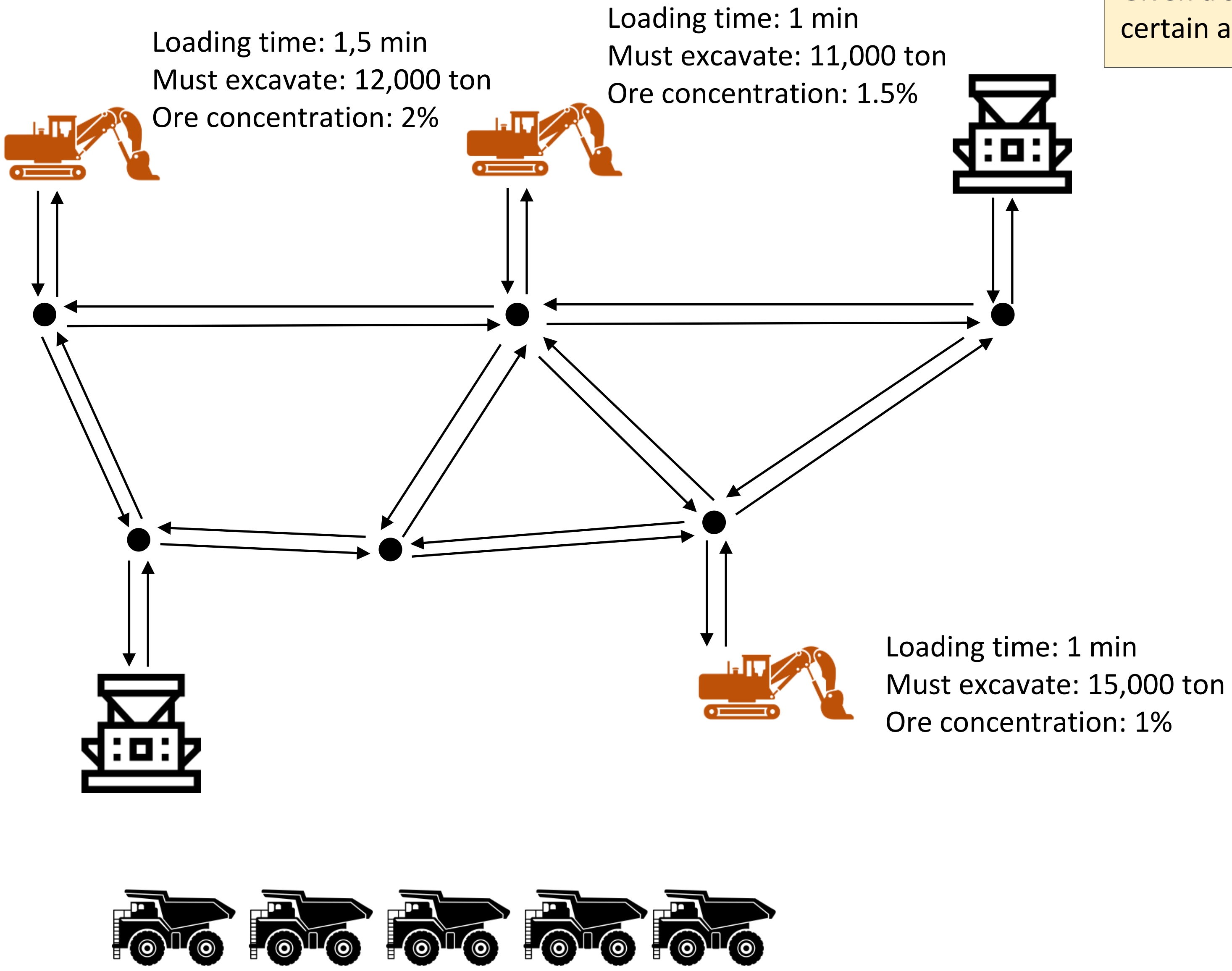
Given a set of shovels, they have specific loading times, must excavate a certain amount of material and have specific ore concentrations.



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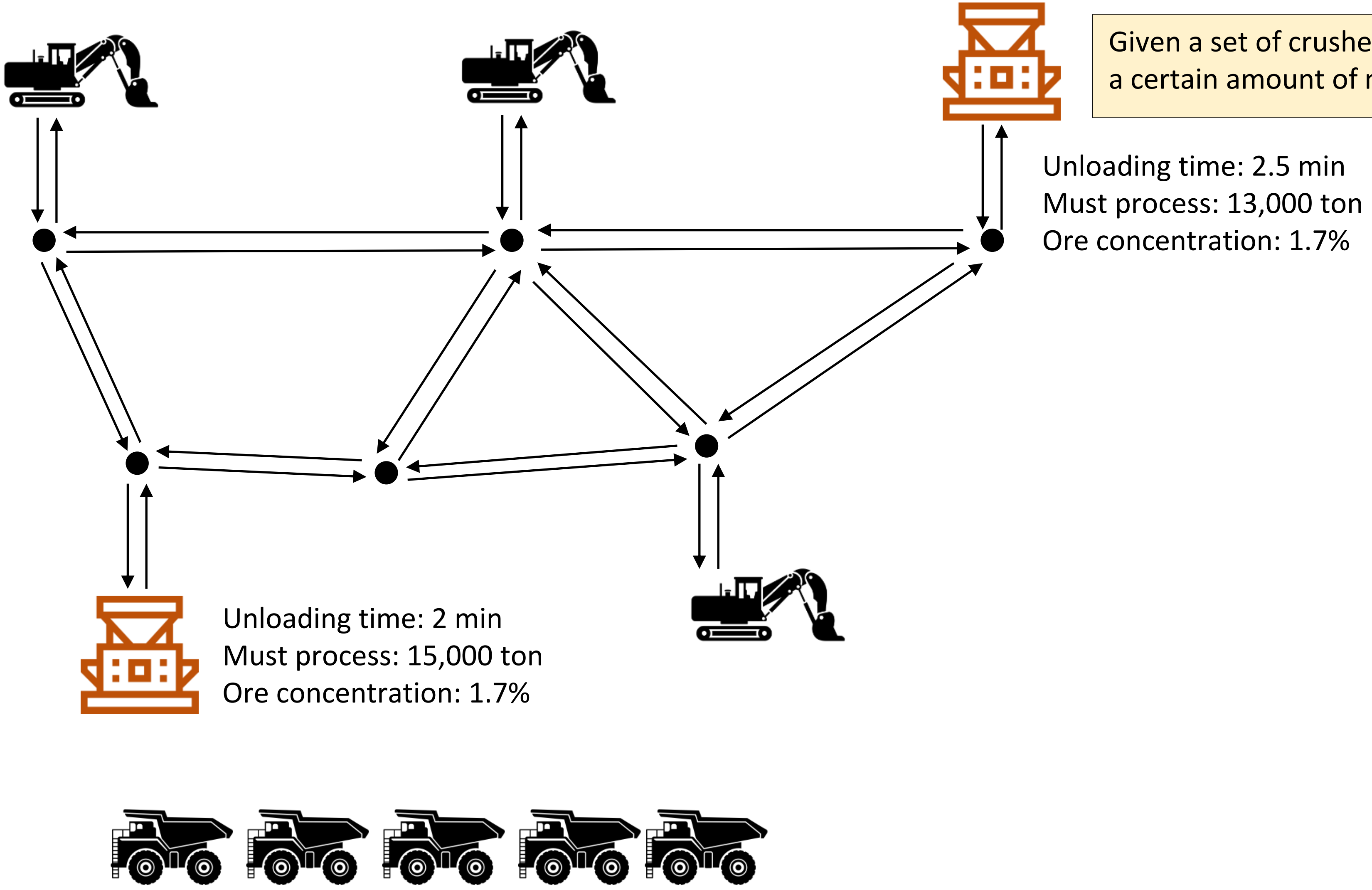
Given a set of shovels, they have specific loading times, must excavate a certain amount of material and have specific ore concentrations.

