SOLVING PRODUCTION PLANING PROBLEMS WHEN SETUPS ARE SEQUENCE DEPENDENT

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AGENDA

1. THE CHALLENGE

- Two-Stage Production Environments
- Production Planning Systems
- Motivation
- Problem Description

2. THE METHODOLOGY

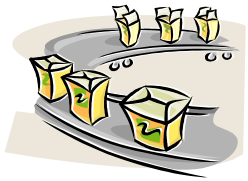
- Models for Sequencing
- Price-and-MIP

3. THE IMPACT

- Results
- Conclusions

1. THE CHALLENGE

TWO-STAGE PRODUCTION ENVIRONMENT



1st Stage

Continuous or batch production of a common resource

Resource

2nd Stage

Discrete production of items on parallel resources

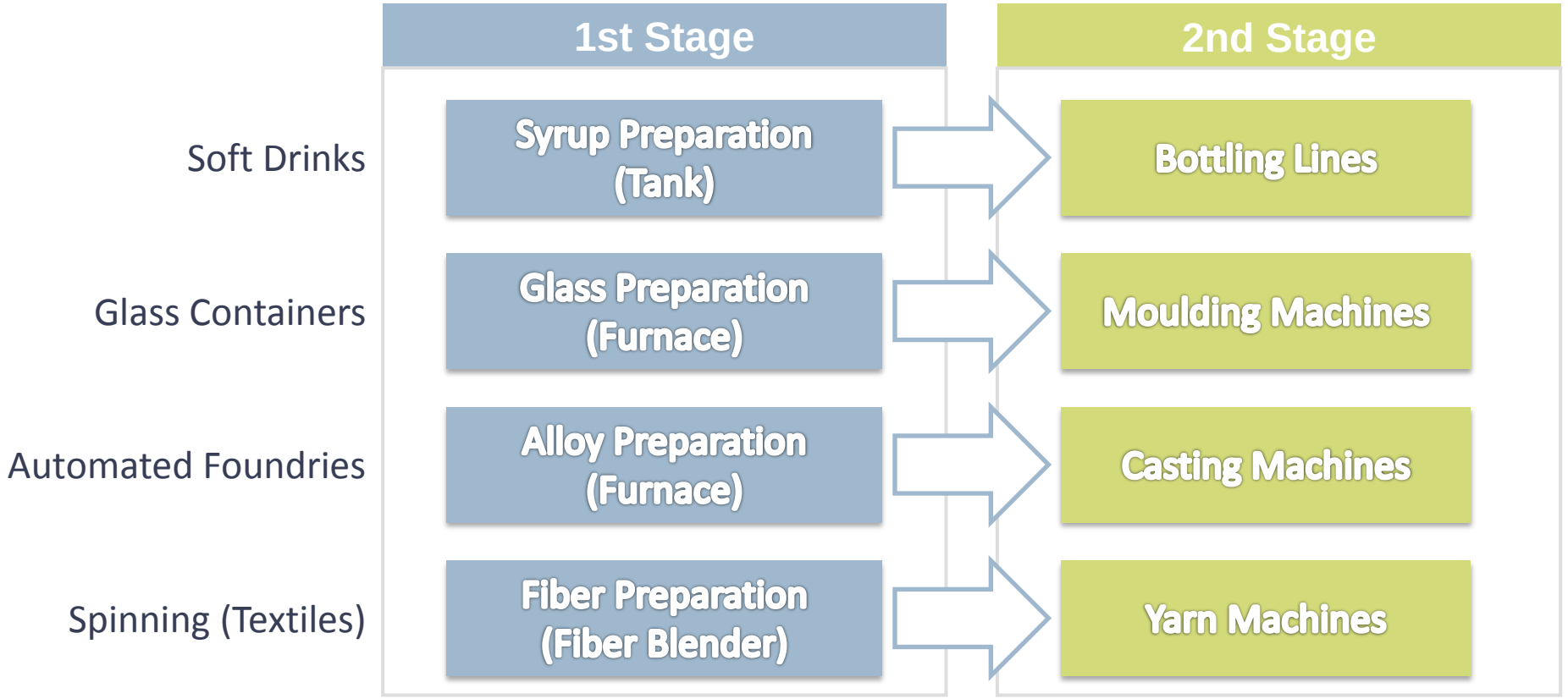
Machine 1

Machine 2

(…)

