Challenges in Multilevel Supply Chain Optimization

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Carnegie Mellon University
Enterprise Wide-Optimization Seminar
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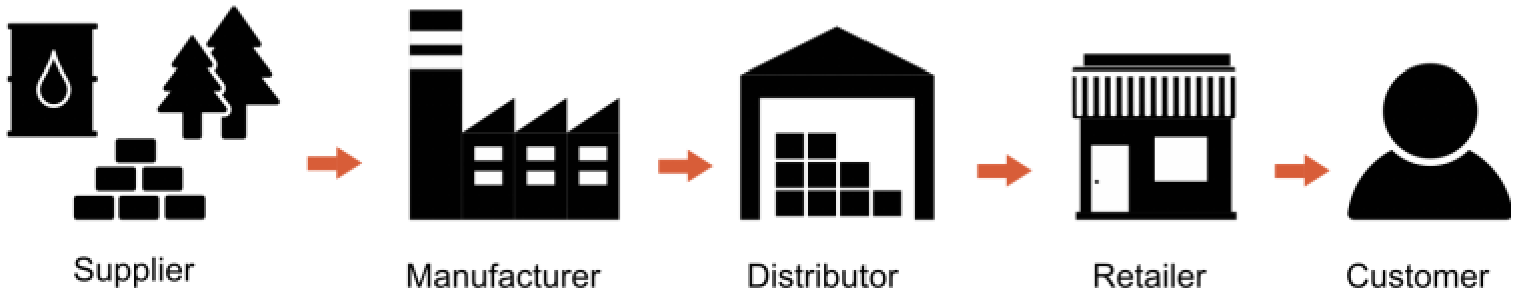
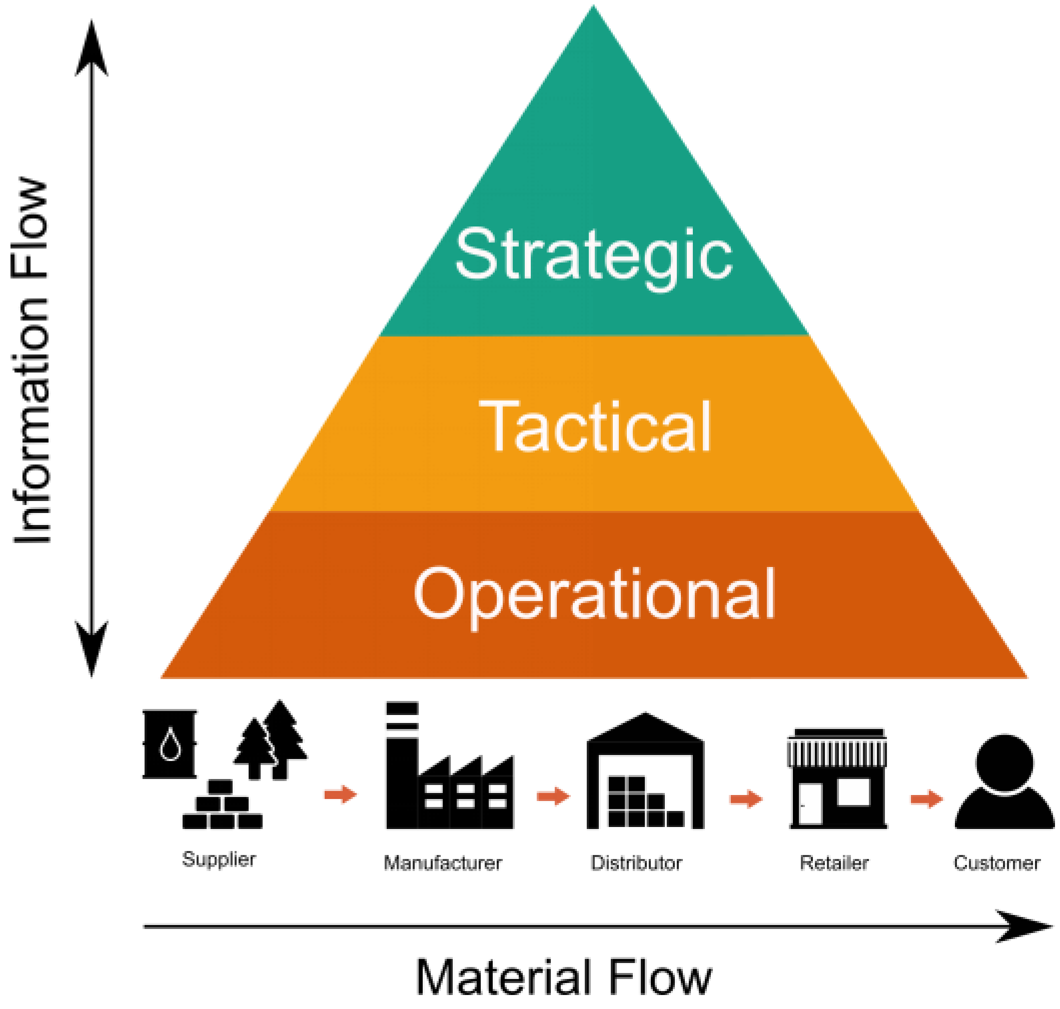
Supply Chain



Objective:

- Make complex decisions to provide finished goods in the right **amount**, at the right **time**, and with the required **quality**

Decision Hierarchy



Decisions are hierarchically organized

- Different time scales
- Different scopes
- Different (conflicting) objectives

The Goal of Integrated Decision-Making

Enterprise Wide-Optimization (Grossmann, 2005)

End-to-End Optimization

Expectation

Reality

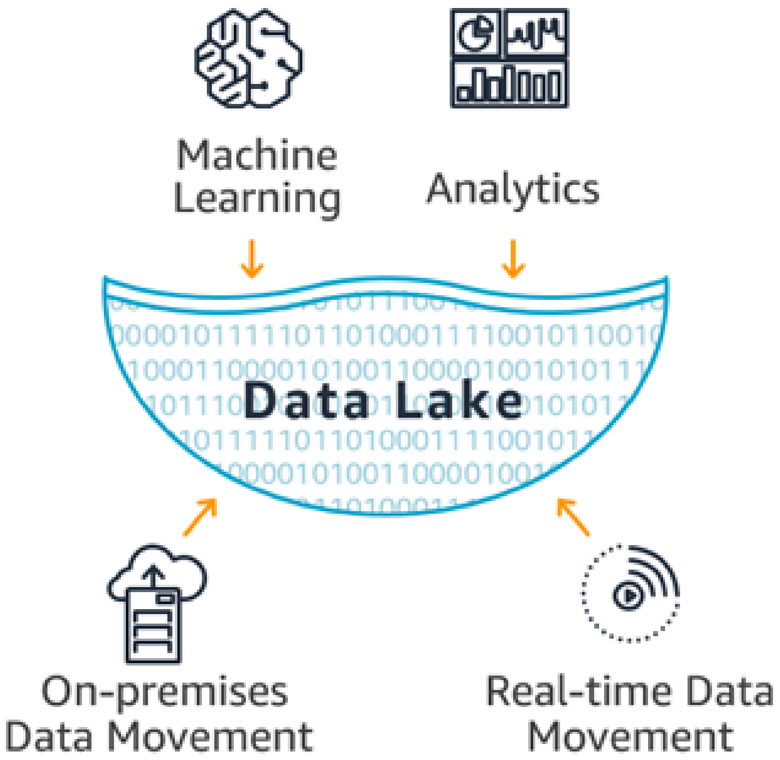
Challenges

1. Data

Data lives in different systems. Not straightforward to combine

Plan:
Let's put everyone in the same system. Standardize and then optimize

Sounds like a good plan?