Given a set of crushers, they have specific unloading times, must process a certain amount of material and require specific ore concentrations.



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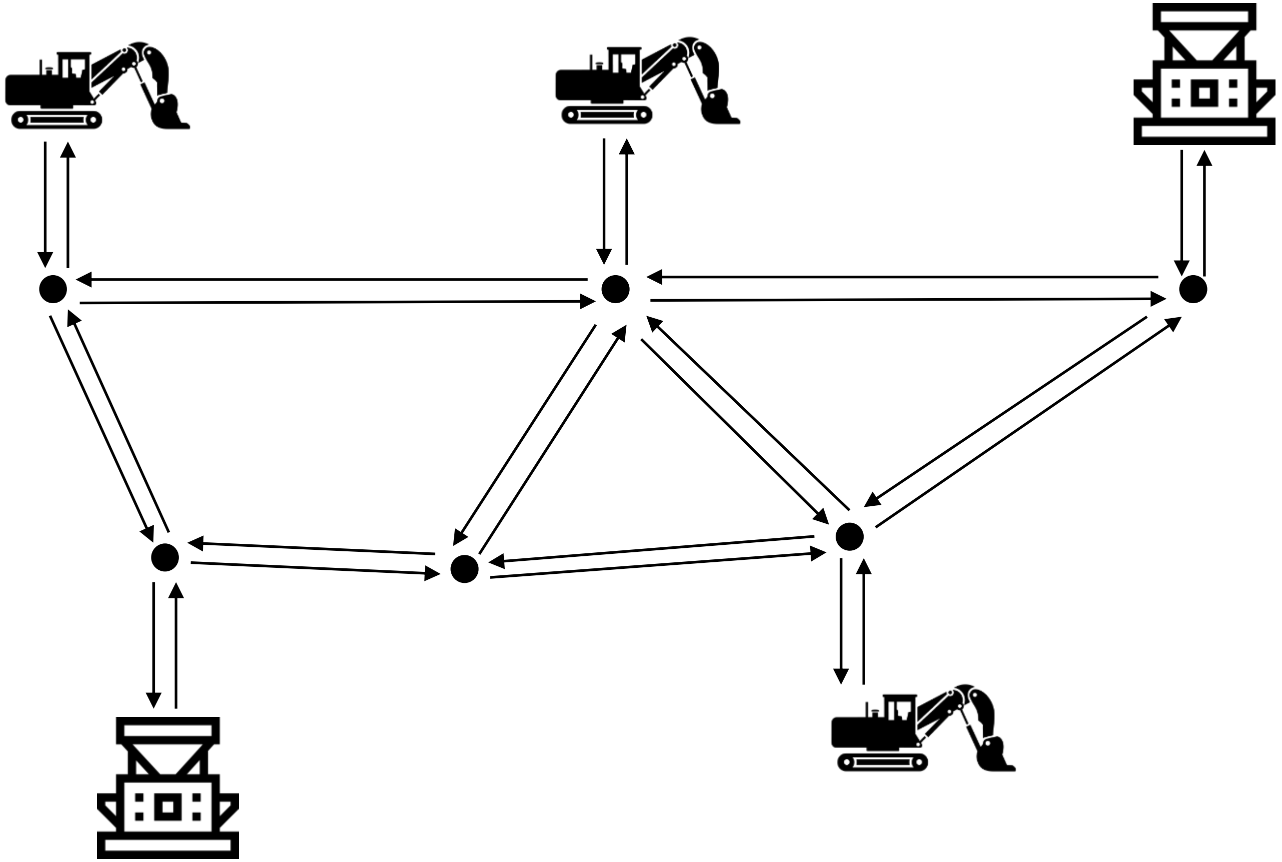

Given a set of shovels, they have specific loading times, must excavate a certain amount of material and have specific ore concentrations.

Given a set of crushers, they have specific unloading times, must process a certain amount of material and require specific ore concentrations.

There is a fleet of trucks available, each one of them with specific loading capacity and speed (which depends if the truck is loaded or unloaded)

Capacity: 80 ton
Max speed when empty: 40 mph
Max speed when loaded: 20 mph

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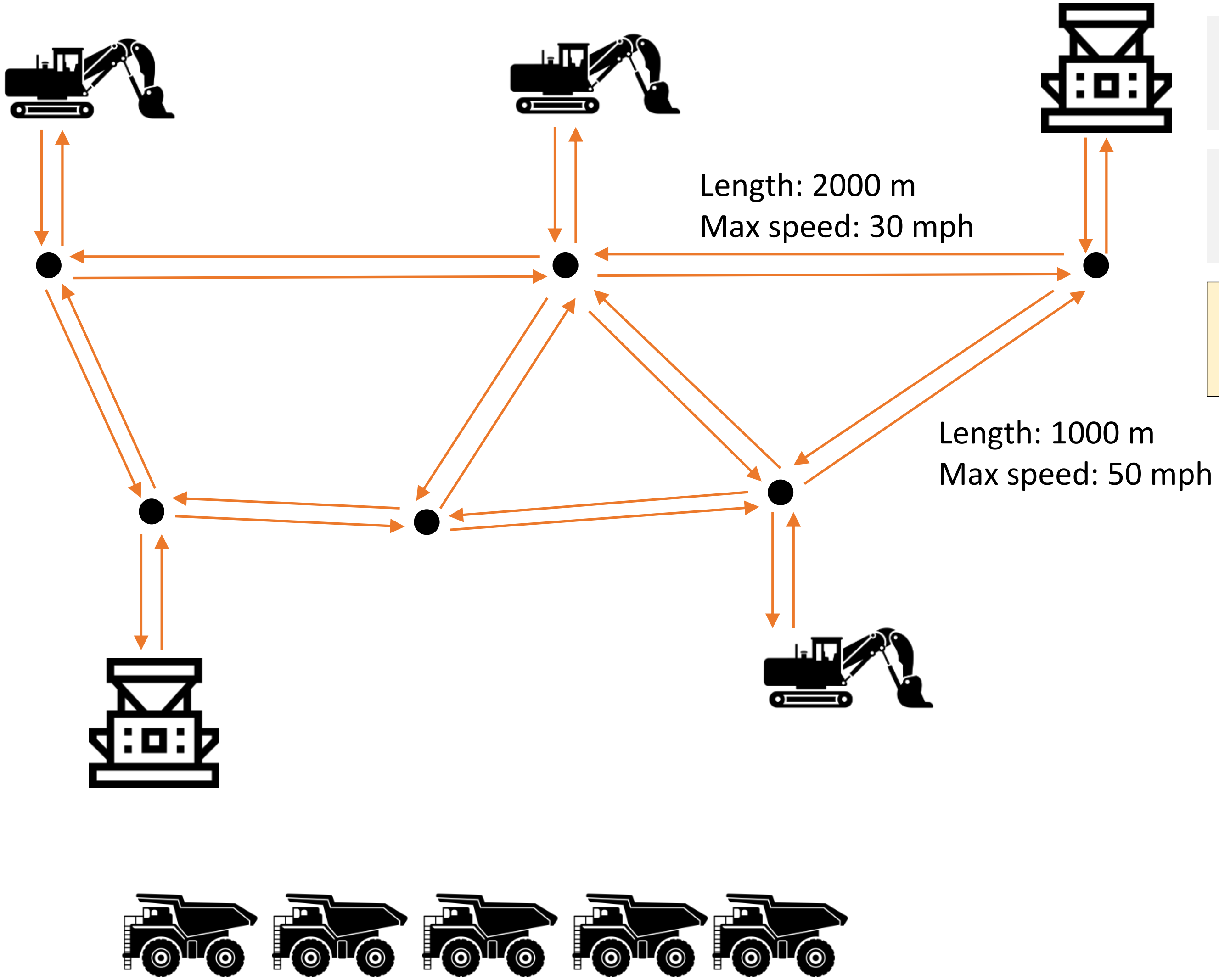