Machine m

TWO-STAGE PRODUCTION ENVIRONMENT EXAMPLES



BREWING PROCESS

1st Stage - Beer Production

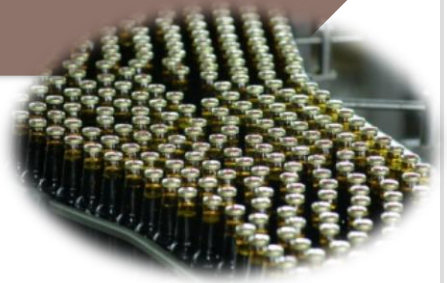
Wort Preparation

Fermentation & Maturation

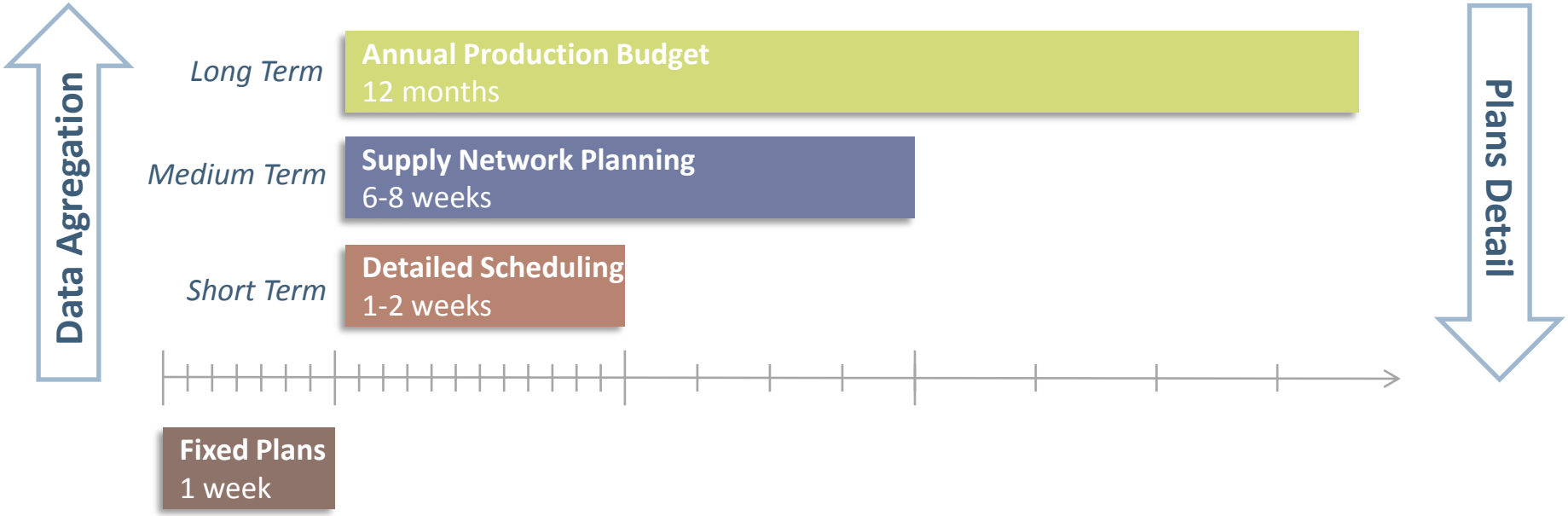
Filtering

2nd Stage - Bottling

Bottling

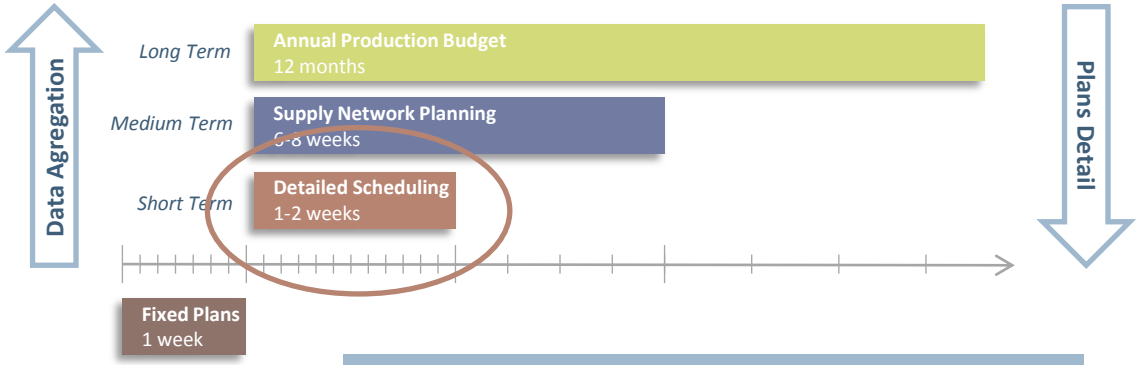


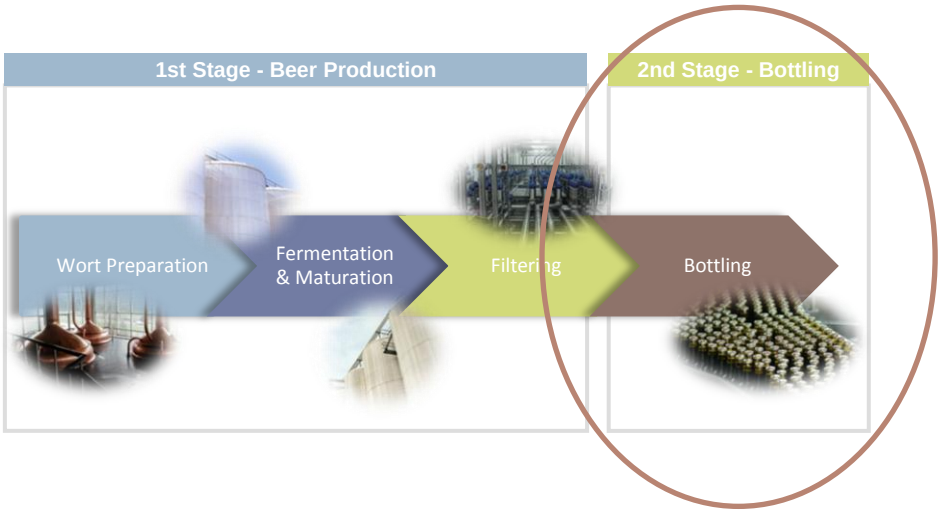
PRODUCTION PLANNING SYSTEM



Detailed Scheduling	Supply Network Planning	Annual Production Budget
Inventory costs Sequence dependent costs Exact processing times	Inventory costs Distribution costs Estimate processing times	Inventory costs Distribution costs Overtime costs Estimate processing times Family aggregation
Bucket: Shifts	Bucket: Weeks	Bucket: Months

MOTIVATION





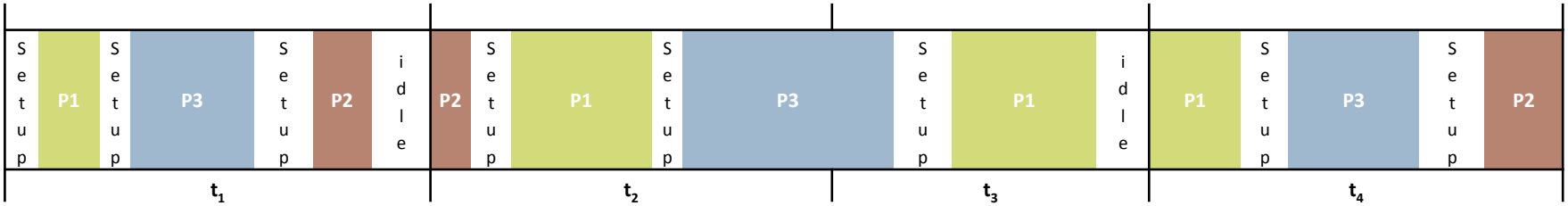
Goal

- Solution Methodology for short term production planning problem arising in the beer (and related industries) industry

Detail Schedule
for the
Bottling Stage

PROBLEM DEFINITION

- Single Machine **C**apacitated **L**otsizing and **S**cheduling **P**roblem (CLSD)
  - Production plan: lot sequence and sizes to meet forecasted demand, no backorders
  - *N* products and *T* periods
  - “Big-bucket” (several setups in each time period)
  - Sequence dependent setup time and costs
  - Setup state is carried between periods
  - Limited capacity



Decisions

- Production Quantity
- Production Sequence

Objective

- Minimize Total Setup and Holding Costs

TRIANGULAR INEQUALITY – OR IS IT THERE?

- In many industries contamination occurs between products
  - Chemical, pharmaceutical, food, dying, etc.
- Cleansing operations are needed when switching production from one product to another

- Cleansing operations can sometimes be avoided
  - Some products “absorb” contaminating substances
  - Intermediate sub products may have economical value

$\Rightarrow$ Non triangular setups exist in several industries

NON TRIANGULAR SETUPS

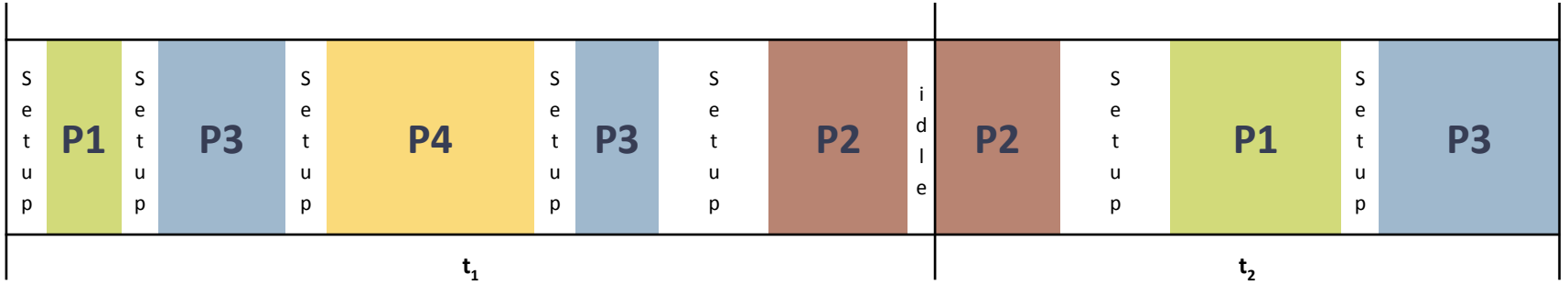
- Examples

***Contains traces** of peanuts, tree nuts, or soy.*

Transition from Yellow to Blue results in Green **sub product** (with economical value)

2. THE METHODOLOGY

MODELS FOR SEQUENCING

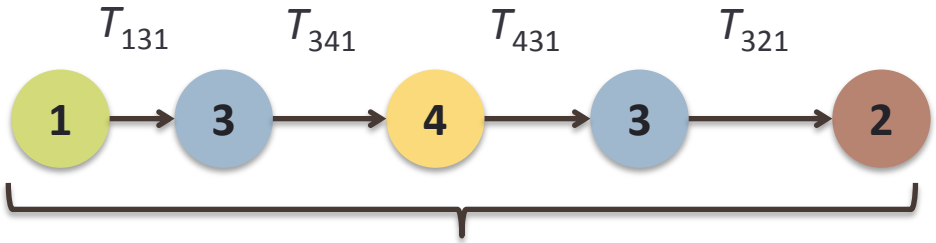


Product oriented

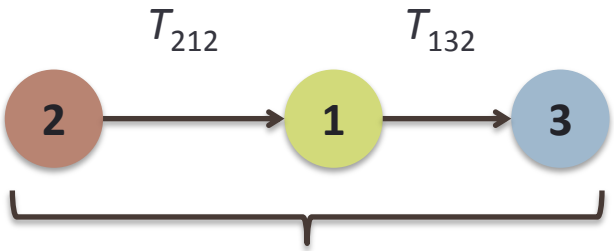
T_{ijt} – (binary) number of changeovers from product *i* to product *j* in period *t*

e.g. [Haase 1996], [Almada-Lobo et al. 2007]

$T_{131} = T_{341} = T_{431} = T_{321} = 1$
$T_{212} = T_{132} = 1$



Sequence 1 : W_{11}



Sequence 2 : W_{22}

$W_{11} = 1$
$W_{22} = 1$

e.g. [Kang at al. 1999], [Haase and Kimms 2000], [Kovács at al. 2009]

