# Turnaround Planning for Integrated Chemical Sites

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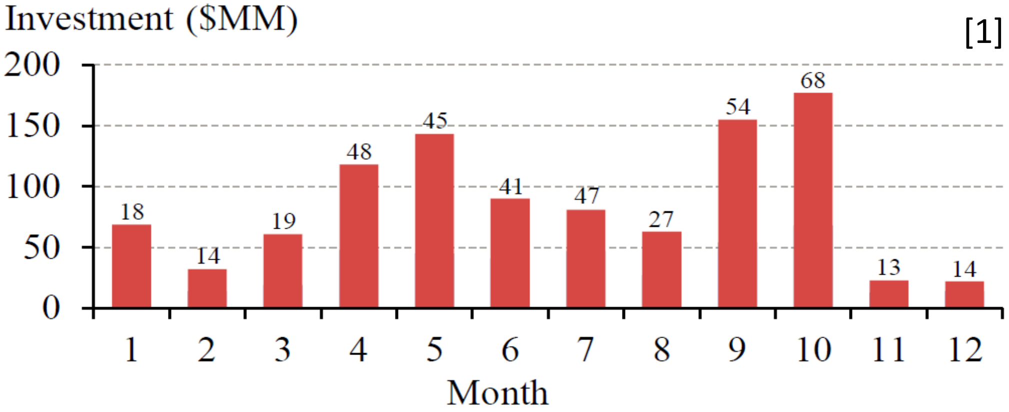
# Motivation

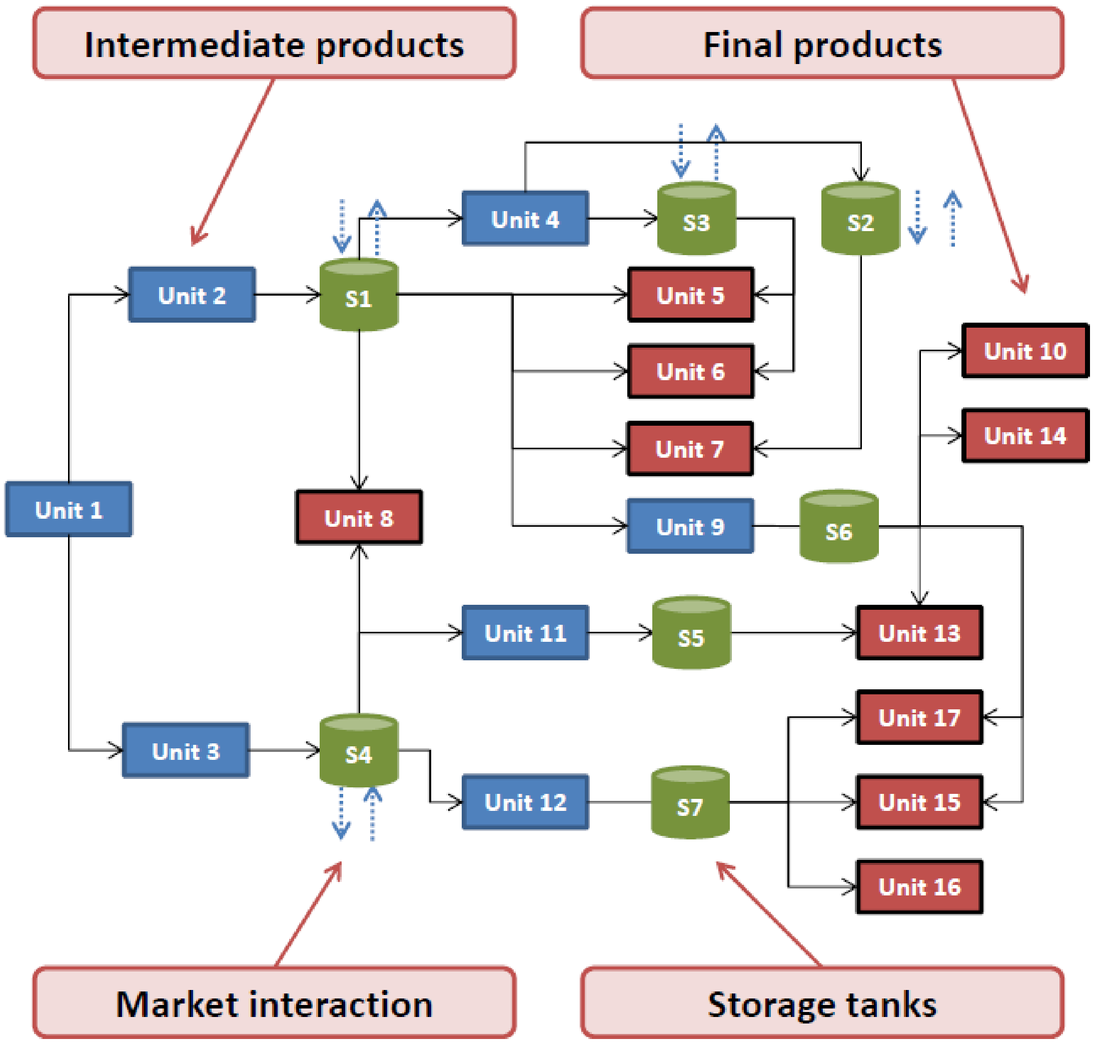
- **Large companies spend on the order of hundreds of millions of dollars on turnarounds annually**
  - **Disruptions to site network**
  - **Takes 1—8 week(s)**
  - **Up to $30,000/hr losses[2]**