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There is a transportation network with directed edges. Each edge has a certain length and a maximum speed allowed for safety reasons.

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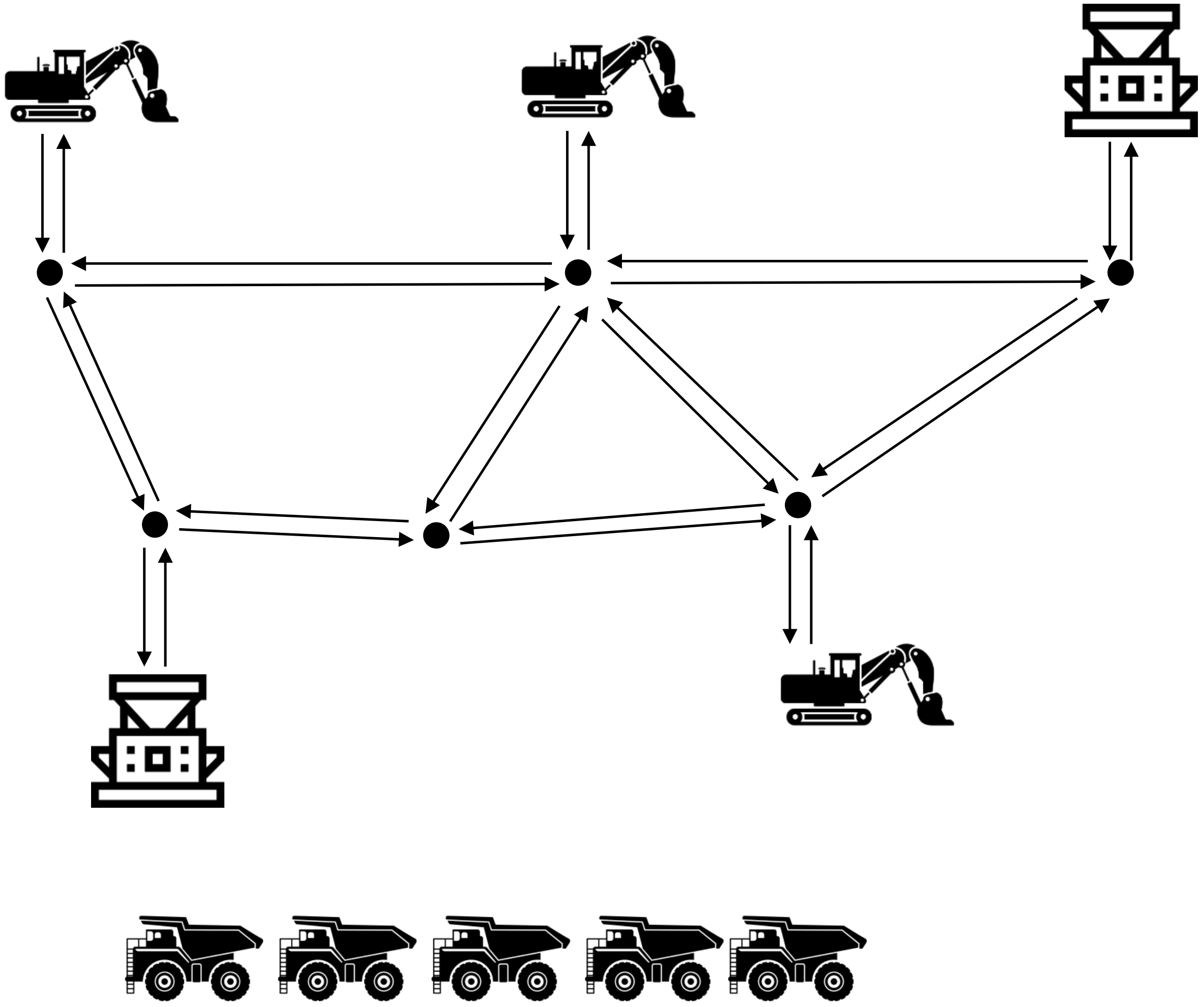

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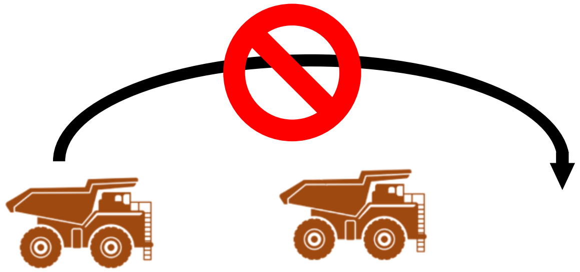
For safety reasons, it is not possible for a truck to overtake another truck in the mine.