Challenges

2. Different Objectives and Incentives

My success depends on my KPI

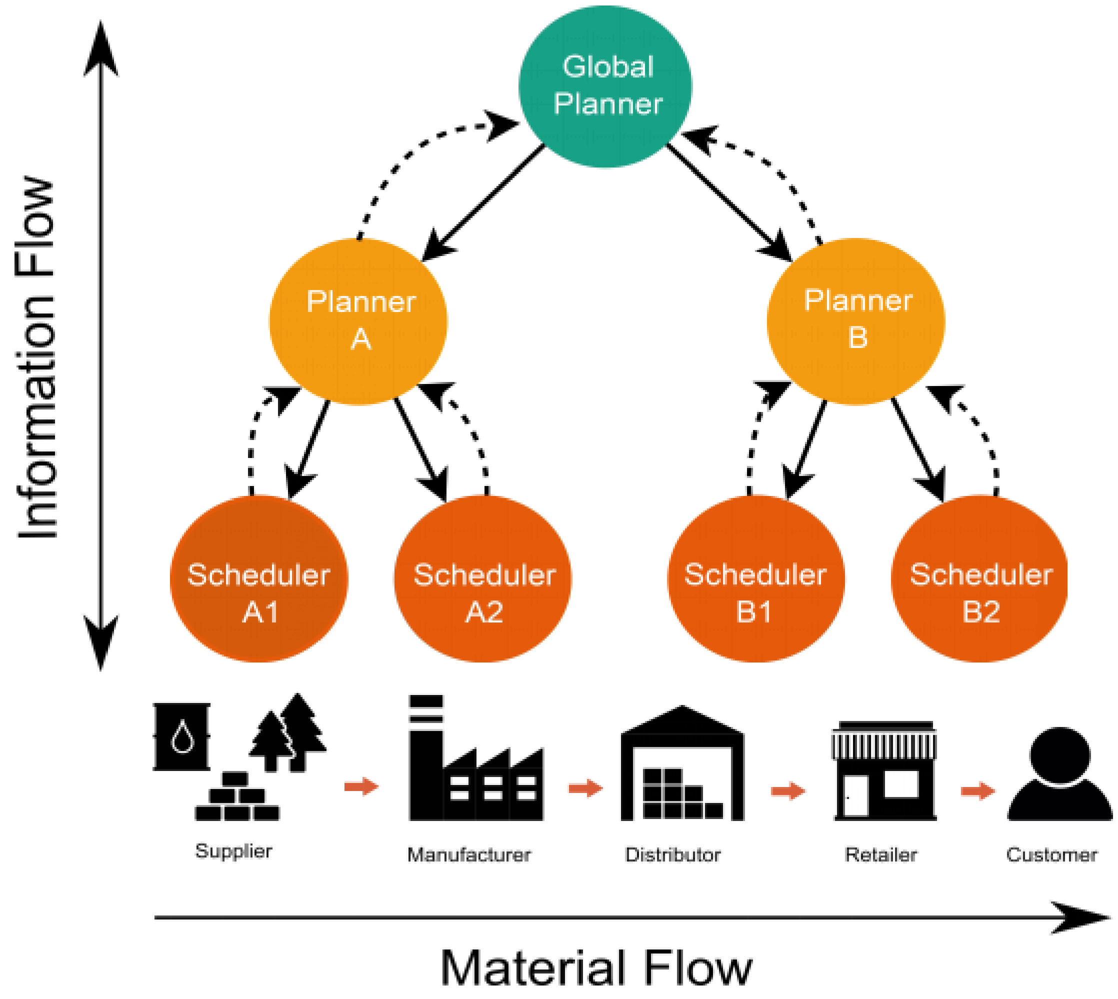
My success depends on my KPI

Challenges

2. Different Systems

As long as the inputs and outputs are correctly connected, the system does not matter

The Decision Network

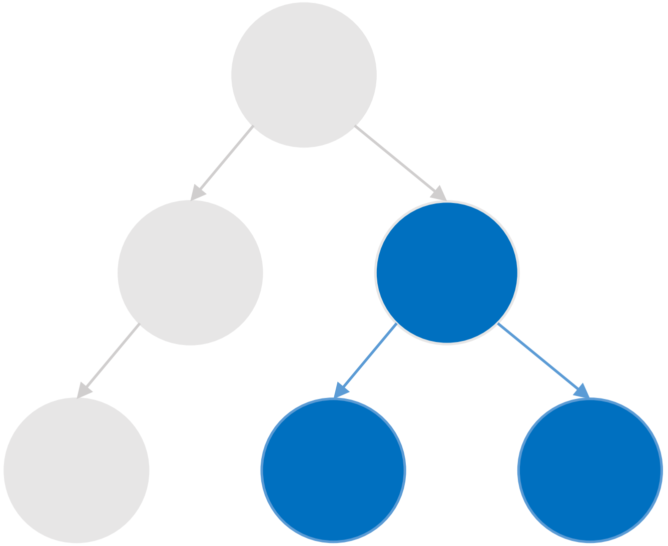


A decision network is a group of people making decisions and exchanging information

Questions:

1. What is the right model for each node?
2. How to effectively coordinate the entire network?

Novel Approaches for the Integration of Planning and Scheduling

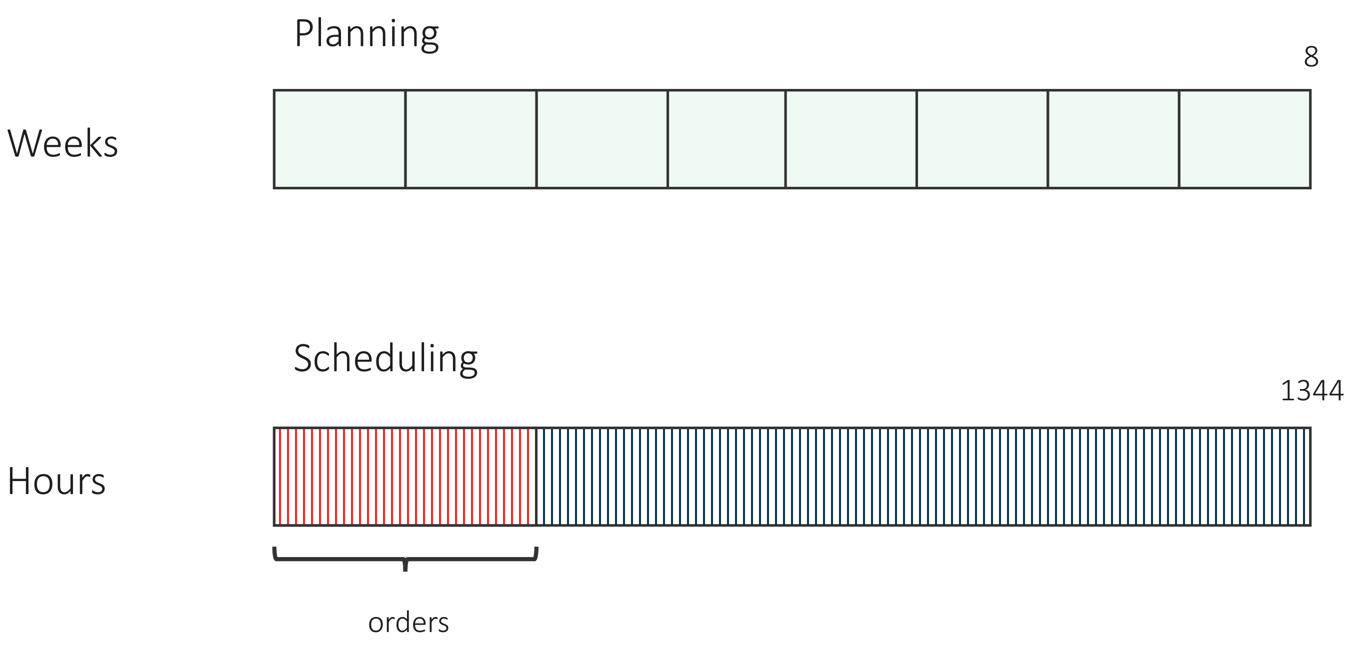


Integration of Tactical and Operation Levels:
Planning and Scheduling

Maravelias, C.T. and Sung, C., 2009. Integration of production planning and scheduling: Overview, challenges and opportunities. *Computers & Chemical Engineering*, *33*(12), pp.1919-1930.

Assumption 1

Planning and Scheduling must be solved in the same optimization horizon



Issues:

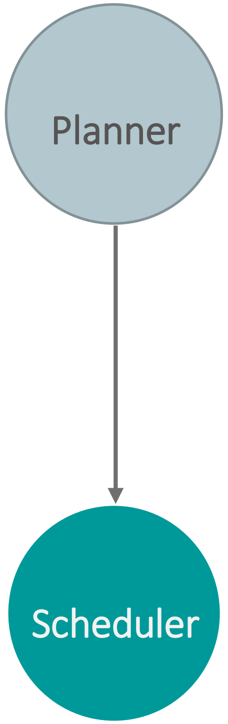
1. It is assumed that both problems need to be solved in the same horizon
   - Very large scheduling problem (Intractable)

2. There is not enough information to solve the scheduling in detail
   - Orders available for short term
   - Representative period approaches