- **Coordinating maintenance in integrated sites is a potential for significant savings while providing a long-term turnaround plan**
- **Practical limitations on manpower – worker contracts , infrequent spikes in manpower utilization, incentive to decrease peak manpower**
- **Most scheduling is done using scenario-based analyses currently**

[1] http://www.industrialinfo.com/media/downloadMedia.jsp?mediaId=344733
[2] J. S. Tan and M. A. Kramer (1997)

# Long-term planning

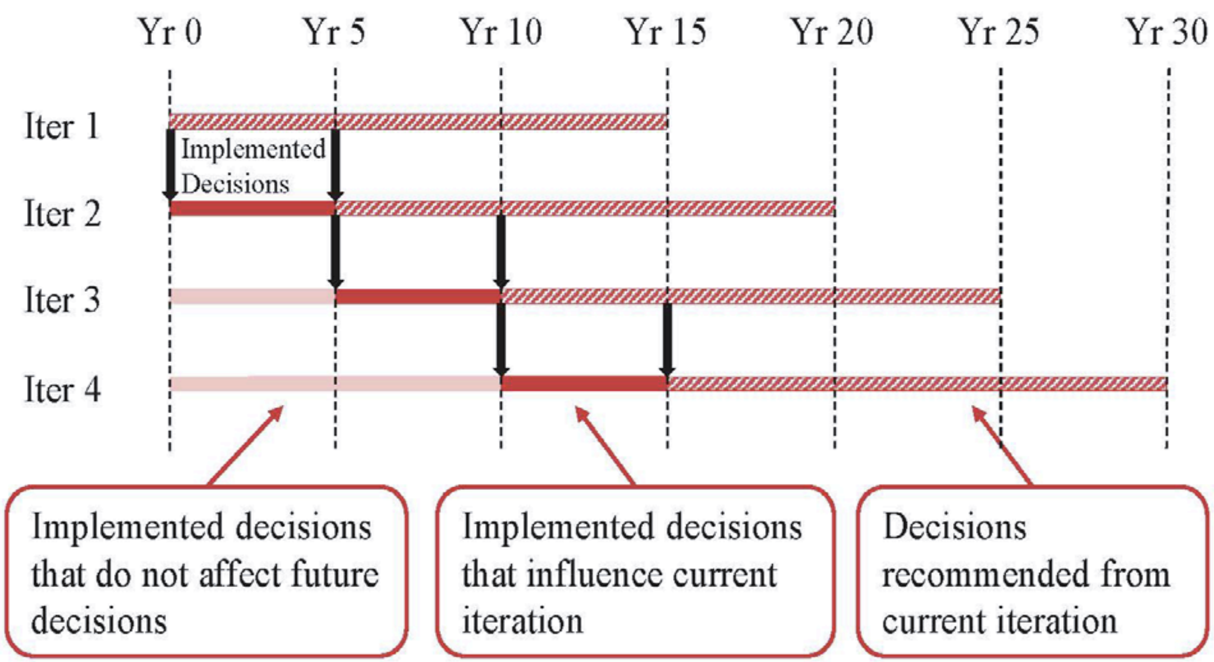



- **Exploit network interactions, storage availability, and prices to schedule maintenance over a multi-year horizon**
- **Scope:**
  - **Max. profit**
  - **Continuous processes**
  - **Time horizon: 5-15 years**
  - **Site-wide (each unit is an entire plant)**
- **Schedule refinement and handling uncertainties: Medium-term**

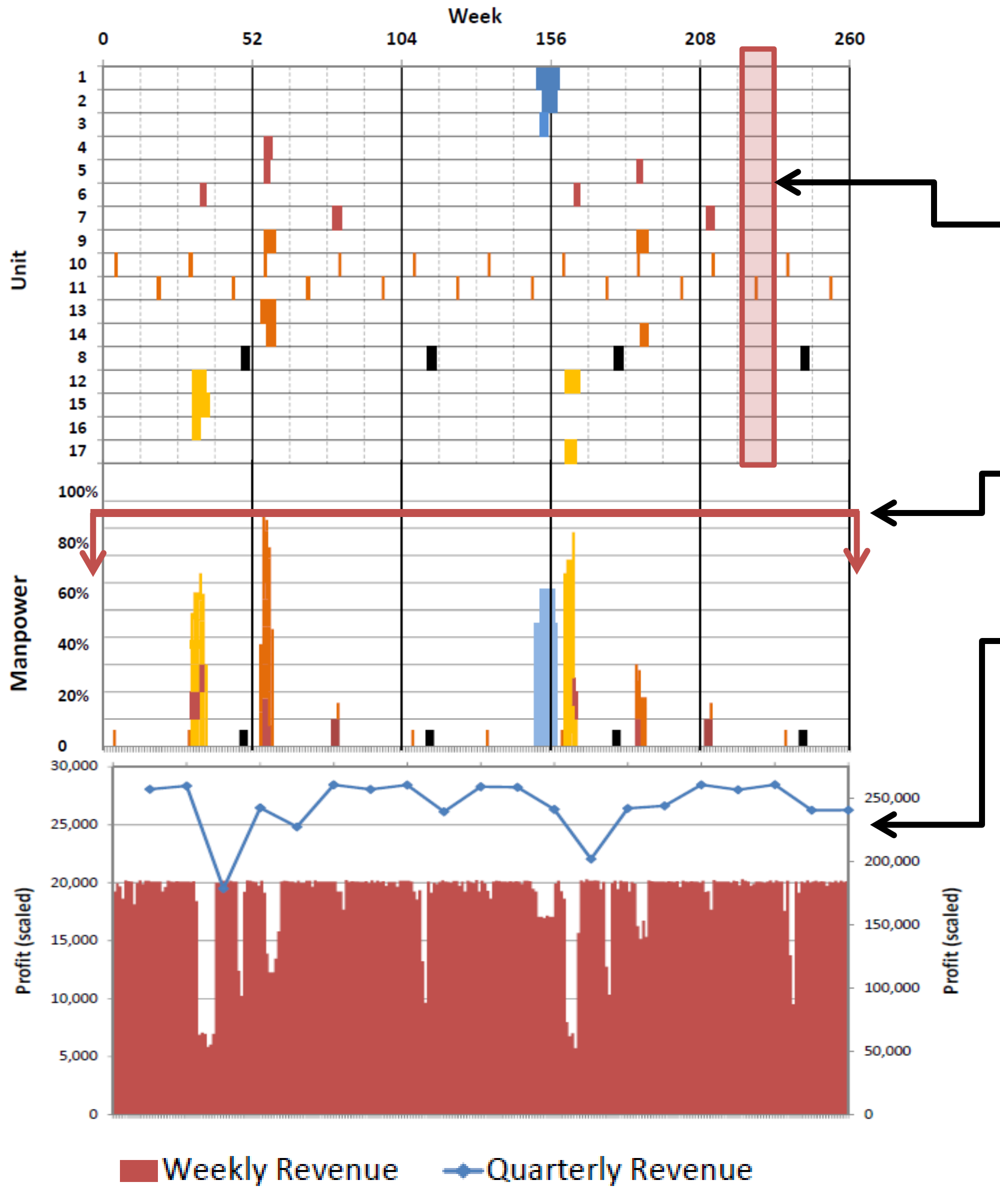
# Mixed Integer Linear Programming model