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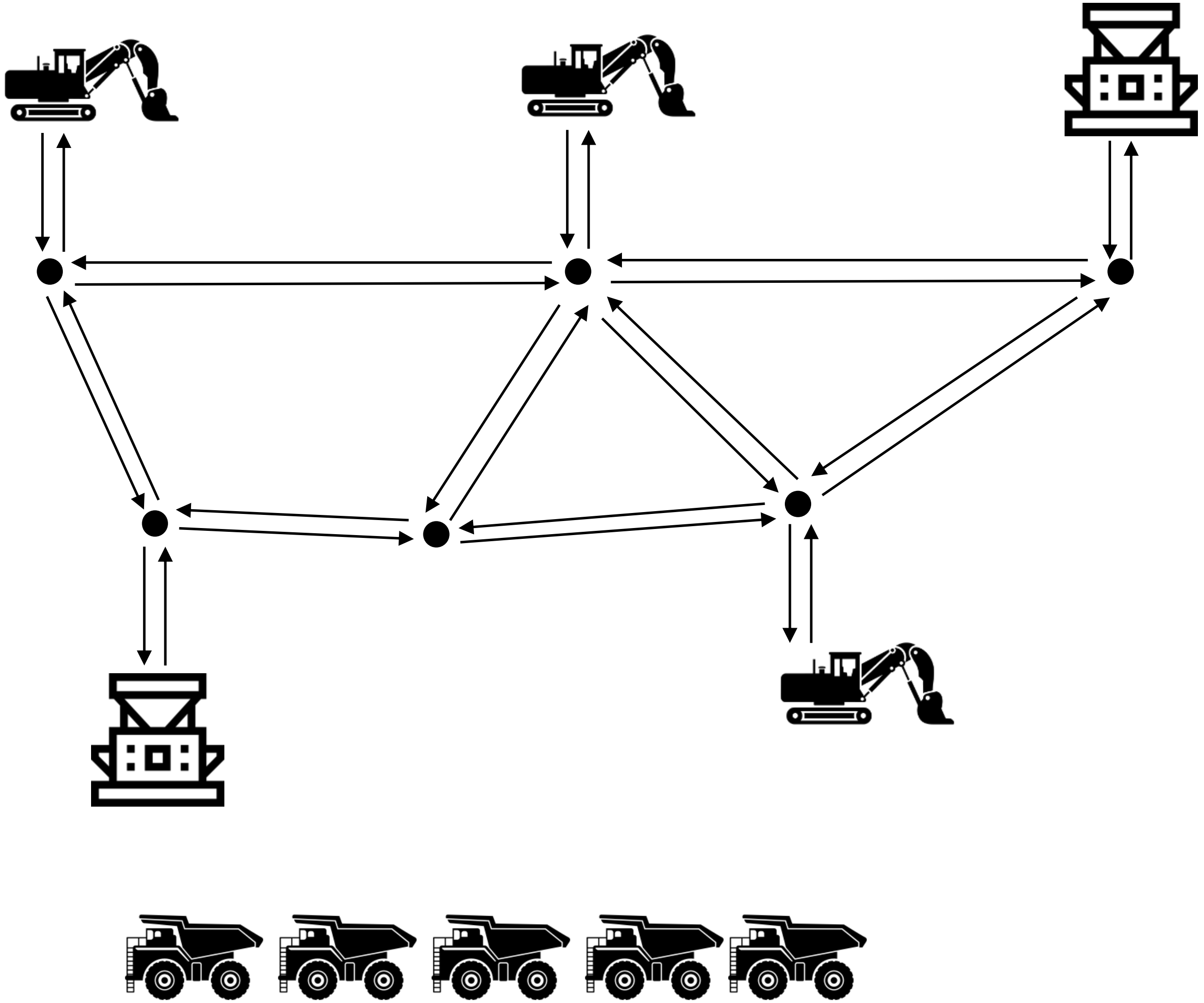

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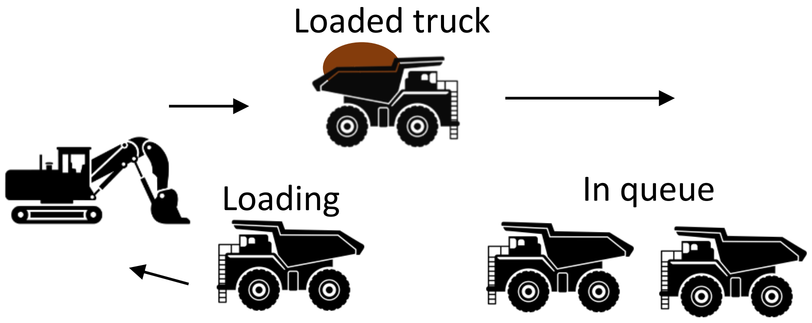
Shovels load the trucks in a FIFO manner.



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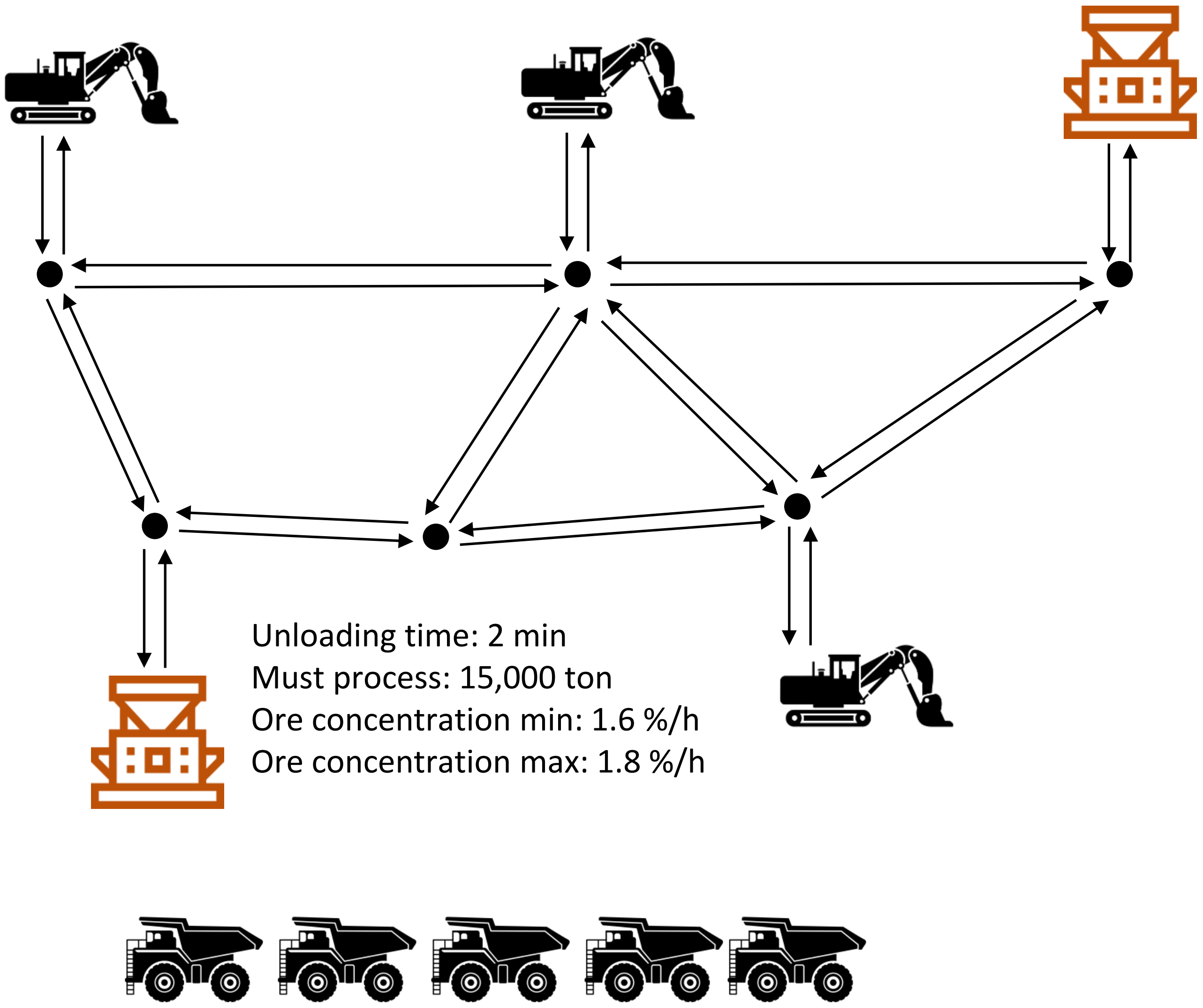

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Shovels load the trucks in a FIFO manner.