Sequence oriented

W_{st} – (binary) if sequence *s* is used in period *t*

MODEL FOR CLSD

- First sequence oriented “big-bucket” model for CLSD with non-triangular setups
  - ✓ More than a production lot for each product within each period
  - ✓ Sequence selection based on product setup

$$(FS) \quad \text{Min} \quad \sum_t \sum_s \widehat{sc}_s \cdot W_{ts} + \sum_t \sum_{l \geq t} \sum_i (l-t) \cdot h_i \cdot X_{itl}$$

subject to:

$$\sum_{t \leq l} X_{itl} = d_{il} \qquad \forall i, l$$

$$\sum_i \sum_{l \geq t} p_i \cdot X_{itl} + \sum_s \widehat{st}_s \cdot W_{ts} \leq cap_t \qquad \forall t$$

$$X_{itl} - d_{il} \cdot (U_{it} + Z_{it}) \leq 0 \qquad \forall i, t, l \geq t$$

$$\sum_s f_{is} \cdot W_{ts} = Z_{it} \qquad \forall i, t$$

$$\sum_s l_{is} \cdot W_{ts} = Z_{i,t+1} \qquad \forall i, t$$

$$\sum_i Z_{it} = 1 \qquad \forall t$$

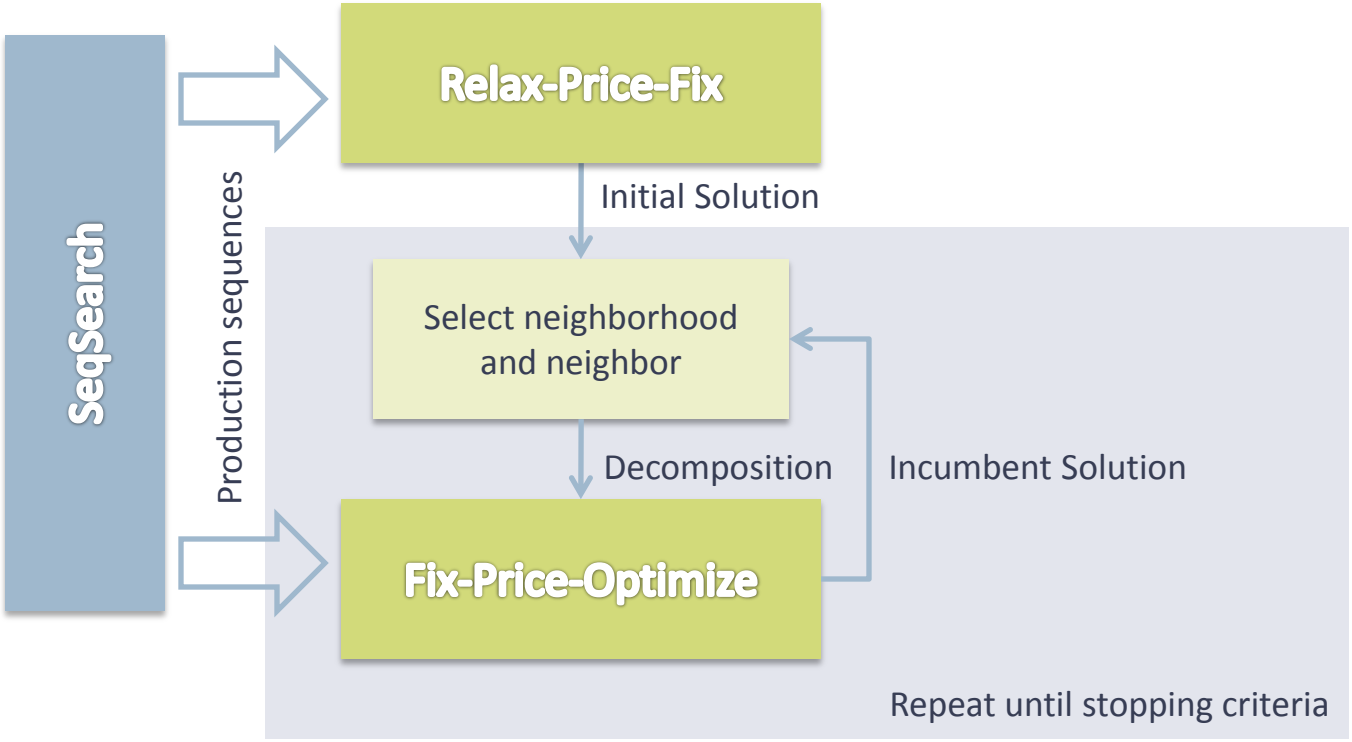
$$\sum_s e_{is} \cdot W_{ts} = U_{it} \qquad \forall i, t$$

$$\sum_s a_{is} \cdot W_{ts} = Y_{it} \qquad \forall i, t$$

$$(X_{itl}, W_{ts}) \geq 0, \quad (U_{it}, Z_{it}) \in \{0,1\}, \quad Y_{it} \in \mathbb{N} \qquad \forall i, s, t, l$$

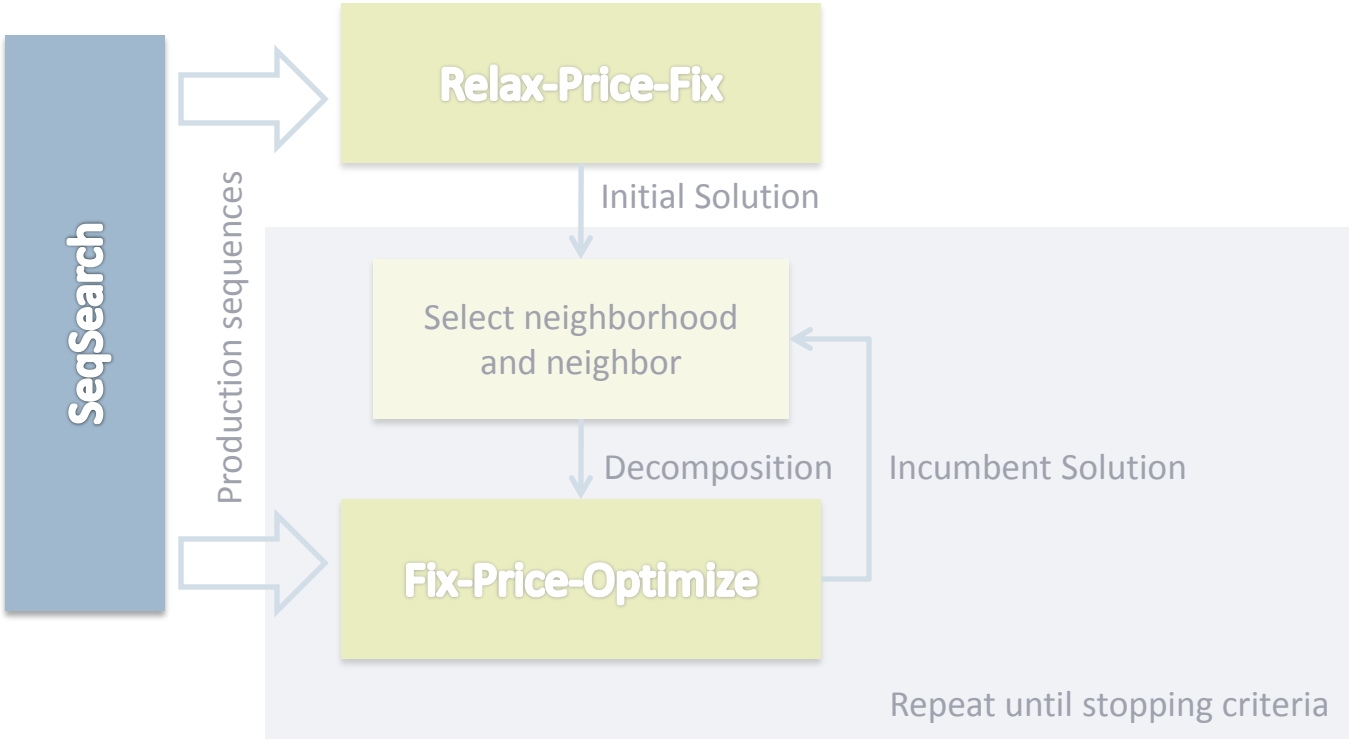
PRICE-AND-MIP

Price-and-MIP - an innovative hybrid heuristic combining exact methods and local search using our sequence oriented model



Price-and-MIP flowchart

PRICE-AND-MIP



SeqSearch – Generates new production sequences (W_{st}) using branch-and-price heuristics