Assumption 2

Communication is done

through production targets



Assumption:
Production Targets
Inventory Targets

Alternative:
Inventory Policiy

Project Goals

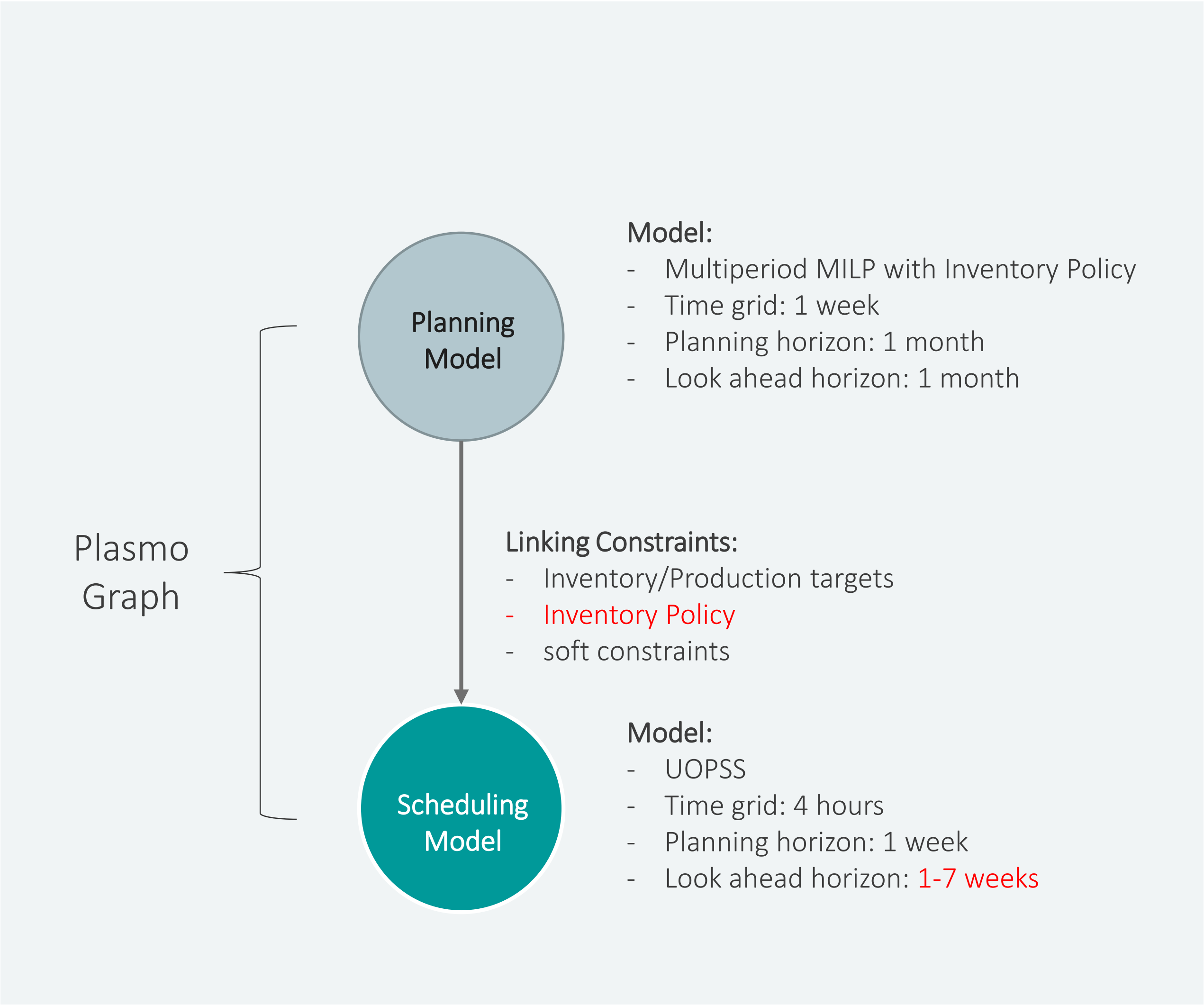
Investigate the impact on integrated planning and scheduling of:

1. Scheduling horizon
2. Communication through inventory policies

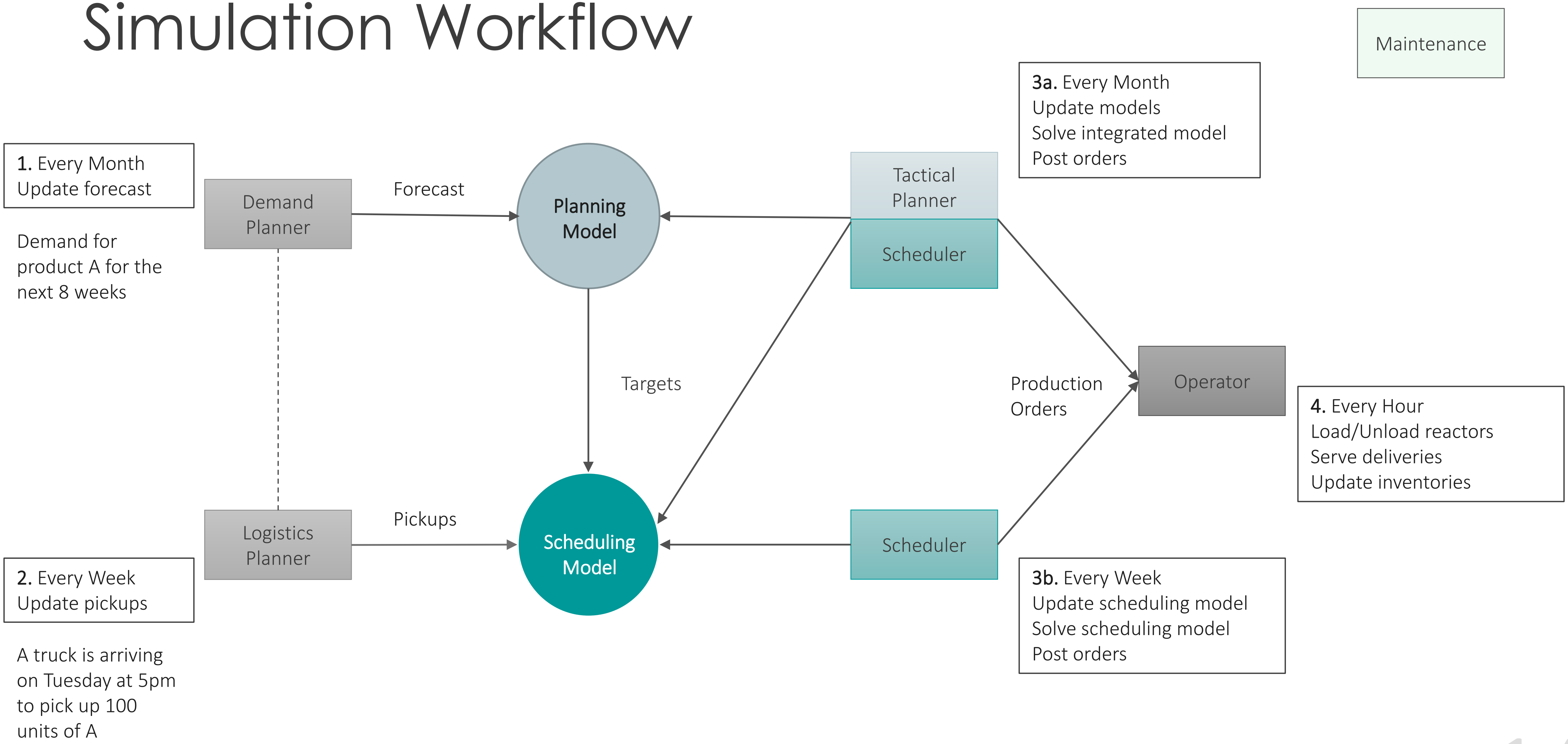
Using Simulation

Simulation Framework

- Decision Agents run optimization models
- 1 year of simulation, hourly events
- Uncertain:
  - Forecast
  - Pick up times
  - Equipment breakdowns



Simulation Workflow



Planning Model

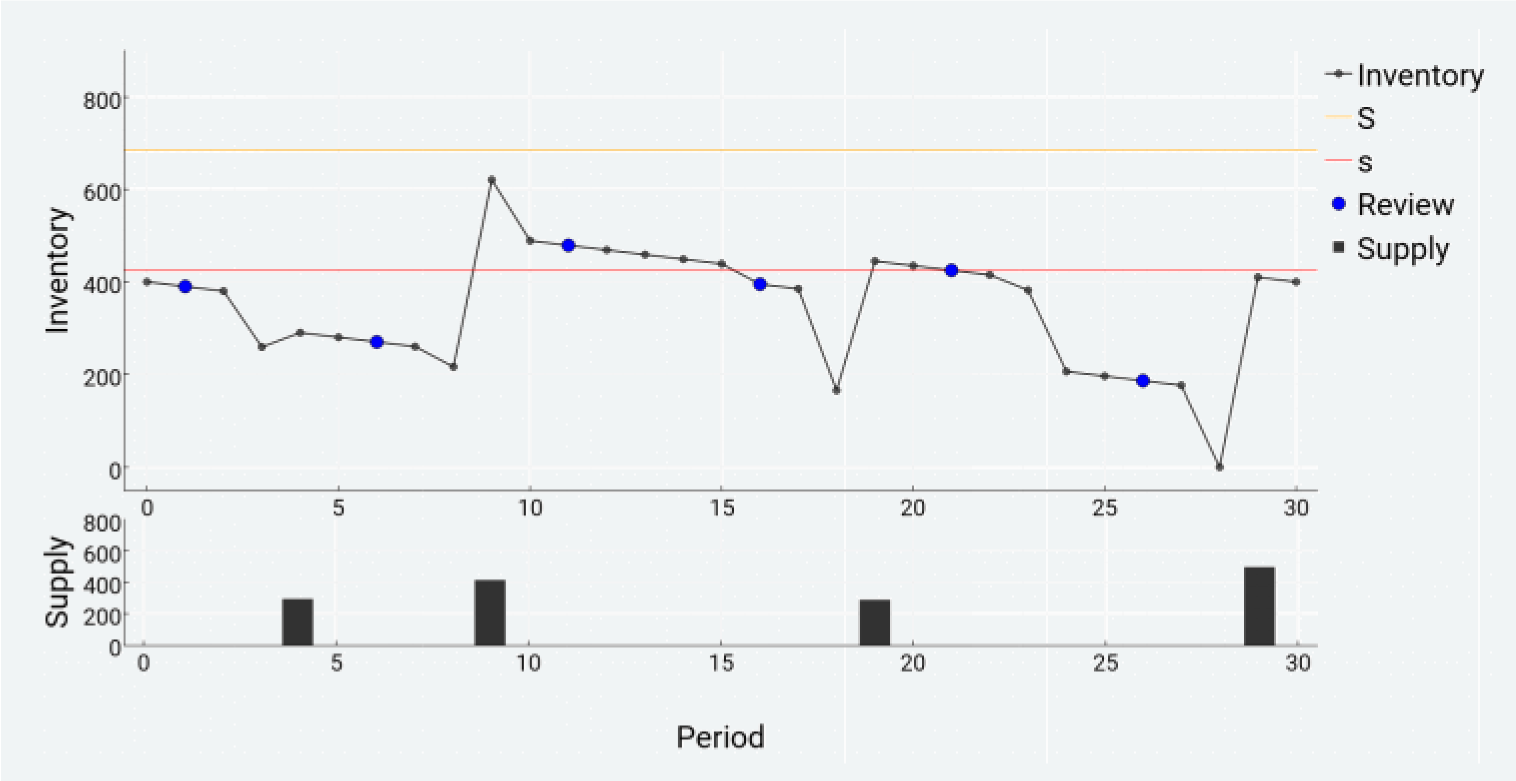
$$Max \quad Revenue - Transportation - Inventory$$