The crushers have specific minimum and maximum thresholds for the concentration of ore received from trucks in a time interval.

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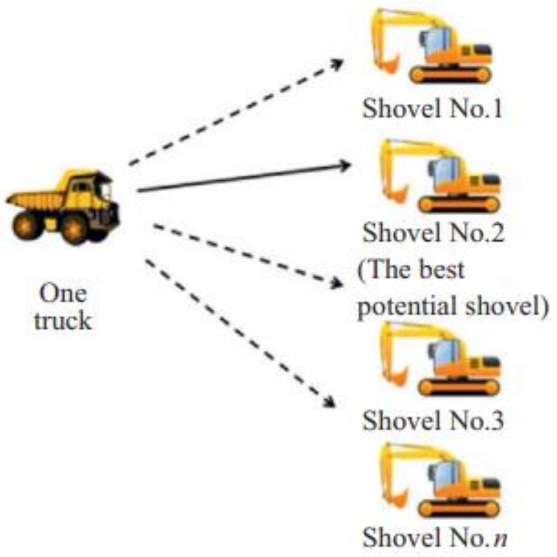
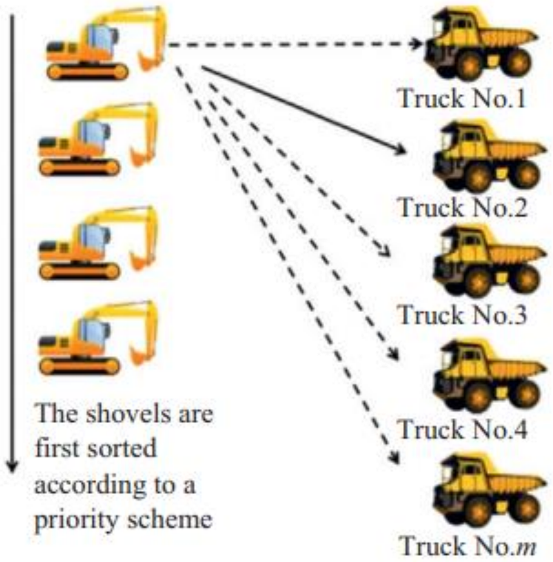
There are 3 types of methods in the literature to solve the truck dispatching problem in mining[1]

1-truck-to-N-shovels



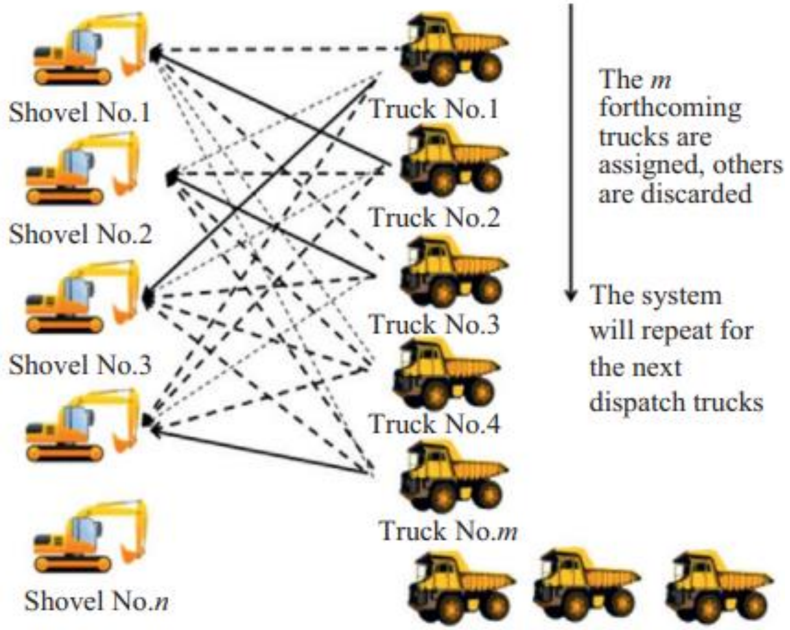
Greedy method: each time a truck is idle, it chooses the shovel that minimizes an objective function (waiting time, delay, etc.)

M-trucks-to-1-shovel



Greedy method: sort the shovels by some cost function, then for each shovel (starting from the most expensive) assign the best truck

M-trucks-to-N-shoves



Combinatorial method: check all combinations possible for a fixed time horizon and pick the optimal assignment. Apply only the immediate allocation.

(1) Alarie and Gamache (2002)

This work fills a gap in the current methodologies

Author	Type	Characteristics considered: Ore grade	Stochasticity	Heterogenous Fleet	Traffic interactions	Queues
Soumis et al (1987)	M-N	Yes	No	No	No	Yes
Weintraub et al (1988)	1-N	Yes	No	Yes	No	No
Li (1990)	1-N	No	No	No	No	No
White and Olson (1986)	M-1	Yes	No	Yes	No	No
Temeng et al (1997)	M-N	Yes	No	Yes	No	No
Jaoua et al (2012)	M-N	No	Yes	Yes	No	No
Our method	M-N	Yes	No	Yes	Yes	Yes

To our knowledge, this is the first method that consider all the major characteristics of the problem in a deterministic environment

(1) Alarie and Gamache (2002)

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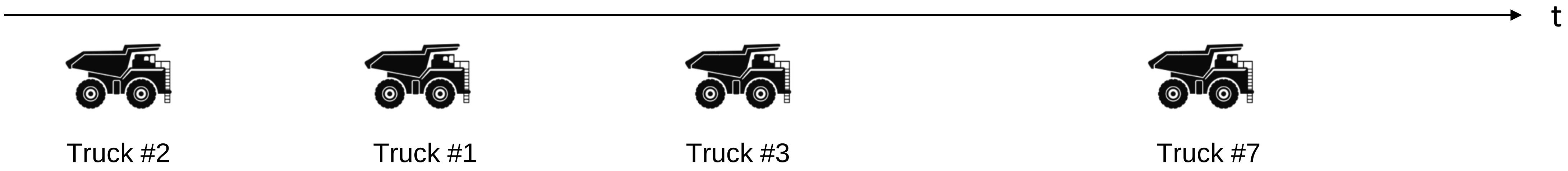
We used an integer optimization model with a rolling horizon to continuously assign the trucks to shovels and crushers

The backend was coded in **C#**

The optimization solver is **CPLEX**

The model language is in **AMPL**

Trucks ordered from the earliest to ask for an assignment to the last to ask for it