PRICE-AND-MIP – SEQSEARCH

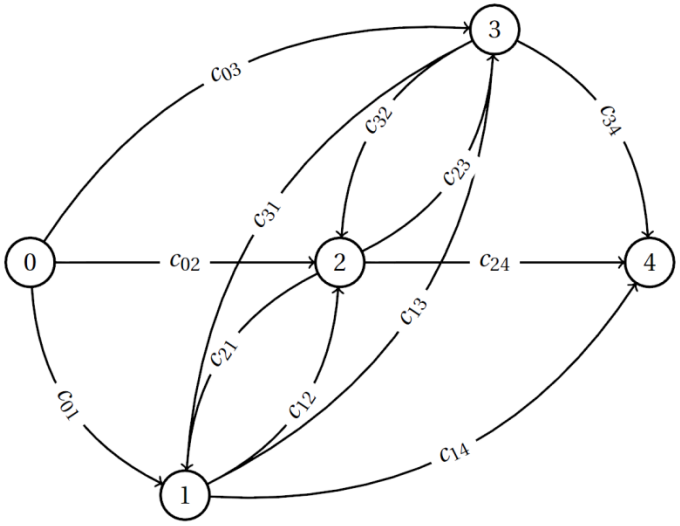
Start with a limited set of production sequences

Use column generation + LP-driven diving heuristic

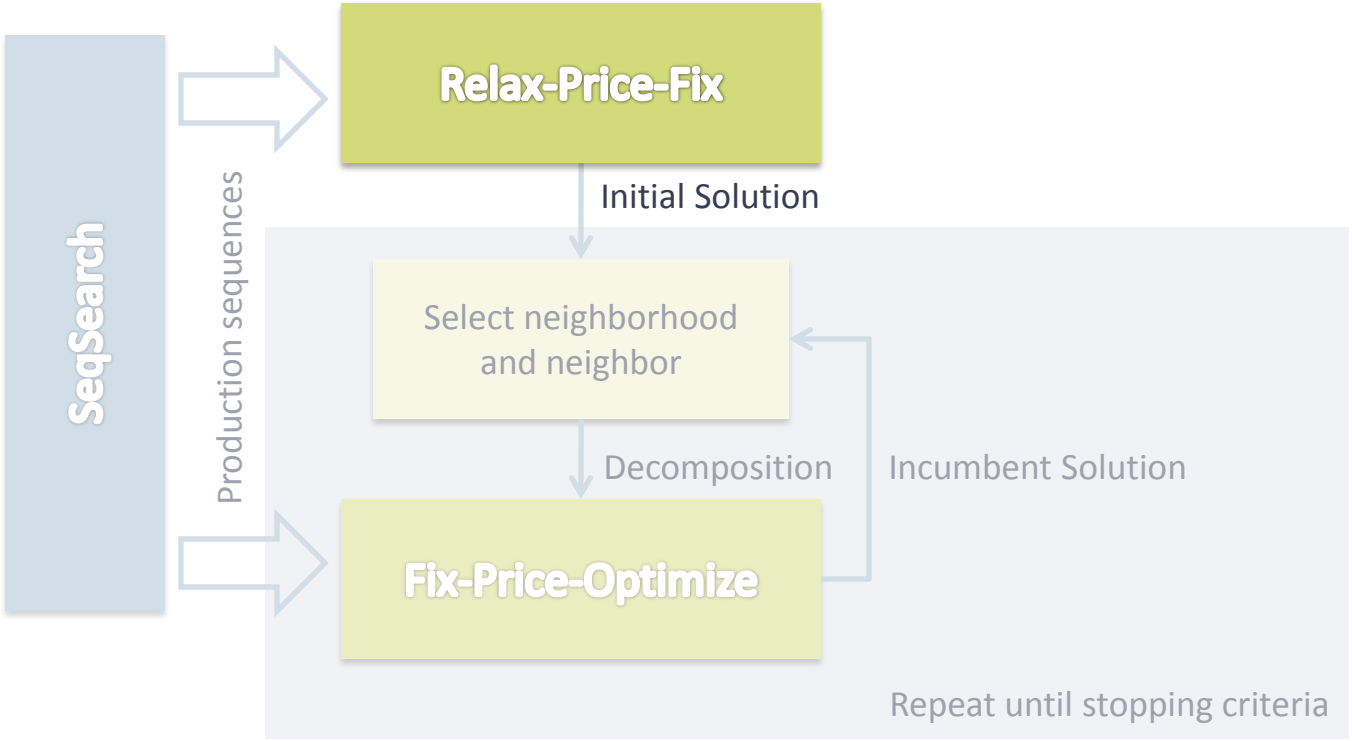
Generate, update and manage the sequence pool in each period