$$s.t. \quad \sum_j f_{jkpt} + rd_{kpt} = D_{kpt} \qquad \forall kpt$$

$$inv_{jpt} = inv_{jpt-1} + x_{jpt} - \sum_k f_{jkpt} \qquad \forall jpt$$

s,S Inventory Policy

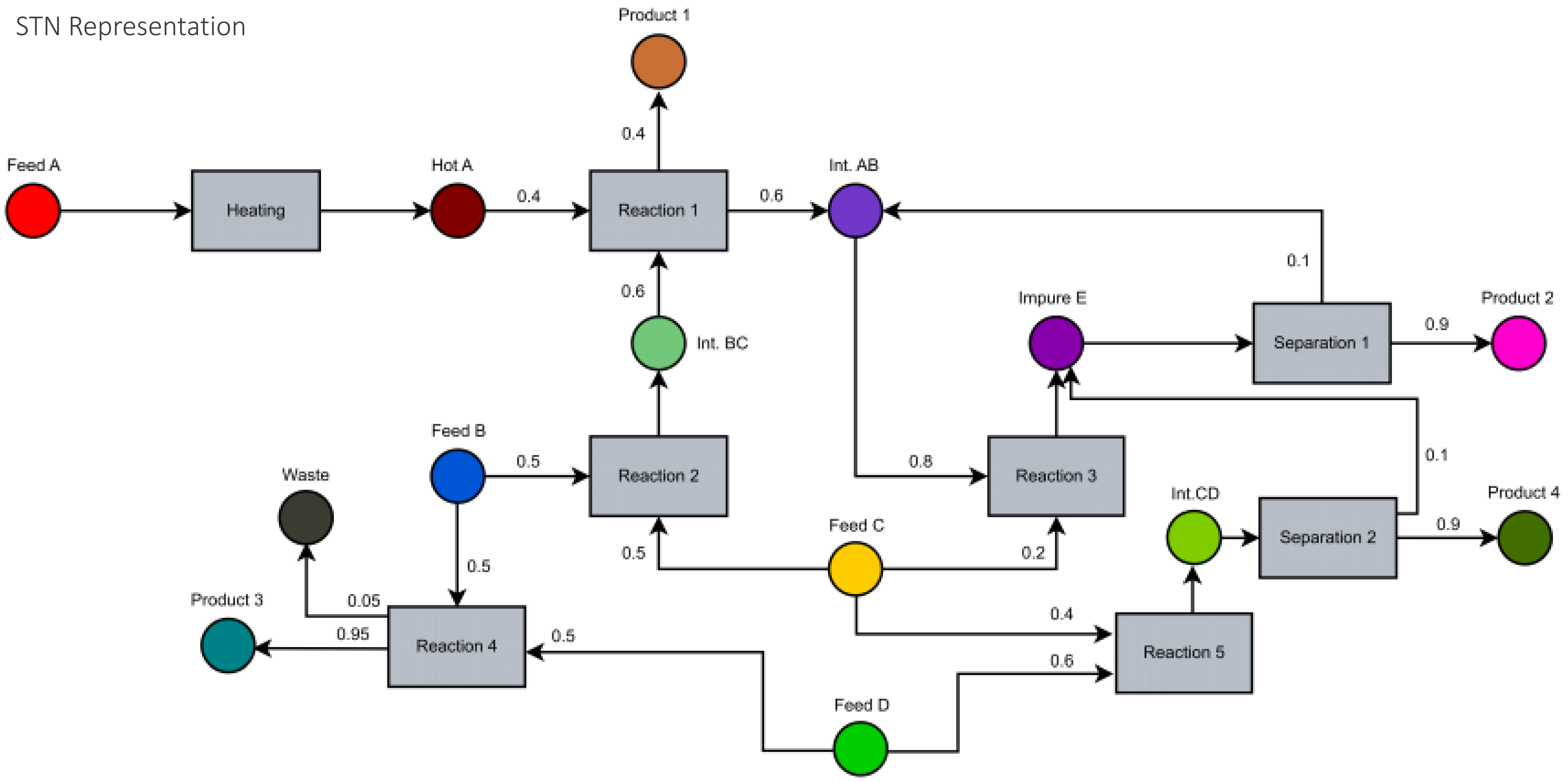
rd: Planner can redirect demand for a lesser profit



Brunaud, B., Laınez-Aguirre, J.M., Pinto, J.M. and Grossmann, I.E., 2018. Inventory Policies and Safety Stock Optimization for Supply Chain Planning. AICHE Journal.

Scheduling Model

STN Representation



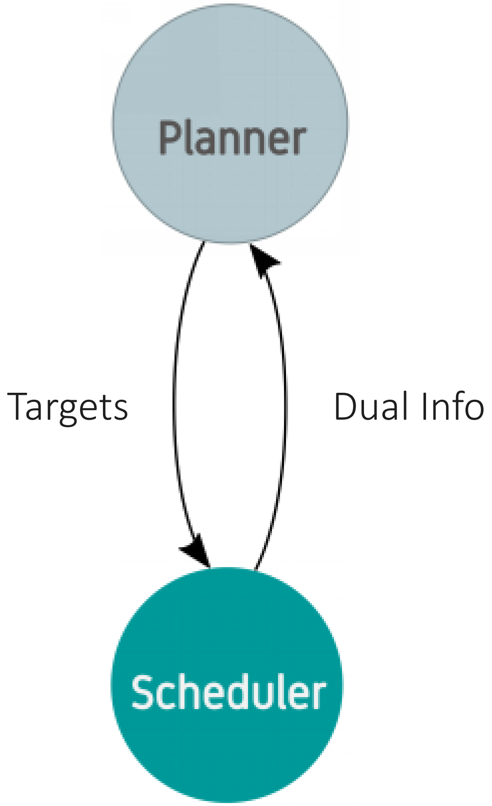
UOPSS Model

Extension of Kondili example

Time-based backlog penalty

Why to integrate Planning and Scheduling?

Effect of number of iterations between planners and schedulers



Benders Decomposition

- Master passes targets
- Subproblem responds with dual information

Out implementation

- Multilevel cross decomposition
- Subproblem convexification with lift-and-project cuts

PLASMO ALGORITHMS

Iterations

1	No iteration. The scheduler takes the instruction from the planner
5	Several iterations between planner and scheduler to improve the solution
Inf	Iterate until convergence

Why to integrate Planning and Scheduling?

(Scheduling Capacity = 800)

Can you do 1000 tons of A this week?

Planner

Totally!

(I think so. I'll try)

Traditional Scheduler

ITERATIONS: 1

Why to integrate Planning and Scheduling?

(Scheduling Capacity = 800)

Can you do 1000 tons of A this week?

Planner

No

PSE Enabled Scheduler

ITERATIONS: 5

Why to integrate Planning and Scheduling?

(Scheduling Capacity = 800)

Can you do ~~1000~~ tons of A this week? 900

Planner

After a few iterations . . .

No

PSE Enabled Scheduler

ITERATIONS: 5

Why to integrate Planning and Scheduling?

(Scheduling Capacity = 800)

You are doing 820

Planner

Ok

PSE Enabled Scheduler

ITERATIONS: 5

Why to integrate Planning and Scheduling?