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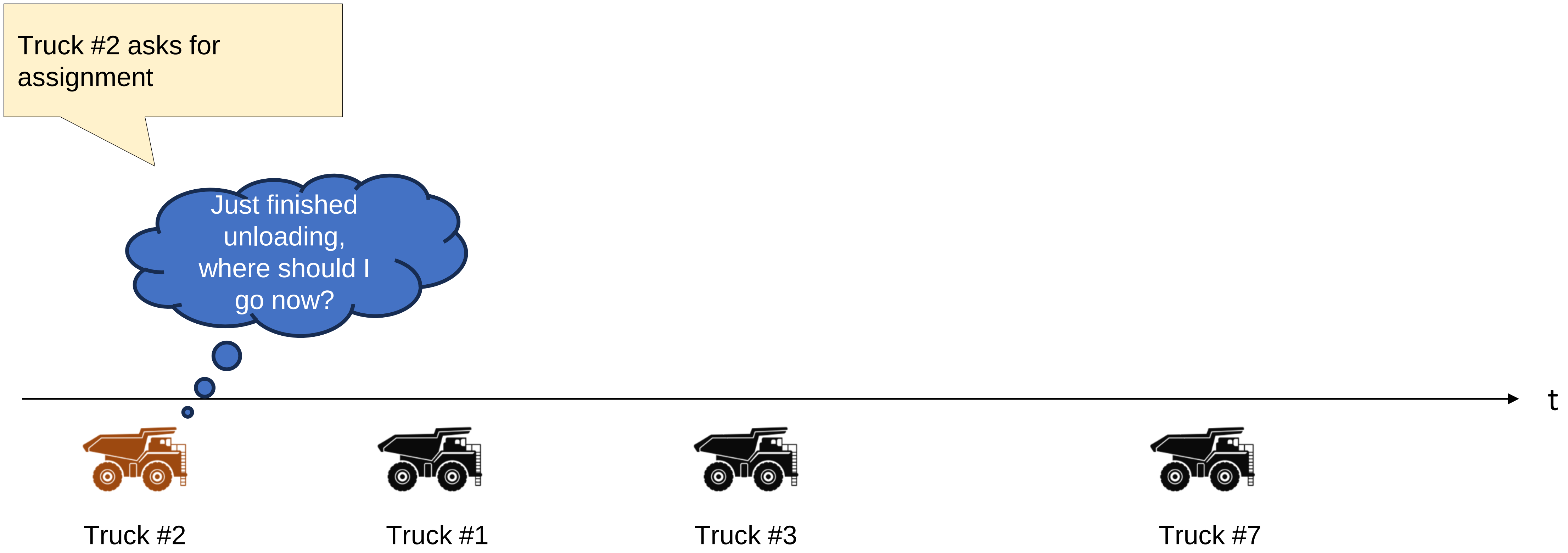

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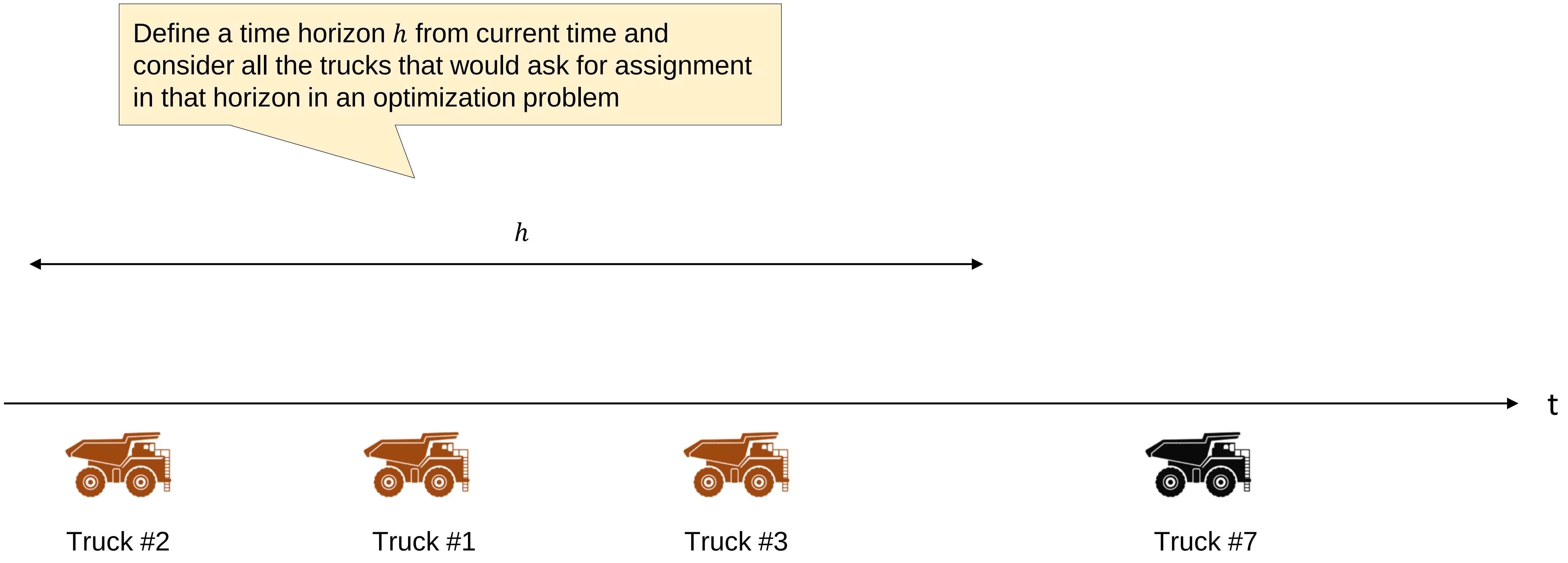