New production sequences

Solve a Prize Collecting High Multiplicity Asymmetric Traveling Salesman

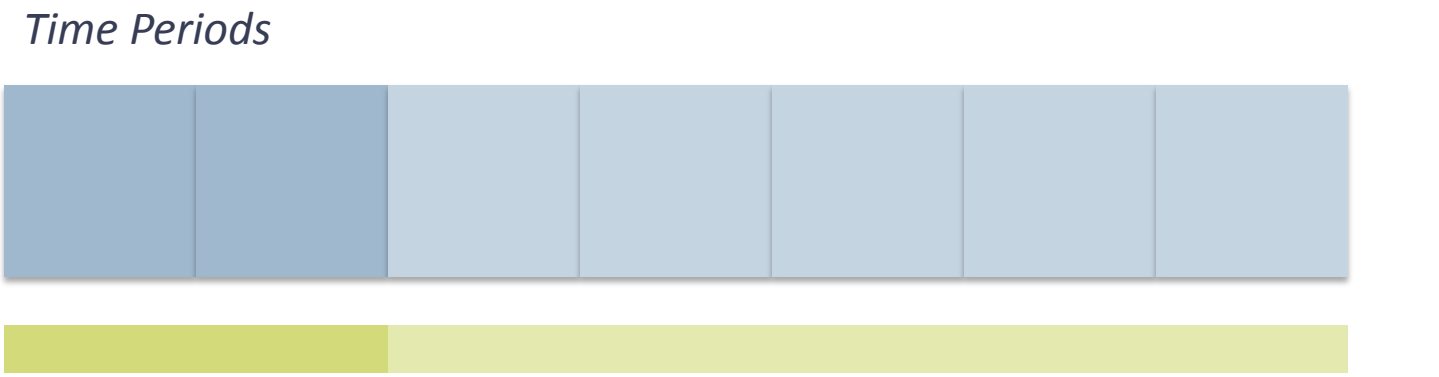


PRICE-AND-MIP

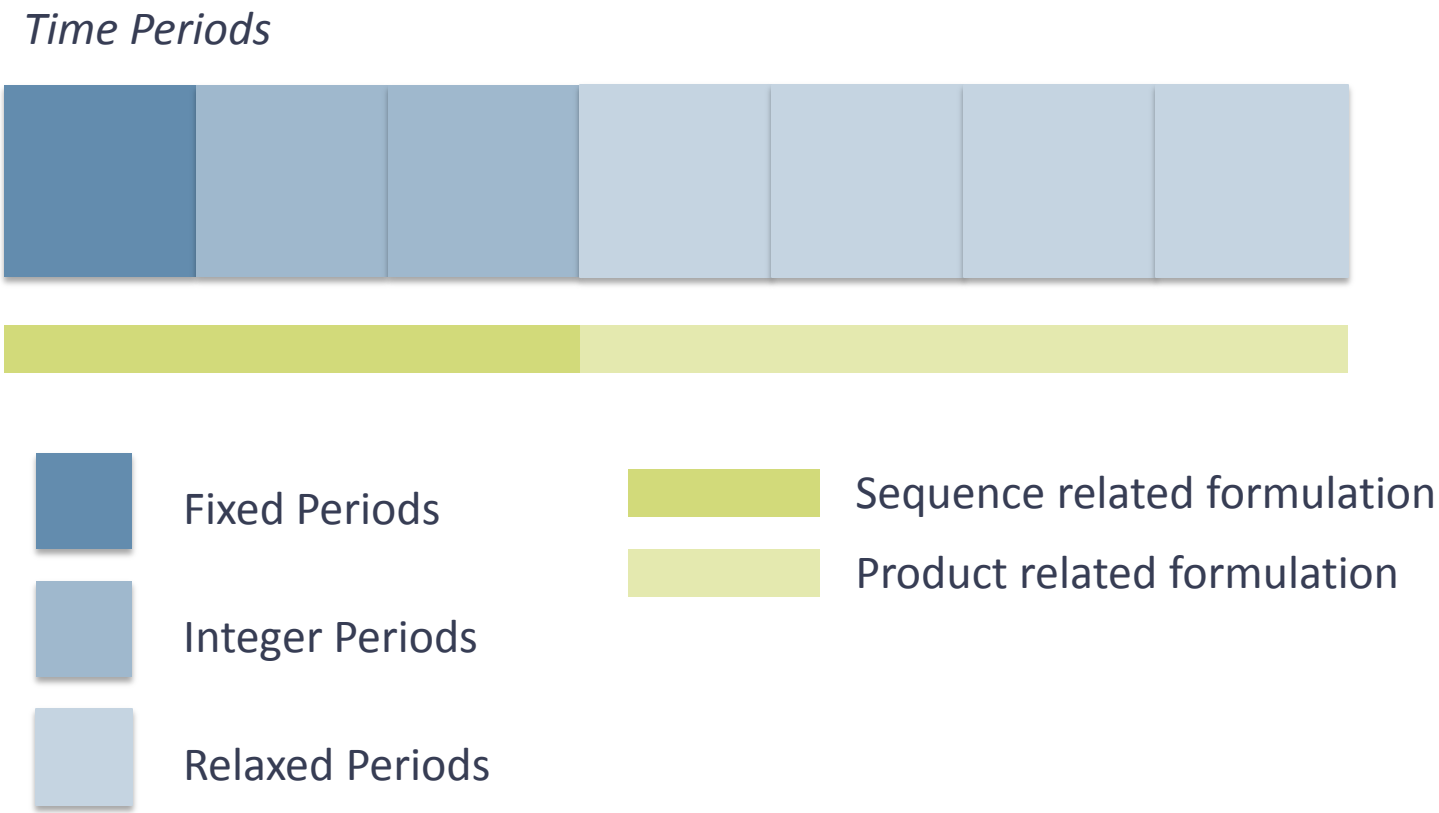


Relax-Price-Fix – Initial solution combining relax-and-fix framework with column generation: RF + SeqSearch