(Scheduling Capacity = 800)

After 52 iterations I suggest a production amount of 800 units of A

Ok

Planner

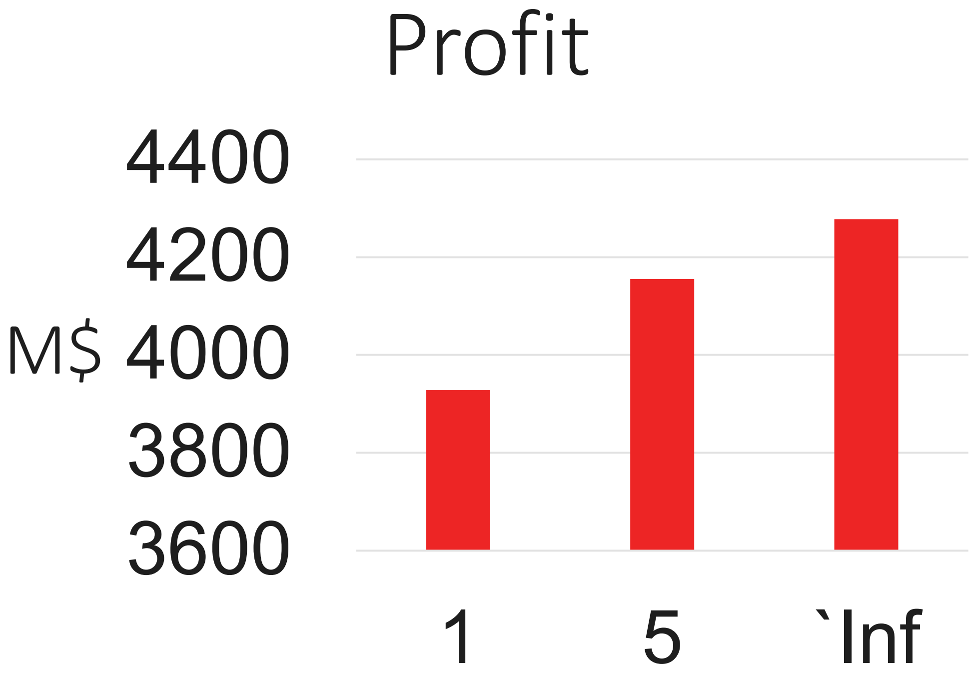
Ok

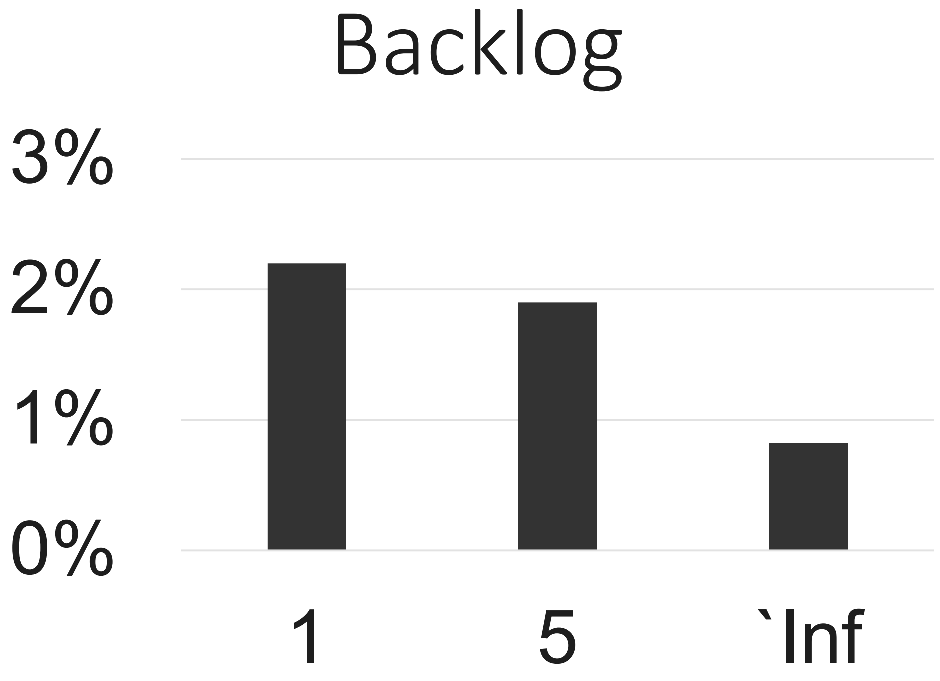
Scheduler

ITERATIONS: Inf

IPSM : Integrated Planning & Scheduling Model

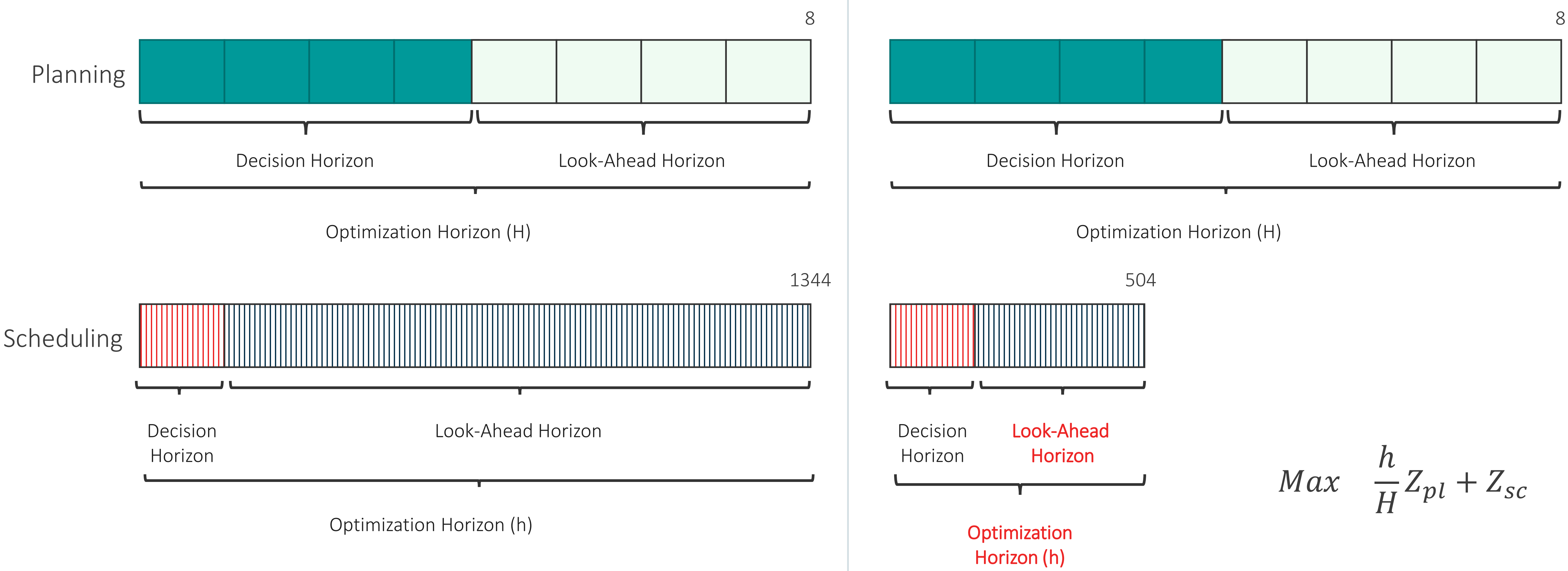
Effect of the Number of Iterations





More communication between planners and schedulers allows to improve the benefit

Effect of Scheduling Look-Ahead Horizon

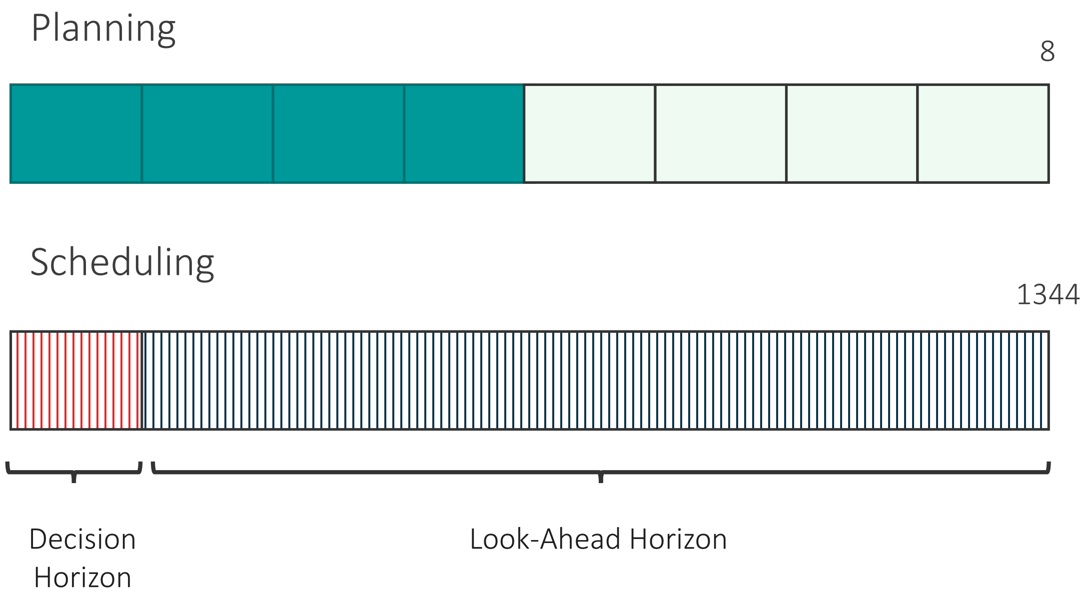


$$Max \quad Z_{pl} + Z_{sc}$$

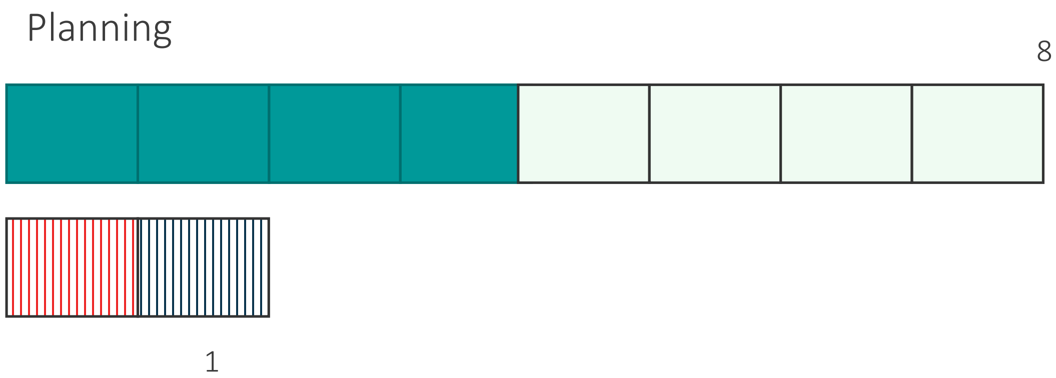
$$Max \quad \frac{h}{H} Z_{pl} + Z_{sc}$$