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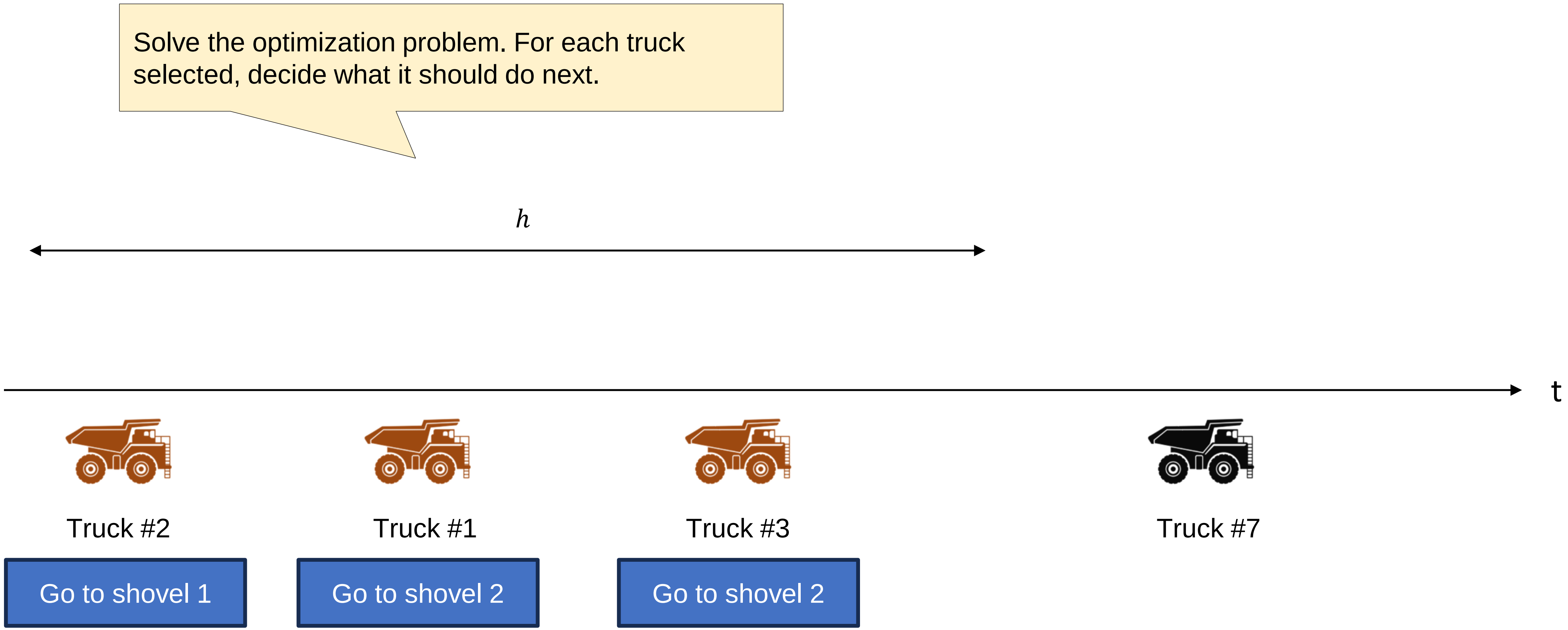

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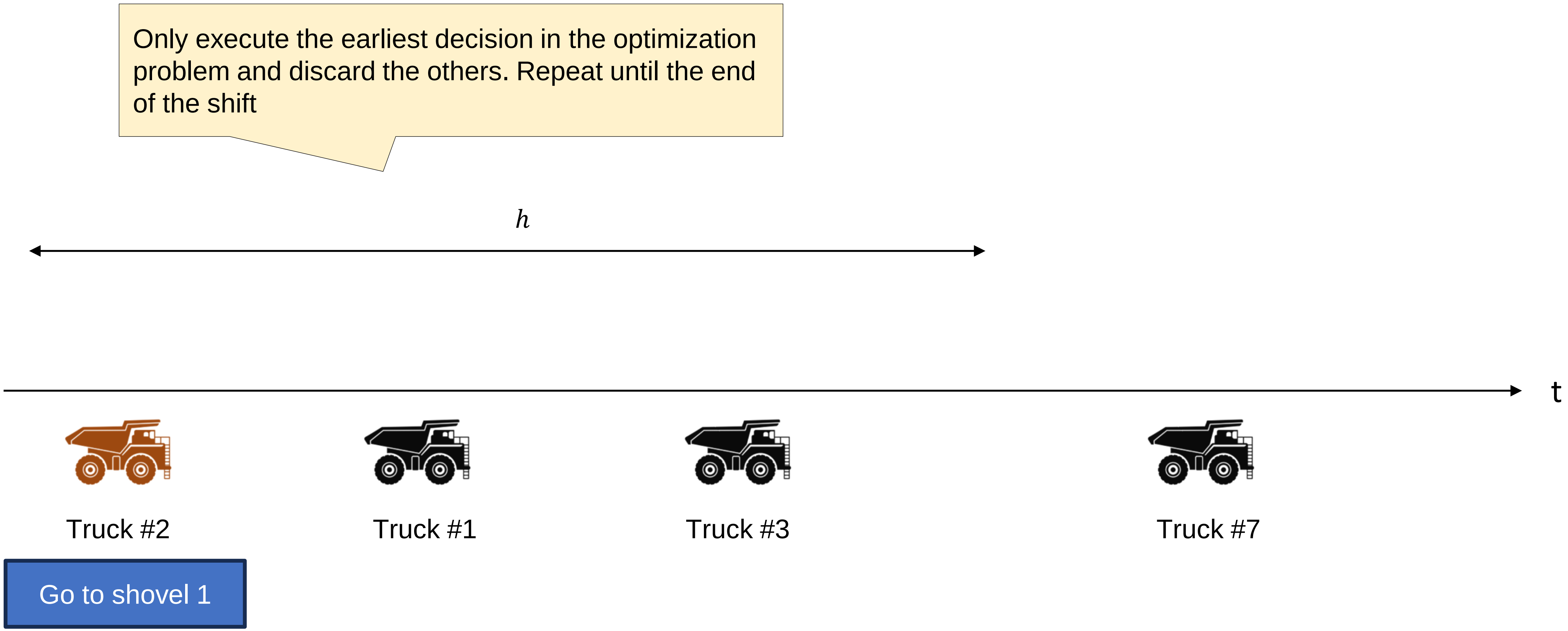

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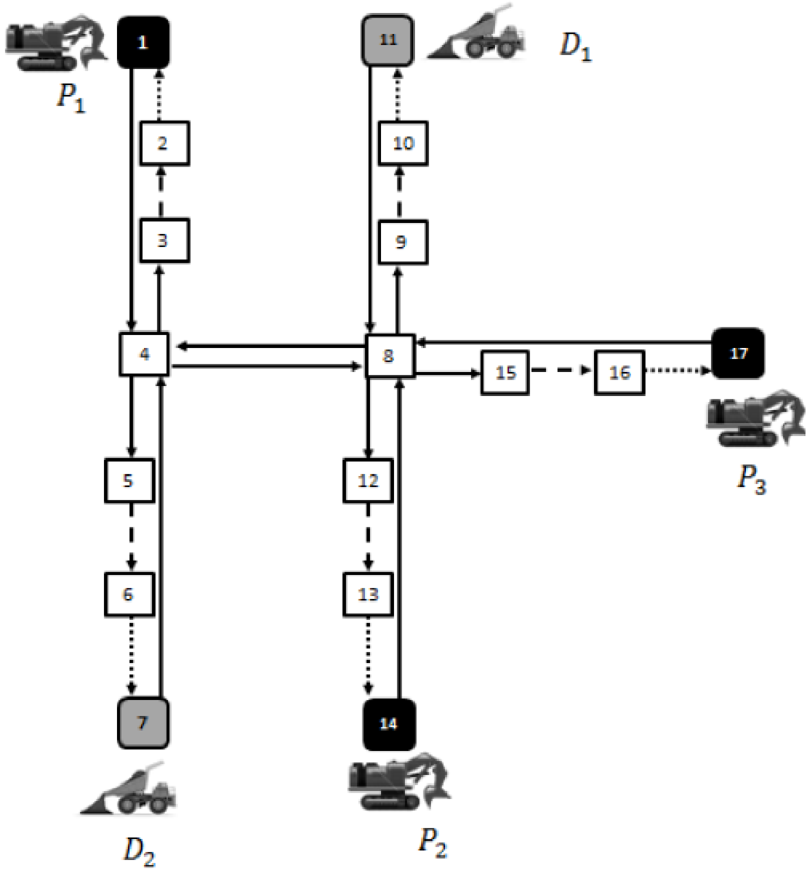
We simulated 3 scenarios for 12 hours with real data from a Chilean copper mine and compared our methodology to other heuristics