- **Max. profit = revenue – maintenance – holding – demand satisfaction penalty – raw material and import**
- **Constraints: network flow, inventory, demand, manpower, financial, turnaround frequencies**
- **Cyclic vs Rolling horizon schedule**

- **Model statistics:**
  - 17-plant integrated site
  - 15-year horizon
  - 1 week discretization (~800 time periods)
  - 16,000 binaries; 600,000 total
  - CPLEX solver used



# Novelty in schedules




**Incorporation of three major concerns:**

- **Avoidance of maintenance tasks in unfavorable conditions**
- **Bringing down peak manpower requirements**
- **Balancing quarterly financial performance**

| | Avg. Profit | Gap | Time (s) |
|---|---|---|---|
| Cyclic | 2,564,801 | 0.7% | 36 |
| Roll. H. | 2,599,798 | 0.4% | 1219/4 |

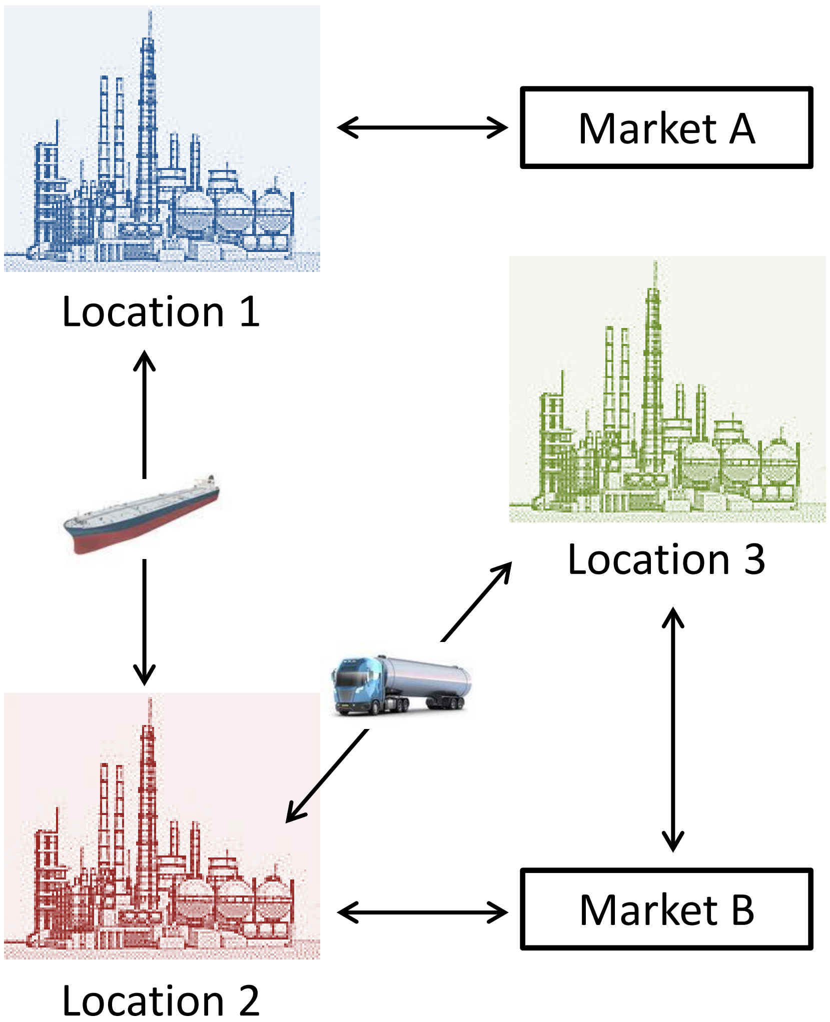
**1.36% improvement in rolling horizon scheme**