Effect of Scheduling Look-Ahead Horizon

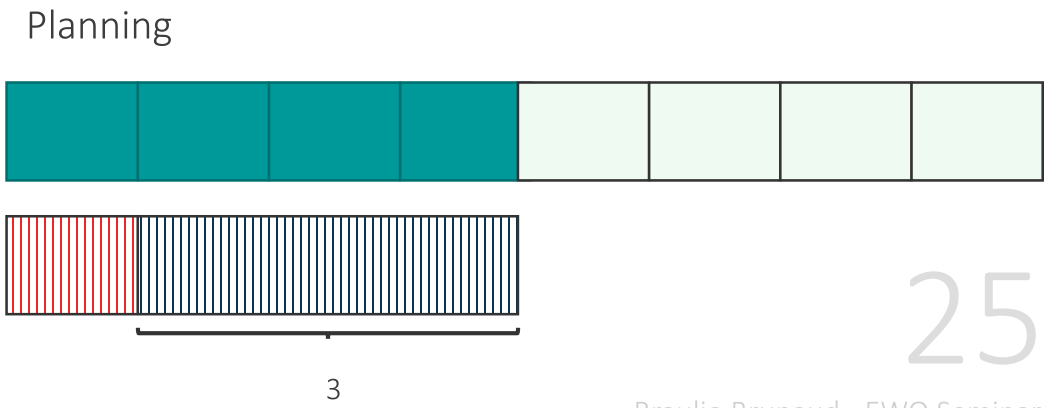
Baseline



Look-Ahead 1 week (LA1)



Look-Ahead 3 weeks (LA3)

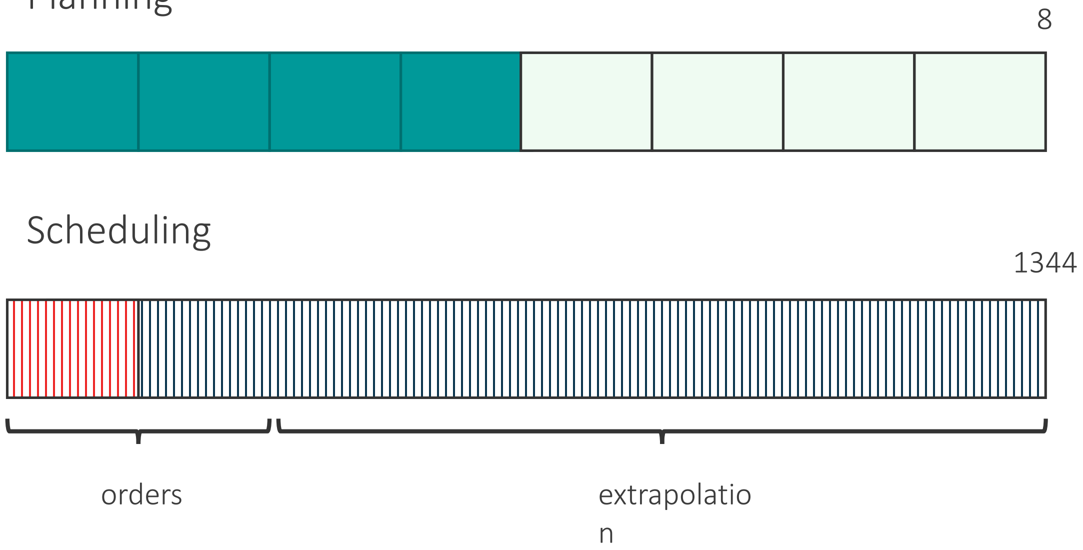


Effect of Scheduling Look-Ahead Horizon

Baseline

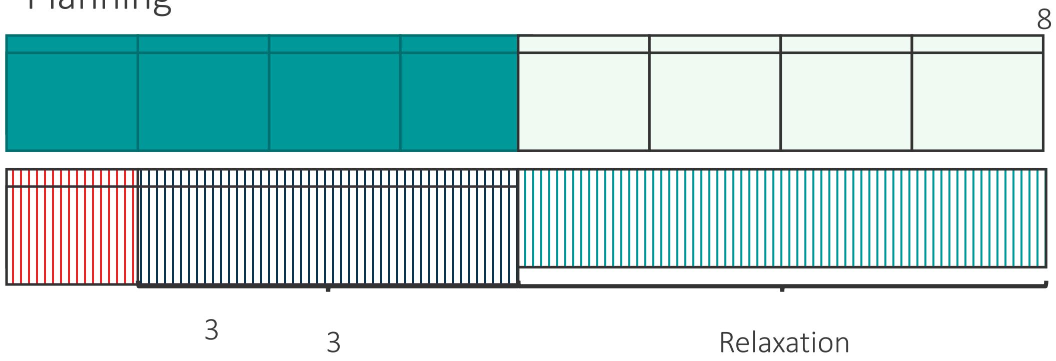
Planning

Scheduling

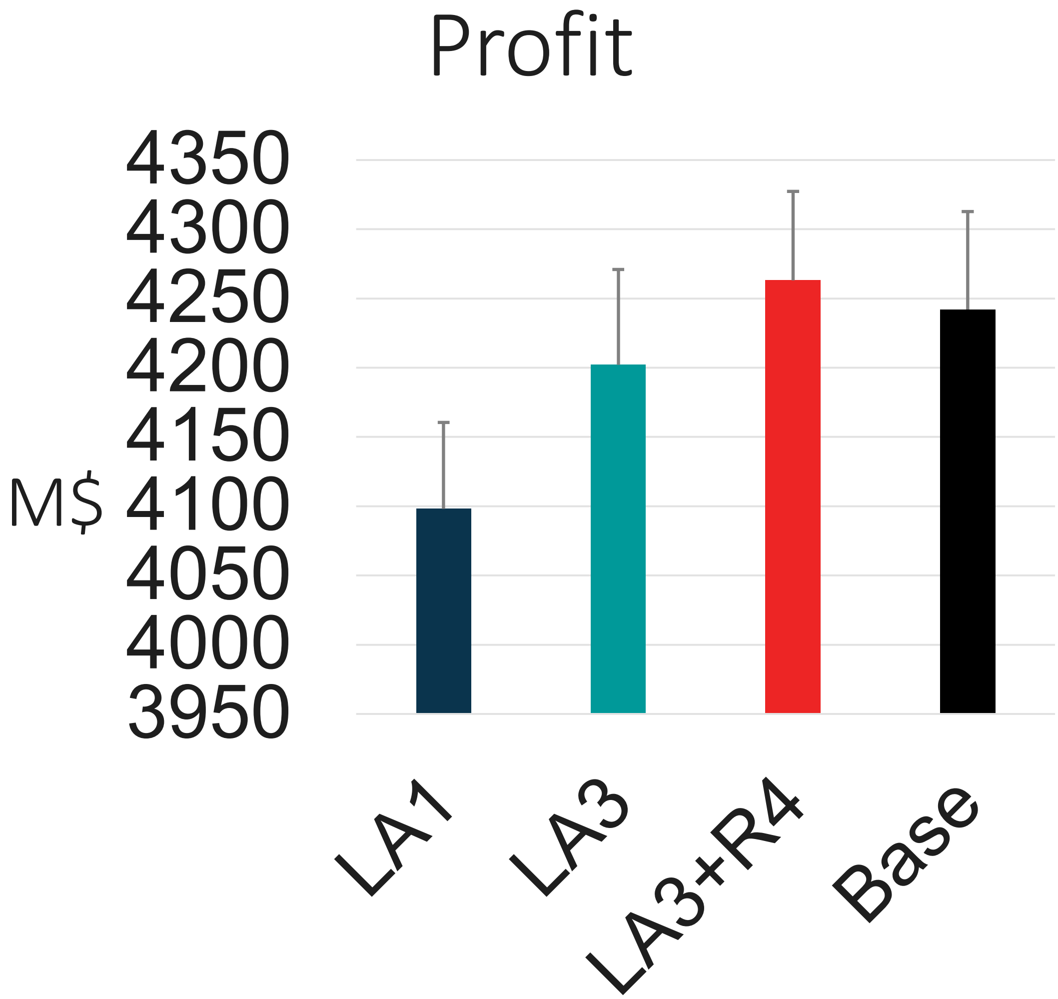


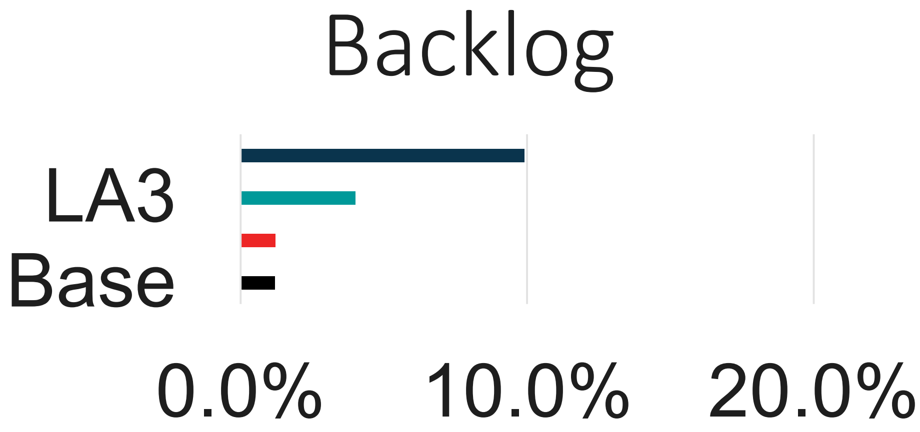
Look-Ahead 3 weeks + 4 weeks relaxation (LA3+R4)
Look-Ahead 3 weeks (LA3)