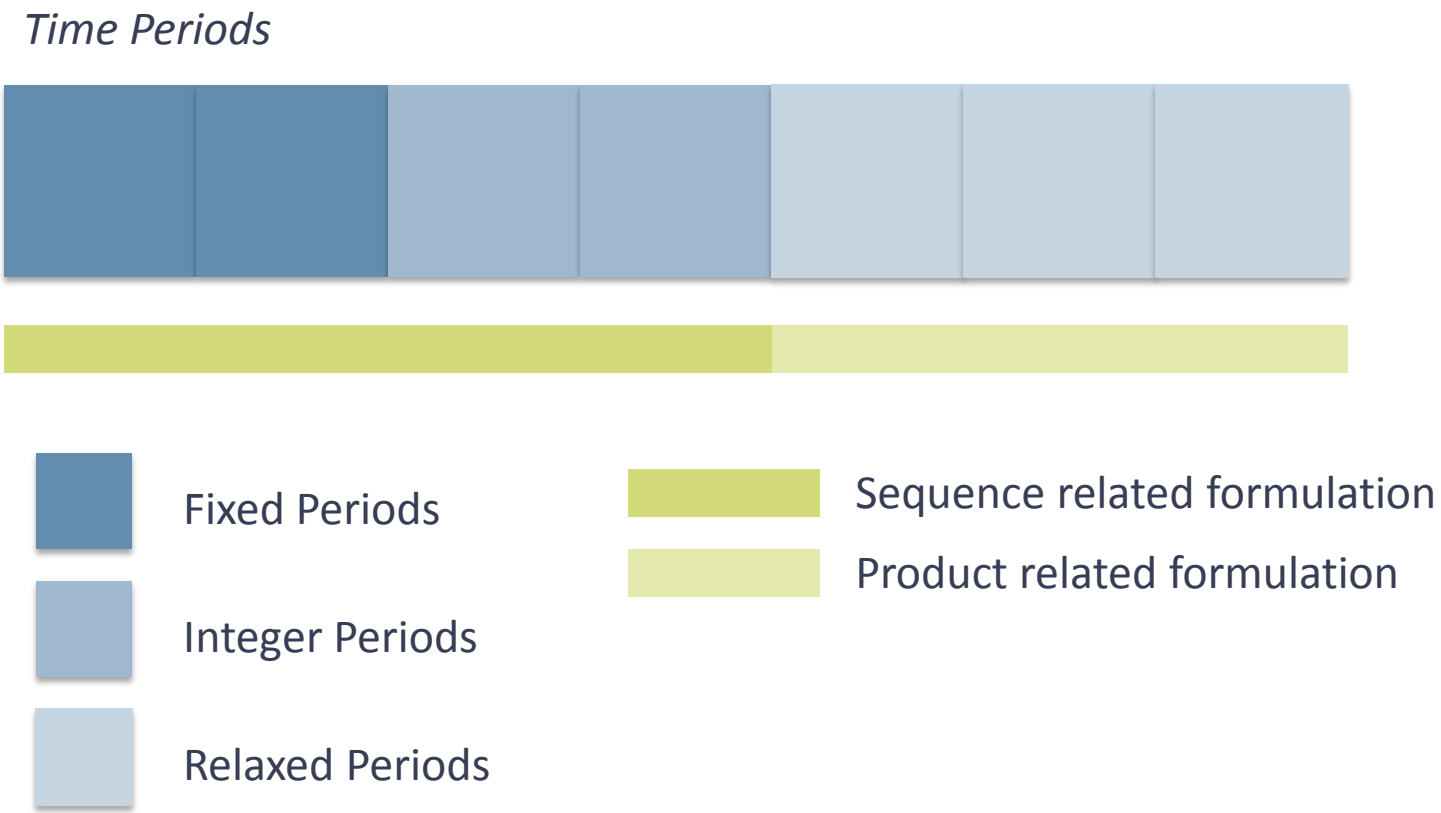
PRICE-AND-MIP – RELAX-PRICE-FIX



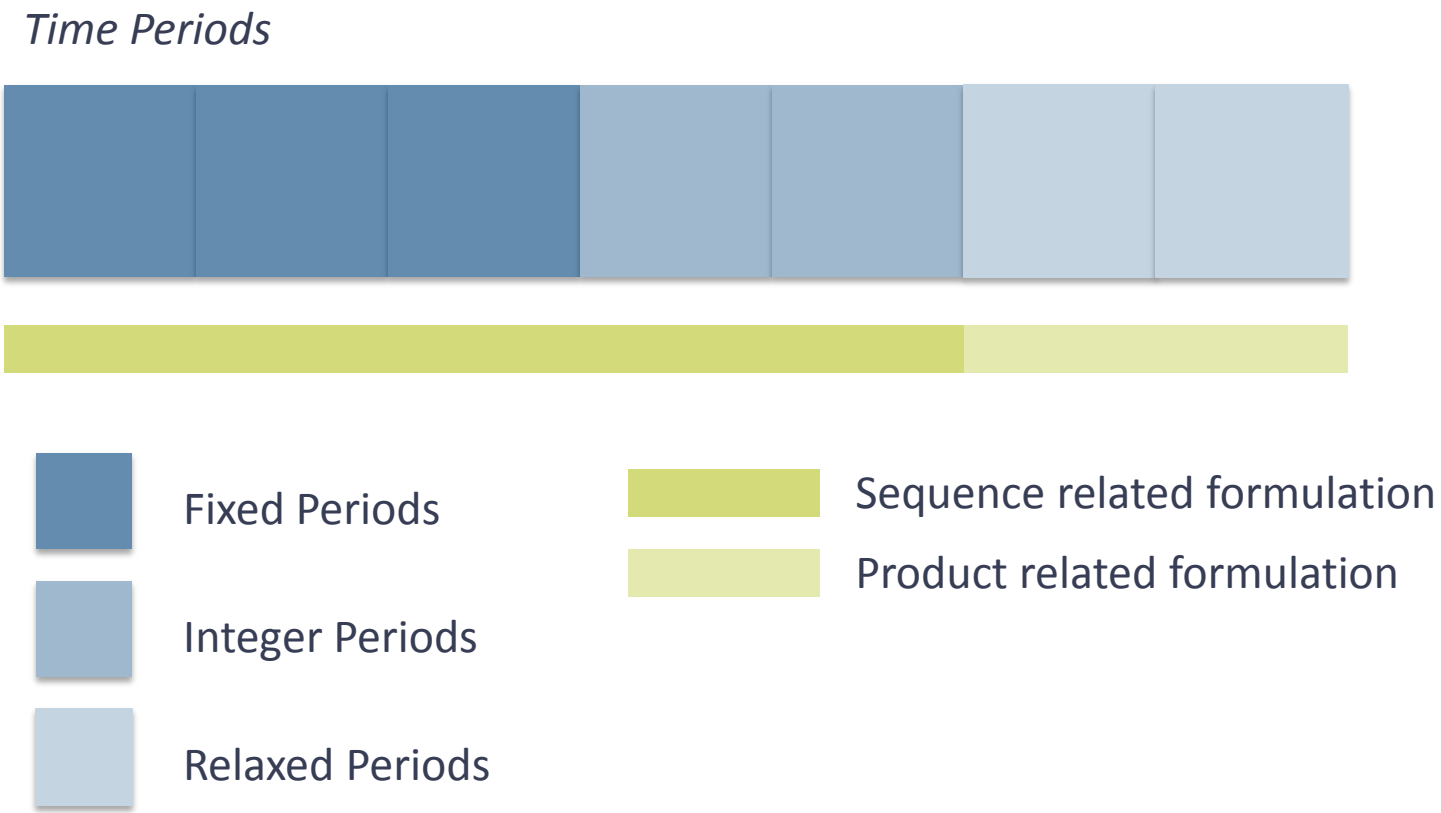
PRICE-AND-MIP – RELAX-PRICE-FIX



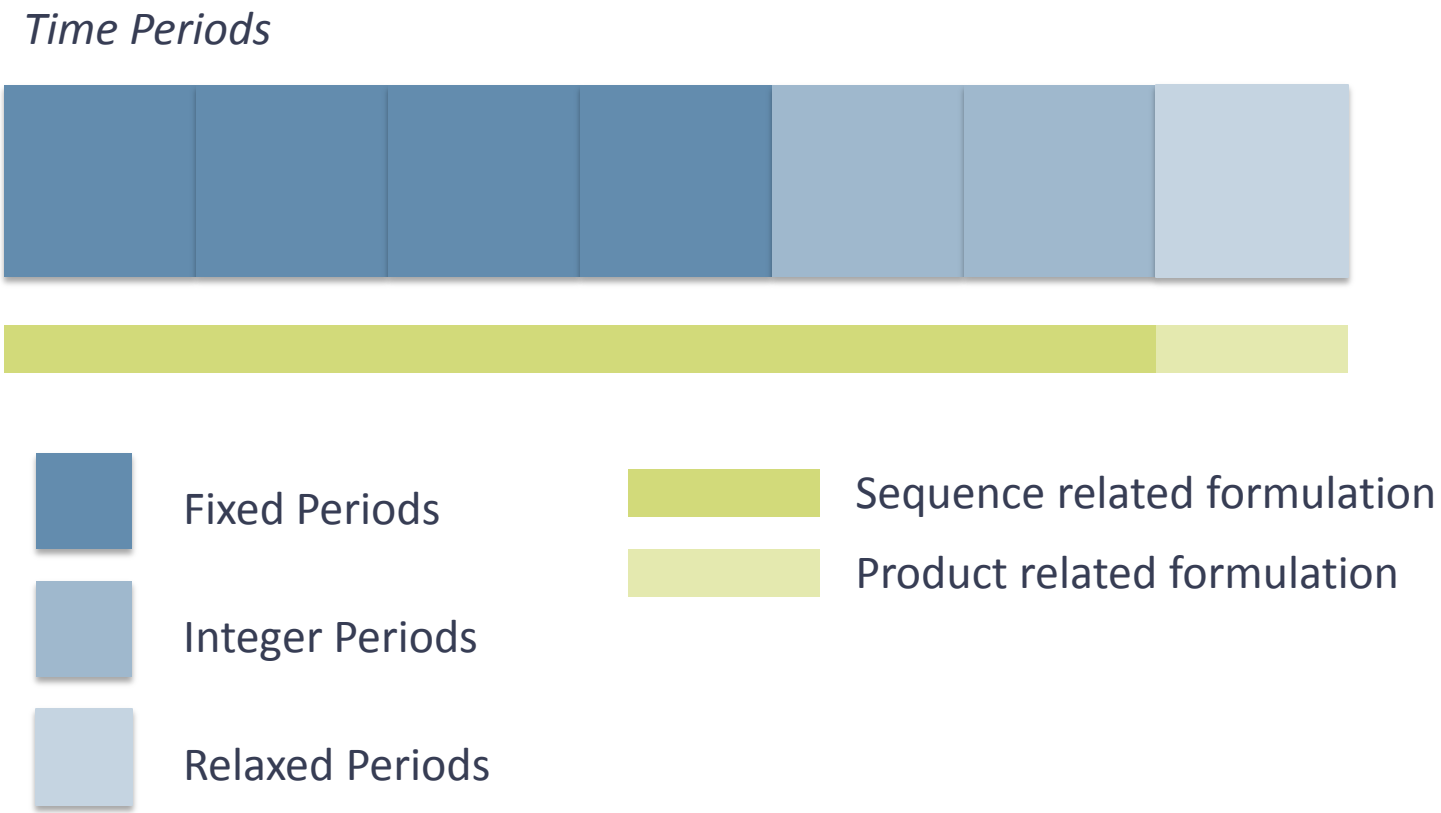
PRICE-AND-MIP – RELAX-PRICE-FIX



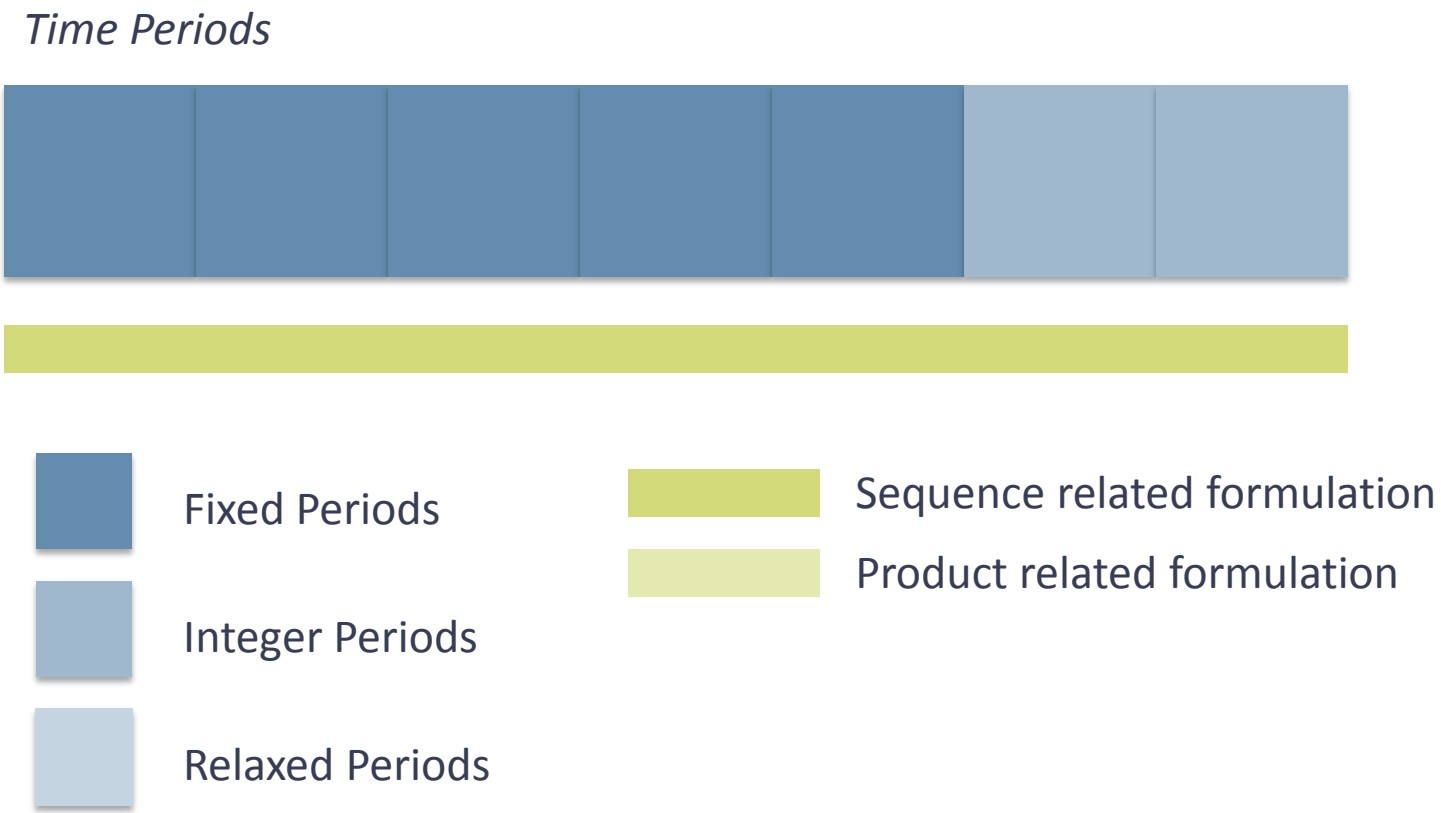
PRICE-AND-MIP – RELAX-PRICE-FIX



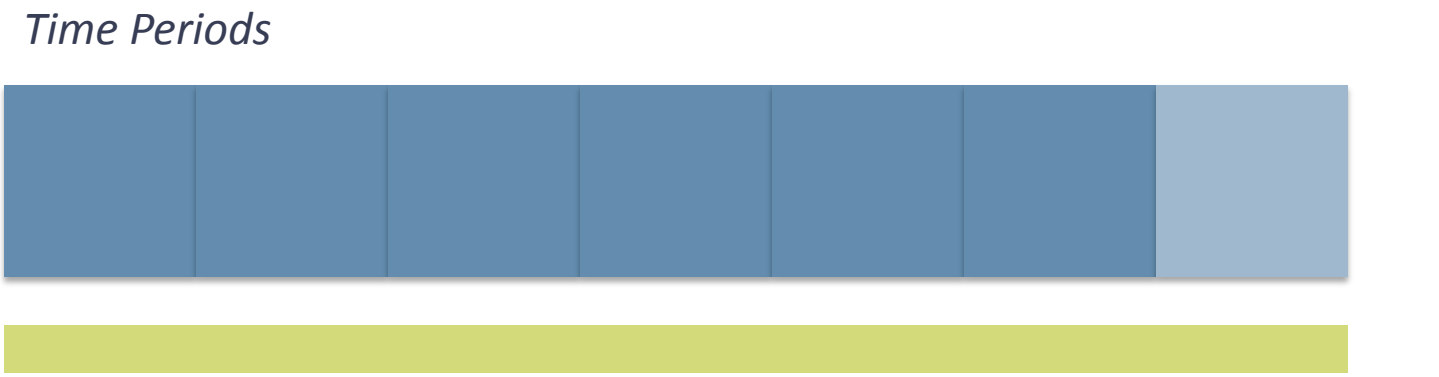
PRICE-AND-MIP – RELAX-PRICE-FIX



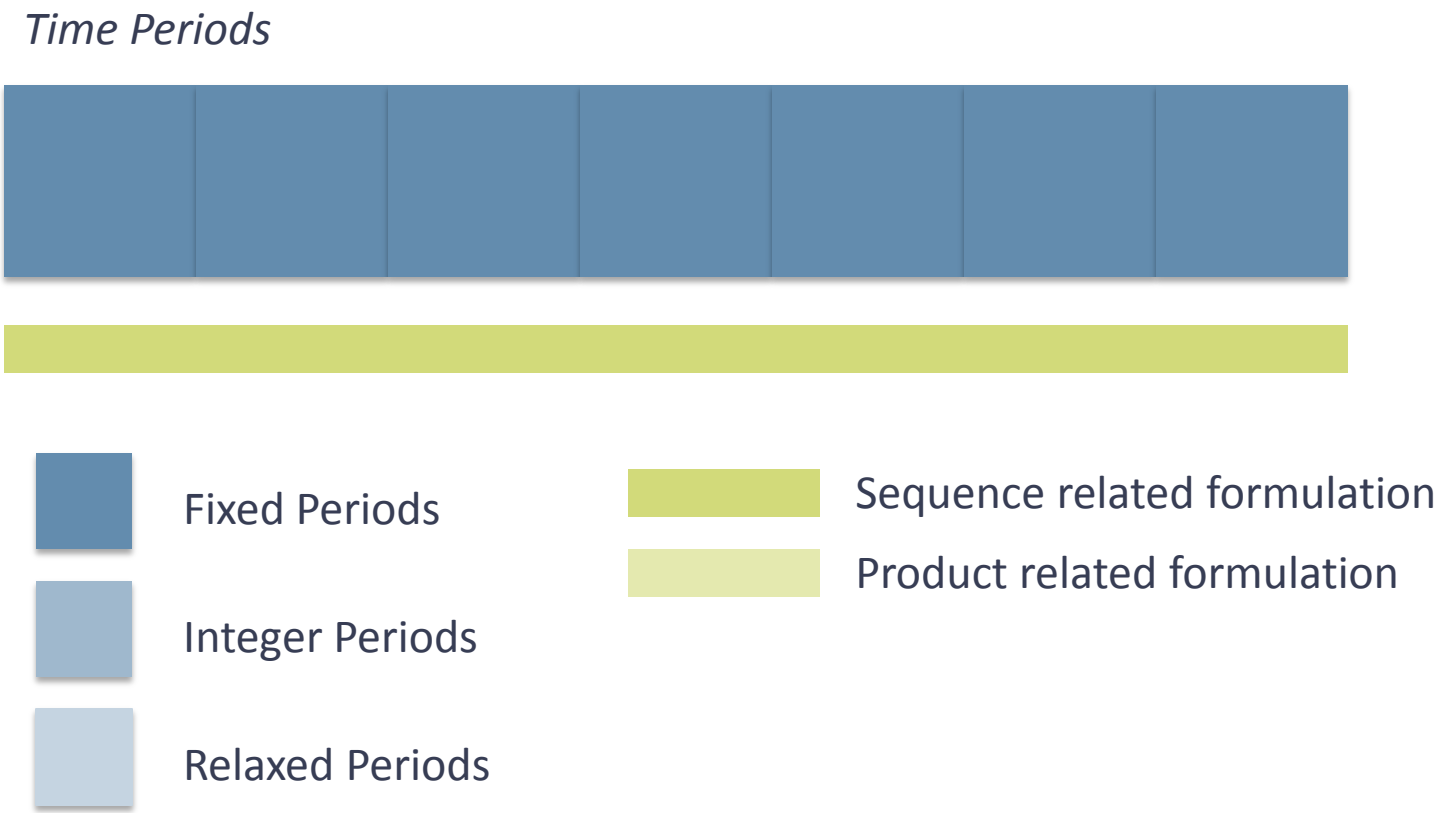
PRICE-AND-MIP – RELAX-PRICE-FIX



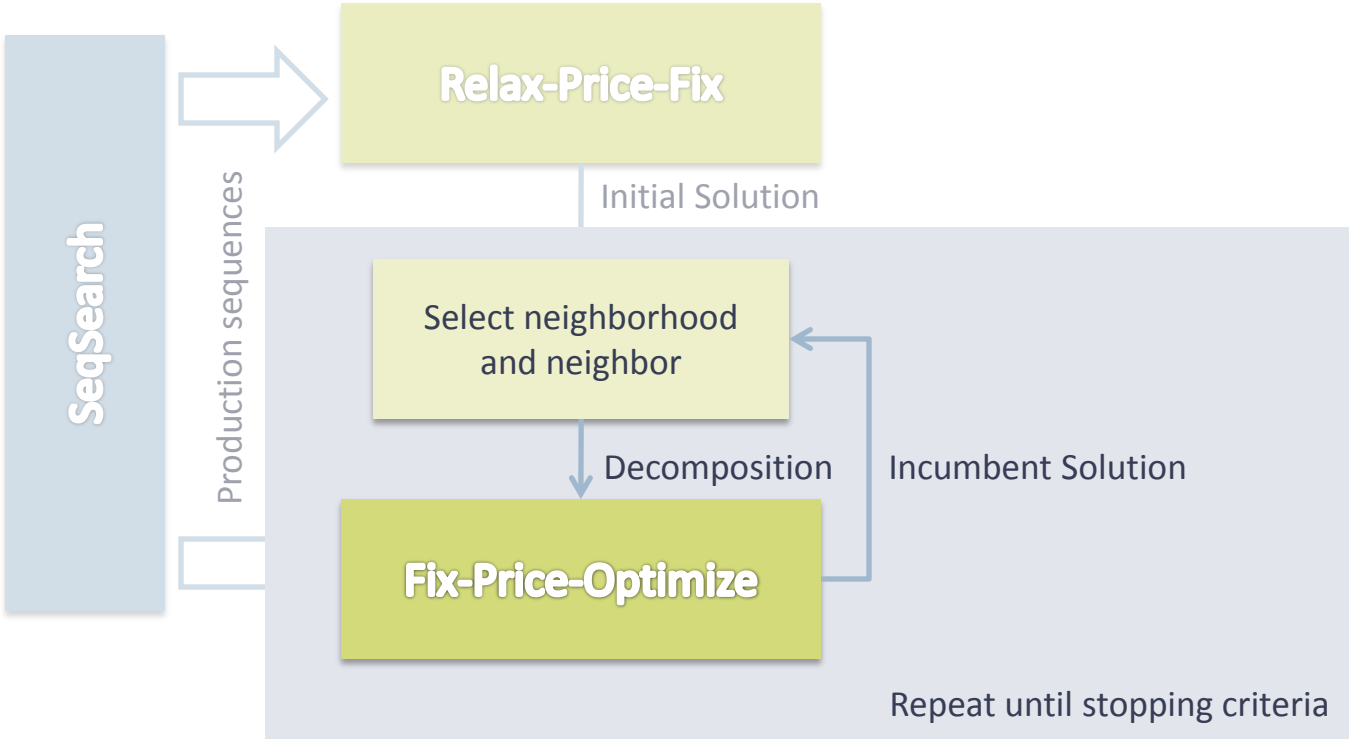
PRICE-AND-MIP – RELAX-PRICE-FIX



PRICE-AND-MIP – RELAX-PRICE-FIX

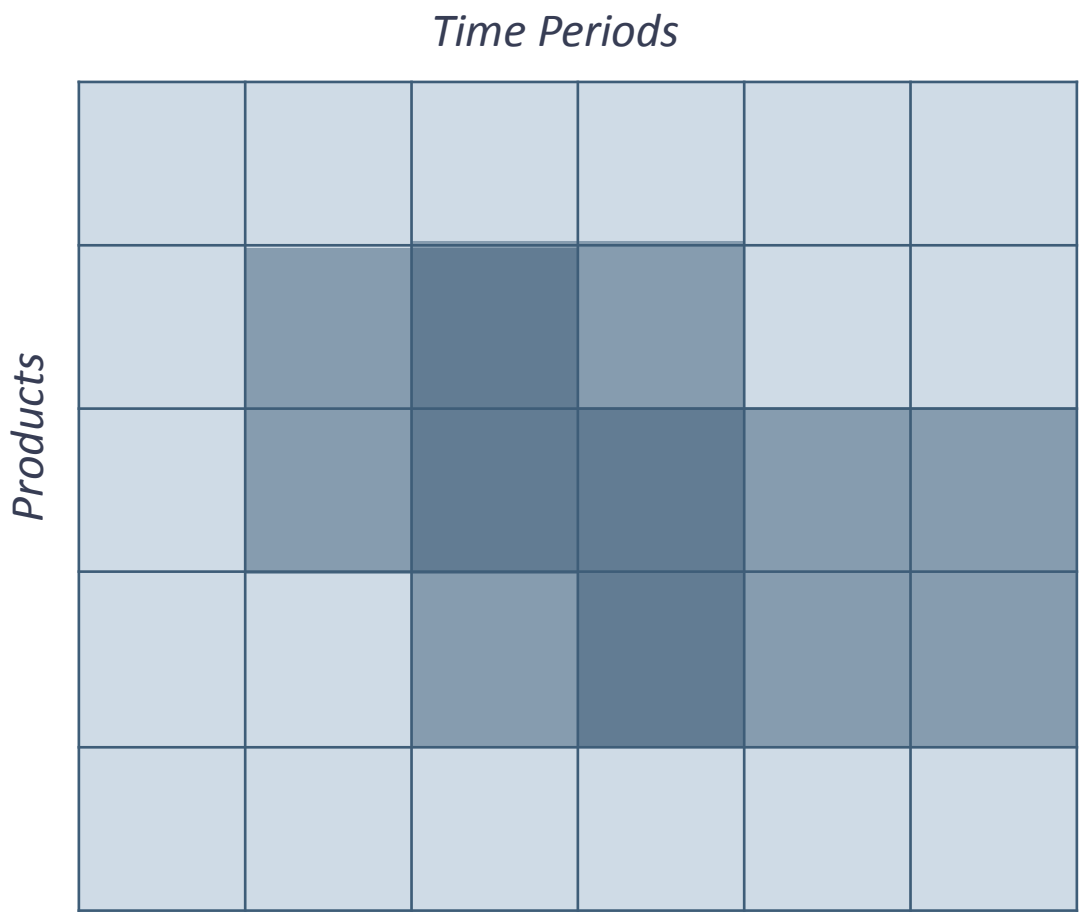


PRICE-AND-MIP



Fix-Price-Optimize – Improvement heuristic SeqSearch and MIP solver

PRICE-AND-MIP – FIX-PRICE-OPTIMIZE