# Current work

## Risk Analysis

- **Quantification of risk of plant breakdown and its impact on profits**
- **TA flexibility post risk-assessment**
  - **Unfavorable market conditions**
  - **External factors forcing deferral**
- **Improving current TA frequencies estimation model**
  - **Incorporating reliability studies and risk analysis**

## Global TA Planning



# Medium-term planning with uncertainty

- Nine months horizon considered (**medium-term**)
- Several months needed to build up downstream inventory (**first six months**)
- **Duration of turnaround is uncertain ( why? )**
  - Transport delay: required material/facility delays
  - Discovery work: unexpected damage found during the inspection

Extended duration:

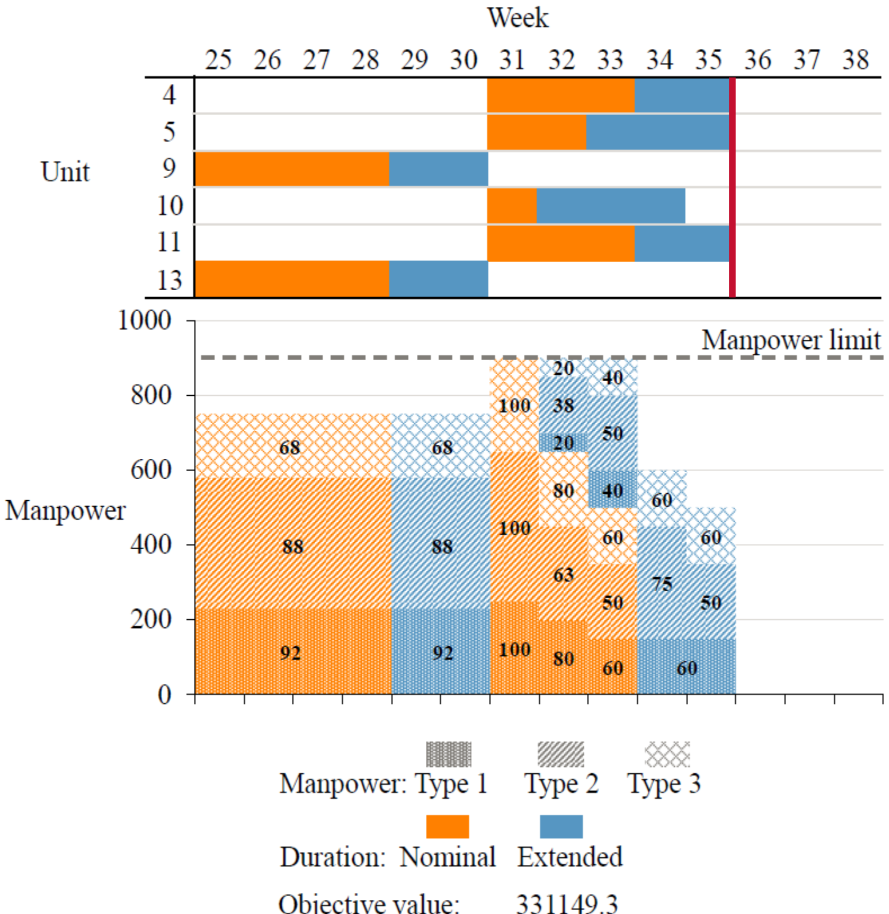
- Schedule *(Manpower)* → Robust optimization
- Flow rate *(Inventory level)* → Stochastic programming

| Sequential | Simultaneous |
| --- | --- |
| Robust Optimization (MILP)<br>*[Min. makespan]*<br>Schedule robust to uncertainty in duration w.r.t. manpower | Combined Robust and 2-stage Stochastic Programming (MILP)<br>*[Max. profit]*<br>Robust schedule and optimal inventory and production |