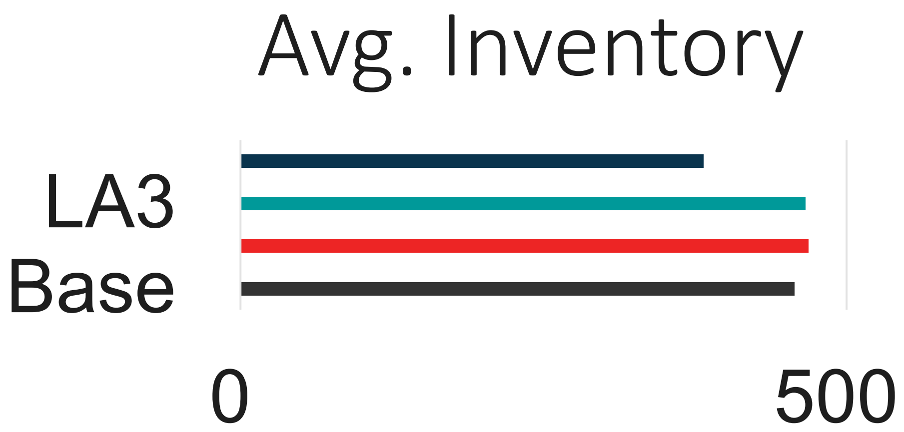
Planning
Planning



Effect of Scheduling Look-Ahead Horizon





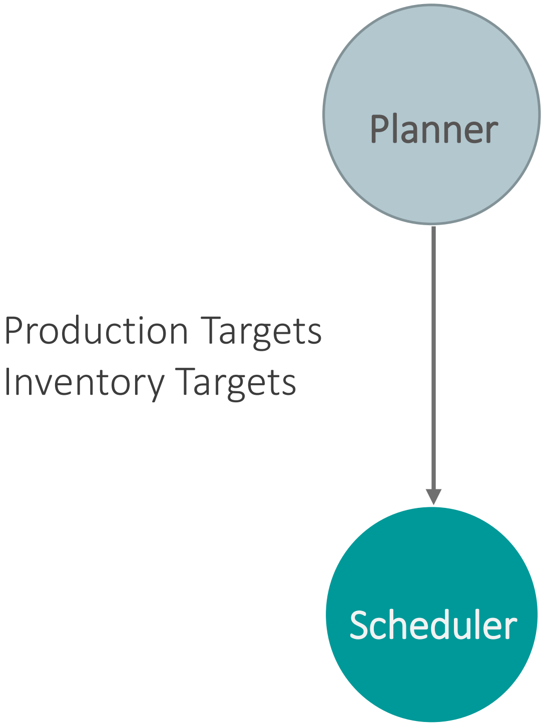


LA: Look-Ahead

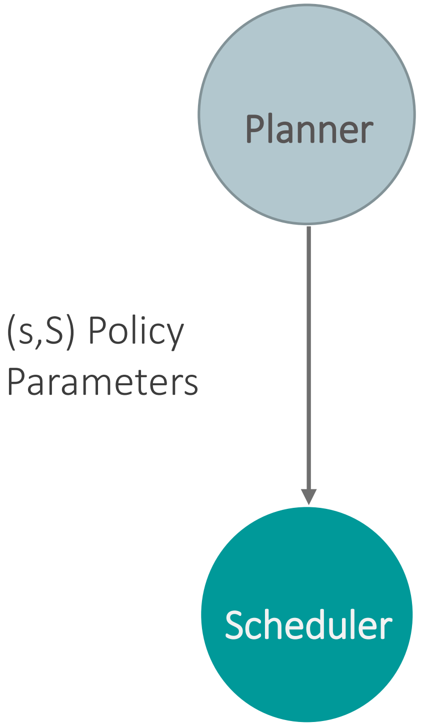
R: Relaxation

Effect of Communication Variables

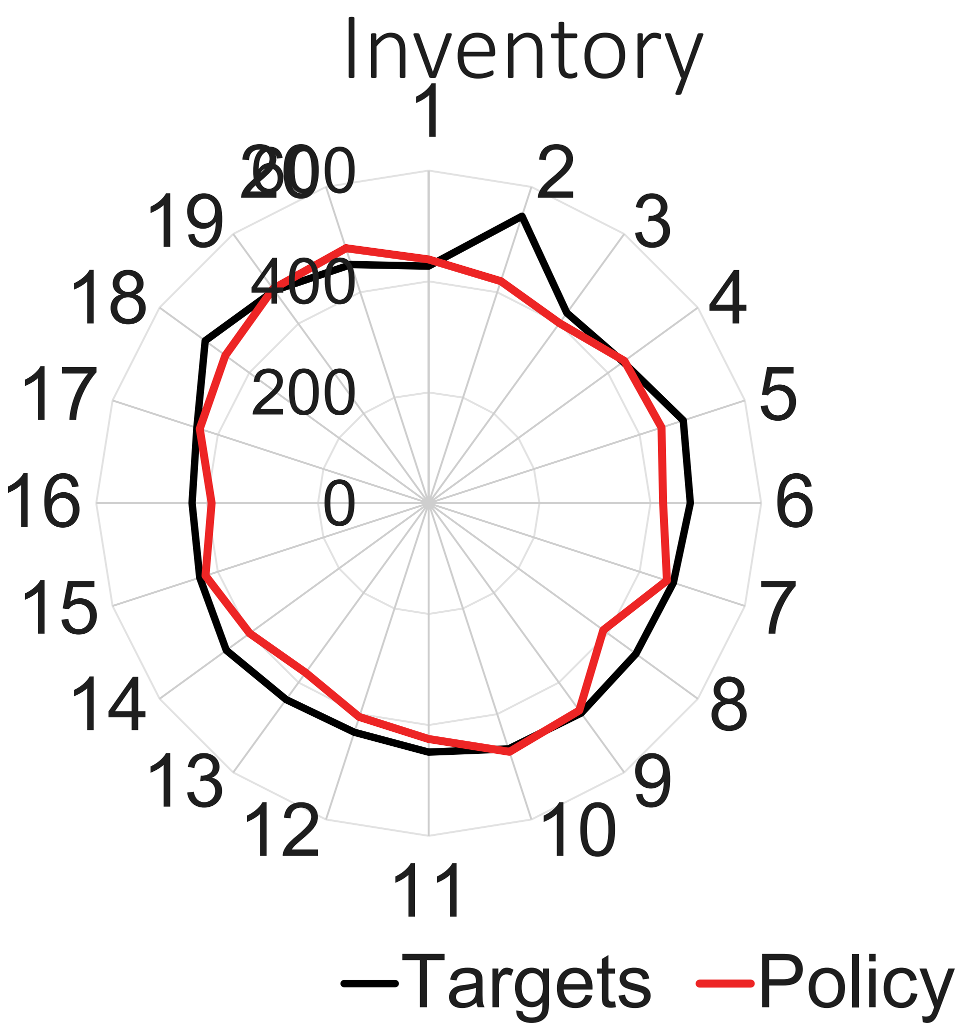
Targets

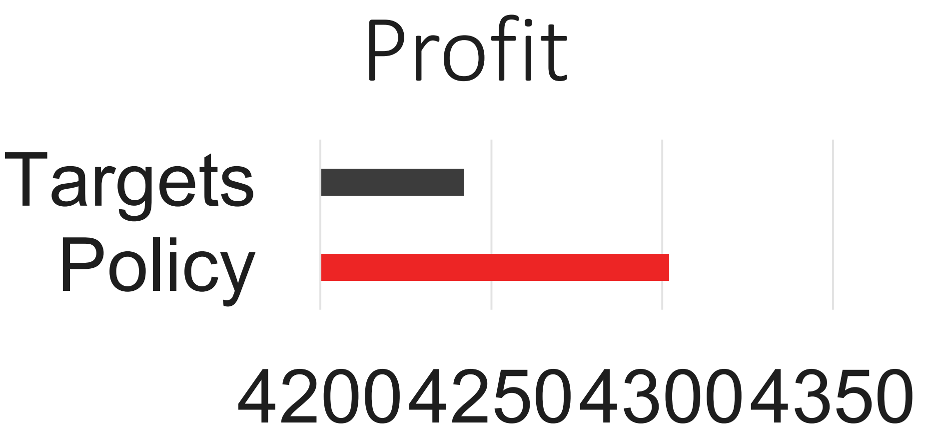


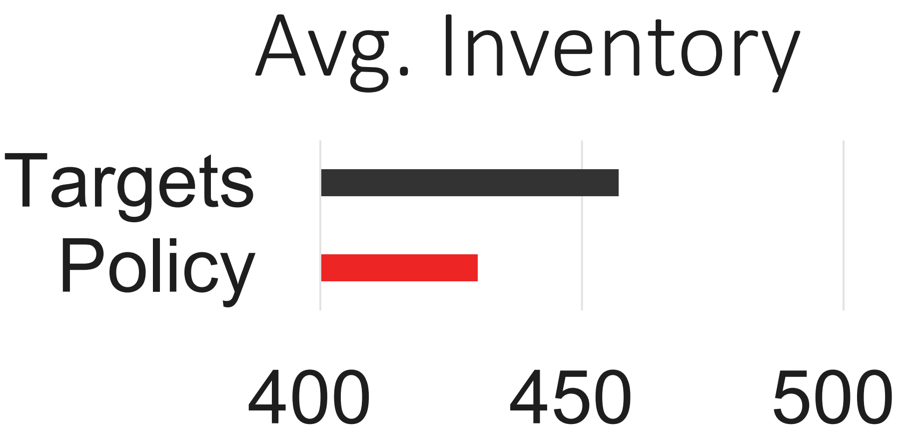
Policy



Effect of Communication Variables





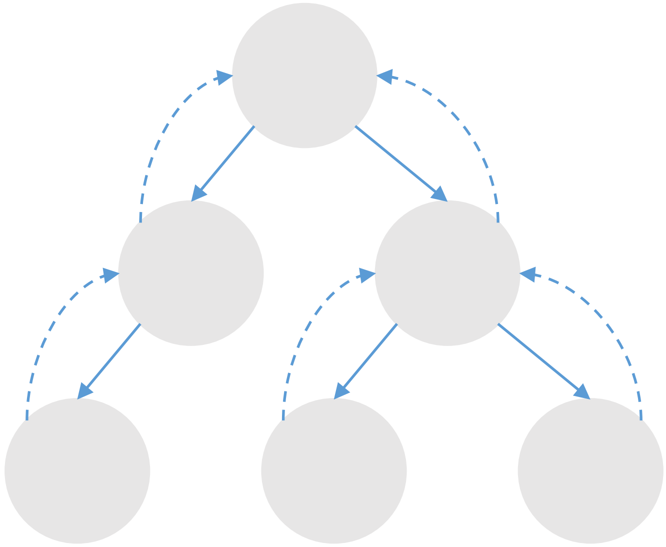


Remarks

1. A simulation framework to evaluate integrated planning and scheduling models was developed
2. Communication through inventory policies leads to lower inventories and larger profits
3. Considering a shorter scheduling horizon does not affect the profit or service level, as long as the planning decision horizon is fully covered

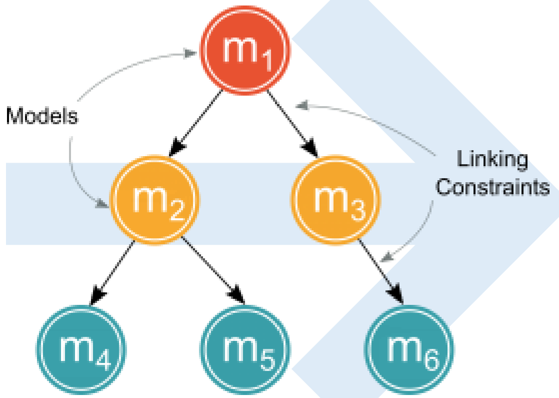
PlasmoAlgorithms
Decomposition Made Easy

Multilevel Coordination:



PlasmoAlgorithms

Generate Graph



Solve

solve(graph)
lagrangesolve(graph, options)
bendersolve(graph, options)
crosssolve(graph, options)

Collect Results

Solution Object

- Objective
- Bounds
- Time
- Iteration Details