Scenario A



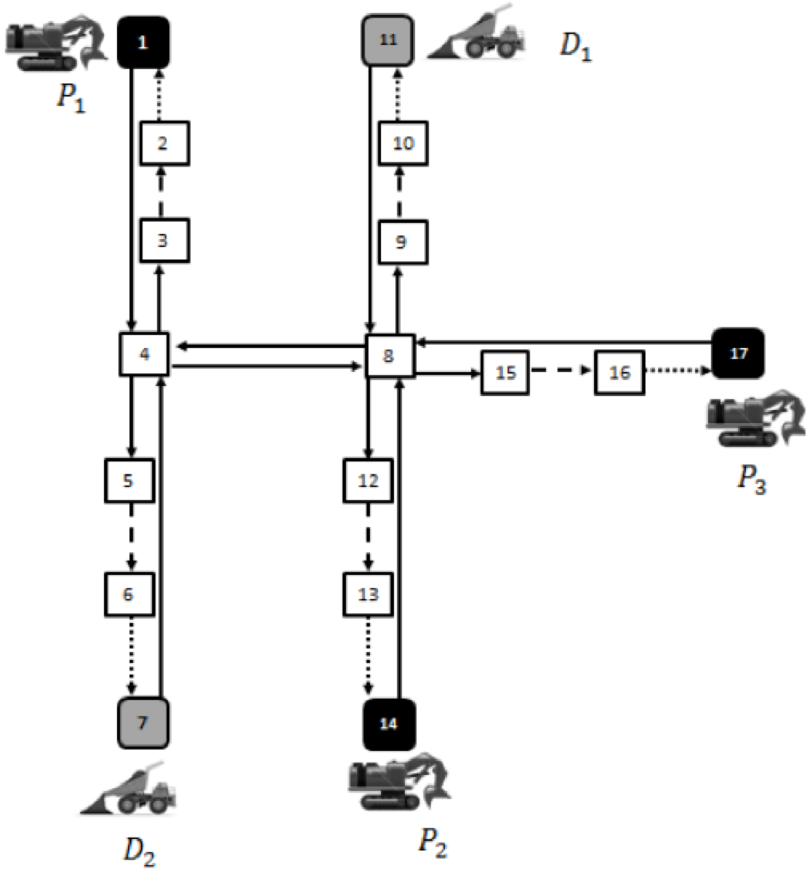
Fleet characteristics:
- Homogenous (85 ton capacity)
- 10 trucks

Ore grades
- Shovel P1 has 0.6%
- Shovel P2 has 0.5%
- Shovel P3 has 0.95%
- D1 and D2 require 0.7%

Requirements
- Move 15k ton from Shovel P1 to D1
- Move 12k ton from Shovel P2 to D2
- Move 6k ton from Shovel P3 to D1
- Move 10k ton from Shovel P3 to D2

We simulated 3 scenarios for 12 hours with real data from a Chilean copper mine and compared our methodology to other heuristics

Scenario B



Fleet characteristics:

- Heterogeneous (85 and 130 ton capacity)
- 5 and 5 trucks for each type

Ore grades

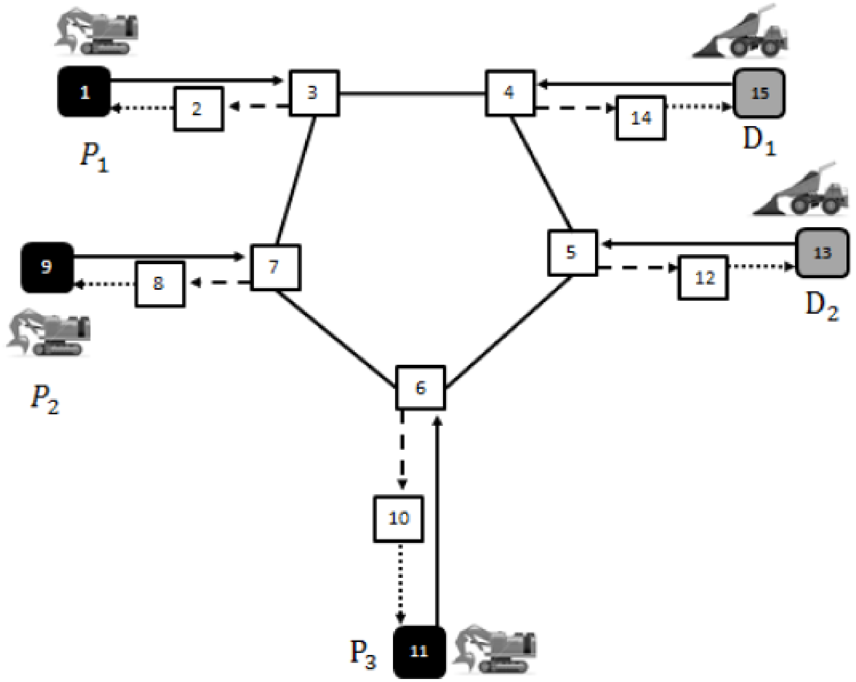
- Shovel P1 has 0.6%
- Shovel P2 has 0.5%
- Shovel P3 has 0.95%
- D1 and D2 require 0.7%

Requirements

- Move 15k ton from Shovel P1 to D1
- Move 12k ton from Shovel P2 to D2
- Move 6k ton from Shovel P3 to D1
- Move 10k ton from Shovel P3 to D2

We simulated 3 scenarios for 12 hours with real data from a Chilean copper mine and compared our methodology to other heuristics

Scenario C



Fleet characteristics:
- Heterogeneous (85 and 250 ton capacity)
- 15 and 15 trucks for each type

Ore grades
- Shovel P1 has 0.84%
- Shovel P2 has 0.53%
- Shovel P3 has 0.00%
- D1 requires 0.0%
- D1 requires 0.7%

Requirements
- Move 16k ton from Shovel P1 to D2
- Move 13k ton from Shovel P2 to D2
- Move 15k ton from Shovel P3 to D1

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Regarding the **productivity** of our methodology: we can achieve up to **+15%** more productivity than traditional heuristics

- If the scenario has more traffic congestion, we get better performance
- If the scenario has heterogenous fleet, we get better performance

Regarding the quality of **ore grade delivered**: we get up to **+5%** in less variance in the ore grade delivered

- If the scenario has more traffic congestion, we get better performance
- If the scenario has heterogenous fleet, we get better performance

Regarding the **size of the instances** solvable:

- Our method can't be used in the biggest mines in Chile yet (~200 trucks per shift) because of RAM constraints, it would have to be decomposed to reduce the RAM consumption
- Our method could be relatively slow compared to heuristics (hopefully in the future better hardware can help!)

Regarding **what's left for the model to** be used in practice:

- We should incorporate stochasticity somehow, currently our method works in a purely deterministic environment.