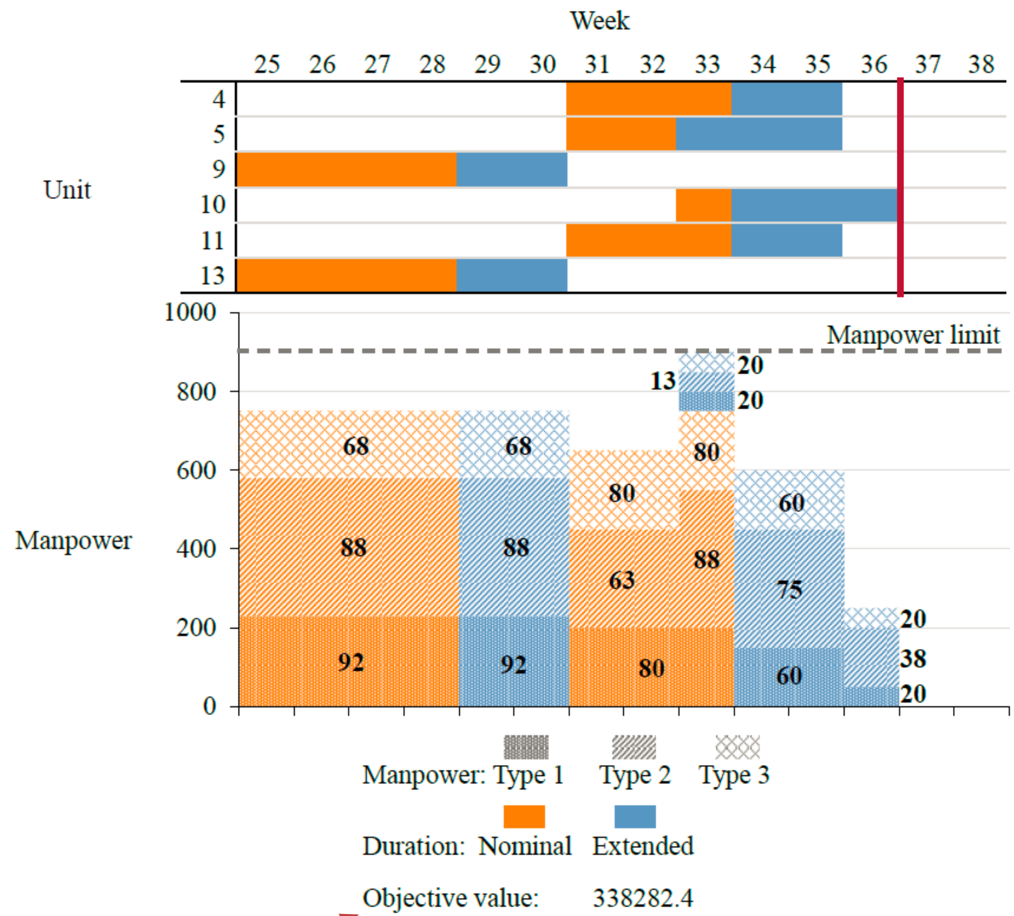
→ Multi-stage stochastic programming (LP)
*[Max. profit]*
Determine optimal production and inventory decisions

# Best sequential vs. simultaneous approach

**Best objective from sequential approach (RO + multi-stage LP)**




**Objective from simultaneous approach (2-stage MILP + multi-stage LP)**




**2% difference, not counting manpower (min. makespan not necessarily best)**

# Solution times

**Solved using CPLEX 12.6**

| | RO MILP | Multi-stage LP (implicit form) | RO+2-stage MILP | Multi-stage LP (explicit form; 4 stages) |
|---|---|---|---|---|
| Avg. Time ($s$) | $< 0.1$ | 19.4 | $2,714$ | 33.32 |
| Size | | | | |
| Equations | 2243 | $87,409$ | $120,212$ | $4,601,645$ |
| Continuous vars | 1900 | $42,736$ | $65,032$ | $712,485$ |
| Binary vars | 252 | - | 277 | - |

Very inexpensive; but many solutions, and quality of final solution not guaranteed

More expensive; better solutions

# Conclusions

- **Successfully demonstrated cost savings from a coordinated turnaround of integrated chemical sites**
- **Efficient solution from a long-term planning perspective while retaining key model features and incorporating practical considerations**
- **Accounted for uncertainties in TA duration and any discovery work through medium-term planning schemes**
- **Combined robust optimization with stochastic programming**