Implementations

Lagrange

- Applicable to any graph
- Several multiplier update methods
- Custom heuristics

Benders

- Multilevel
- Multicut
- Single-pass workflow

Cross

- Multilevel
- Uses the included Benders and Lagrange implementations

How easy is it?

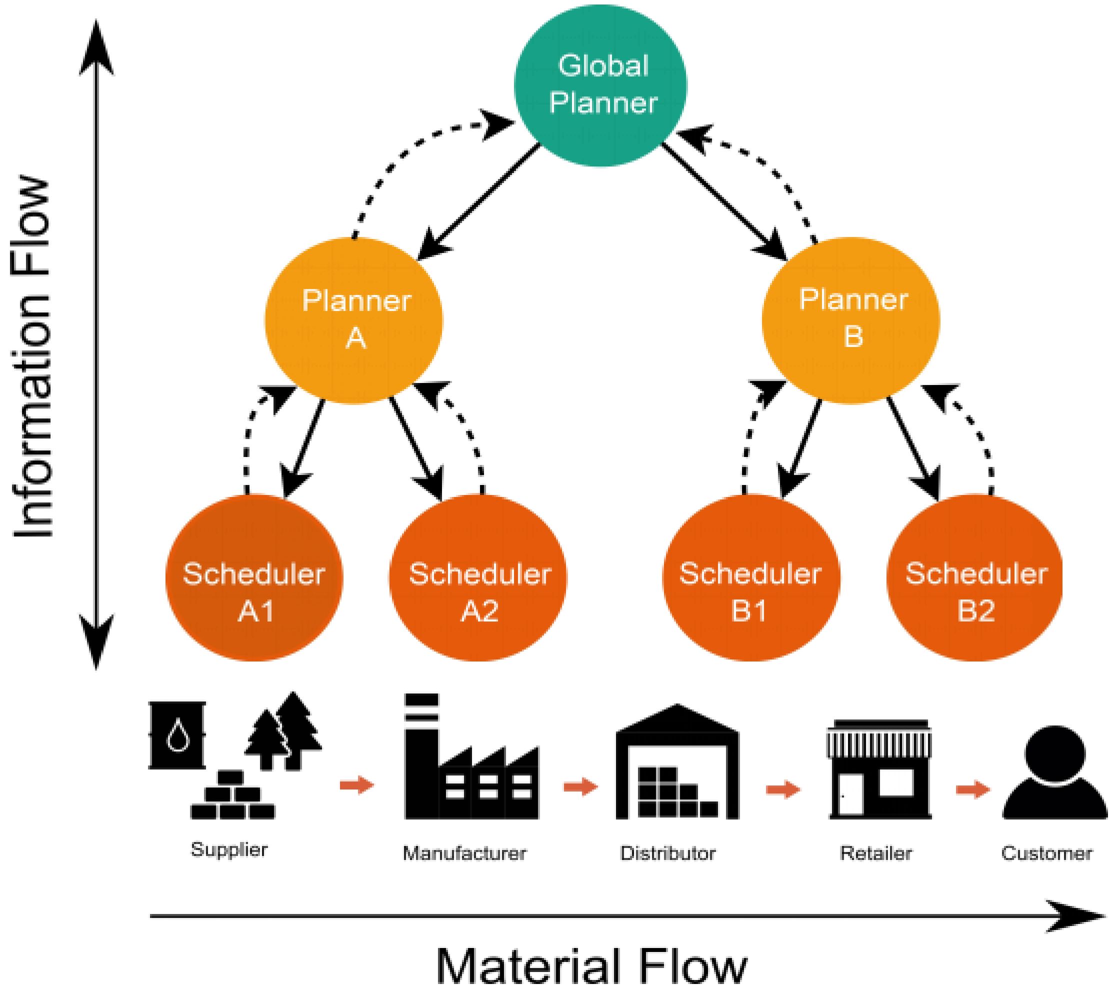
```
# Define Plasmo Graph
g = ModelGraph()
n1 = add_node(g)
setmodel(n1, mp)
n2 = add_node(g)
setmodel(n2, sp)

#Set n2 as a child node of n1
edge = add_edge(g, n1, n2)

## Linking constraints between MP and SP
@linkconstraint(g, n1[:y] == n2[:y])

# Solve
sol = bendersolve(g, max_iterations=5)
```

Future Research Directions



1. Supply Chain Control
2. Model-based Design of Organizational Structures
3. Modeling and Optimization of Transactional Processes
4. Combining Reinforcement Learning and Optimization

Our mission is not to replace our colleagues with machines, but to help them make better decisions aided by computers

Thank you!

Ignacio E. Grossmann, John Wassick, Scott Bury, Satya Amaran, Yisu Nie, Anshul Agarwal, Jose Pinto, José Miguel Lainez, Inmaculada Ortiz, Maria Yañez, Alfredo Ortiz, Alisandra Welch, Can Li, and María Paz Ochoa