- Decomposes the integer variables into two subsets F and R in every iteration.
- Variables in F are fixed to the values of the best solution found so far; the other variables are “released” and need to be optimized, yet restricted to take integer values
- Problem partition
  - ✓ Re-solve selected periods/products
  - ✓ All other periods/products values are fixed

3. THE IMPACT

RESULTS

Collection of 7 real-world based problems

			Solution			Deviations			Running Time		
Instance	N	T	CPLEX[a]	P&MIP Eval[b]	P&MIP Rnd[c]	(b-a)/a	(c-a)/a	(c-b)/b	MIP	P&MIP Eval	P&MIP Rnd
S2	8	8	**100915.6**	101470.1	101470.1	0.55%	0.55%	0.00%	132	182	108
L3	10	8	**94010.79**	94191.8	94090.05	0.19%	0.08%	-0.11%	142	208	221
L5	11	8	**77514.12**	77833.78	77582.06	0.41%	0.09%	-0.32%	192	153	162
S1	15	8	267409.2	183722.9	**183068.8**	-31.30%	-31.54%	-0.36%	3600	998	1062
R2	19	8	159439.4	**155985.9**	158674.1	-2.17%	-0.48%	1.72%	3600	3601	2904
S7	20	8	-	**189556.7**	199323.2	-	-	5.15%	3600	3603	3507
L6	33	8	-	**464409.8**	489310.4	-	-	5.36%	3603	3659	3611

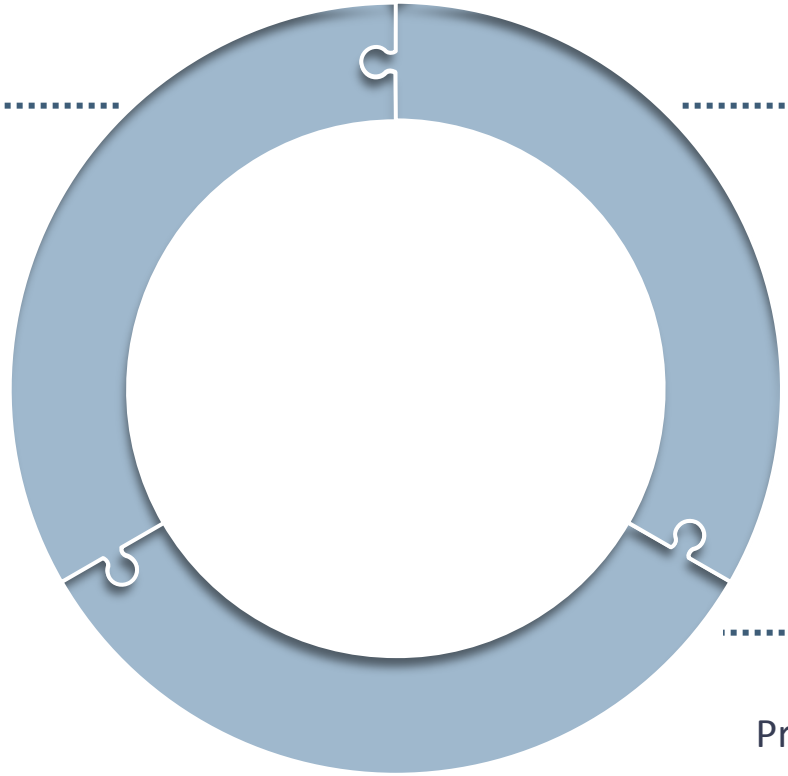
- Price-and-MIP outperforms CPLEX (commercial solver) for larger instances
- Price-and-MIP always provides a feasible solution to the problem

SUMMARY

Motivation

Two-stage Production Environments

Detail Scheduling of the 2nd Stage



Develop a solution methodology

Innovative heuristics combining column generation and mathematical programming based heuristics

Real-world application

Promising method to solve real world production planning problems