Manufacturing Execution Optimization

DR. LEYUAN SHI
INDUSTRIAL ENGINEERING AND MANAGEMENT
PEKING UNIVERSITY

DEPARTMENT OF INDUSTRIAL & SYSTEMS ENGINEERING
UNIVERSITY OF WISCONSIN-MADISON
AUGUST 24, 2017
Outline

- Introduction
- Manufacturing Execution Optimization
- A Case Study
- Research Issues
- Road map to digital supply chain management
Background

- Harvard
- U. Wisconsin-Madison

- NSF-SBIR
- Tech. Transfer
- MRO-2 V1.0
- MEO V1.0
- NOV-WLY NOV-ORG Phase I

- 1992
- 1994
- 2004
- 2007
- 2008
- 2009
- 2013
- 2014
- 2015
- 2016--2017

Phase I
Phase II
Case 1

Fortune 500

550 manufacturing facilities and service centers

Mass customization
A Real Example

- Transition from “knee-jerk” manual spreadsheet scheduling
- No validation to schedule changes
- 15 mins spent per operation to change formatting and calculations
Case 2

<table>
<thead>
<tr>
<th>Structures</th>
<th>MSDC</th>
<th>S&amp;I</th>
<th>Join</th>
<th>FA</th>
</tr>
</thead>
</table>

### MSDC

<table>
<thead>
<tr>
<th>Task</th>
<th>Description</th>
<th>Start Date</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task 1</td>
<td>Process A</td>
<td>2023-01-01</td>
<td>1 day</td>
</tr>
<tr>
<td>Task 2</td>
<td>Process B</td>
<td>2023-01-02</td>
<td>2 days</td>
</tr>
<tr>
<td>Task 3</td>
<td>Process C</td>
<td>2023-01-03</td>
<td>3 days</td>
</tr>
</tbody>
</table>

### S&I

<table>
<thead>
<tr>
<th>Task</th>
<th>Description</th>
<th>Start Date</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task 1</td>
<td>Process D</td>
<td>2023-01-04</td>
<td>1 day</td>
</tr>
<tr>
<td>Task 2</td>
<td>Process E</td>
<td>2023-01-05</td>
<td>2 days</td>
</tr>
<tr>
<td>Task 3</td>
<td>Process F</td>
<td>2023-01-06</td>
<td>3 days</td>
</tr>
</tbody>
</table>

### Join

<table>
<thead>
<tr>
<th>Task</th>
<th>Description</th>
<th>Start Date</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task 1</td>
<td>Process G</td>
<td>2023-01-07</td>
<td>1 day</td>
</tr>
<tr>
<td>Task 2</td>
<td>Process H</td>
<td>2023-01-08</td>
<td>2 days</td>
</tr>
<tr>
<td>Task 3</td>
<td>Process I</td>
<td>2023-01-09</td>
<td>3 days</td>
</tr>
</tbody>
</table>

### FA

<table>
<thead>
<tr>
<th>Task</th>
<th>Description</th>
<th>Start Date</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task 1</td>
<td>Process J</td>
<td>2023-01-10</td>
<td>1 day</td>
</tr>
<tr>
<td>Task 2</td>
<td>Process K</td>
<td>2023-01-11</td>
<td>2 days</td>
</tr>
<tr>
<td>Task 3</td>
<td>Process L</td>
<td>2023-01-12</td>
<td>3 days</td>
</tr>
</tbody>
</table>
Case 3: Kimberly-Clark: Real-time Optimization

Lost of capacity by 10-15%
Execution is not optimized
Background

- 1992: Harvard
- 2004: NSF-SBIR
- 2007: Tech. Transfer
- 2008: MRO-2 V1.0
- 2009: MEO V1.0
- 2013: NOV-ORG Phase I
- 2014: NOV-WLY
- 2015: Phase II
- 2016--2017:
Outline

- Introduction
- Manufacturing Execution Optimization
- A Case Study
- Research Issues
- Road map to digital supply chain management
Manufacturing Execution Optimization (MEO)

- A set of **digital tools** for enterprise system analysis, design, planning, scheduling, optimization, and improvement (based on Nested Partitions optimization framework)
- Highly **configurable & scalable**
- Full **visibility** to production outcomes
- Provide a common **platform** within Factory for information sharing and exchange
- Supports data-driven decision making in **real time**
MEO Architecture

Supply Chain Optimizer | SC portal | Outscoring Management | Control & Monitoring | E-E Optimization

Planning Optimizer | Sales Order Management | Purchasing Management | Work Order Management | Data Analytics

Scheduling Optimizer | SO-A | SO-J | SO-H
| SO-F | SO-P | SO-C

Feedback & Coordination | Feedback | Coordination | Reports | Visualization

MES
Scheduling Modules

Job Shop
- little Item repetition, no BOM
- Focus on machine scheduling

Assembly
- Labor-dependent Operation Duration
- Simultaneous Operations
- Various precedence constraints

Specialized
- Heat treatment
- Fabrication
- Paint
- Service
Planning Coordination

- Released Schedule used as starting point (link with scheduling)
- Plans remaining Released Work Orders
- Plans Unreleased Work Orders
- Determines release and completion date
- Balances utilizations and due date performance by simulating releases, available hours, or earliest start dates
Production Control

- Uses information from ERP
  - FG inventory, WIP inventory w/ released schedule
  - raw inventory w/ released plan
- Assigns supply to demand
- Determines if Sales Order Due Dates can be met
- Minimizes MCT
  - Total time required to deliver final products
  - Identifying critical Work Orders (shifting)
Scheduling-Planning-Control

- Start from shop-floor: the source of variability
- Link local areas together to create coordination
- Bottom-Up visibility to the impact on top-level demand
- Top-down prediction to results and control over top-level demand
- Response to changes and disturbances in real-time
Outline

- Introduction
- Manufacturing Execution Optimization
- A Case Study
- Research Issues
- Road map to digital supply chain management
Case 1: Houston WLY Plant
• Sales Order Status
  - Due date
  - Cost
  - Manufacturing Critical-Path Time
Production VP

Capacity Planning

WO release
<table>
<thead>
<tr>
<th>Performance</th>
<th>Before</th>
<th>After</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Business Income per Capita</td>
<td>40M</td>
<td>60M</td>
<td>↑65%</td>
</tr>
<tr>
<td>Order delay rate</td>
<td>78%</td>
<td>45%</td>
<td>↓42%</td>
</tr>
<tr>
<td>Capacity Utilization</td>
<td>36%</td>
<td>48%</td>
<td>↑33%</td>
</tr>
<tr>
<td>Machine shop Utilization</td>
<td>46%</td>
<td>80%</td>
<td>↑74%</td>
</tr>
<tr>
<td>Inventory turnover</td>
<td>25%</td>
<td>53%</td>
<td>↑112%</td>
</tr>
<tr>
<td>Number of Schedulers</td>
<td>25</td>
<td>0</td>
<td>↓88%</td>
</tr>
</tbody>
</table>
Comment from WLY

“The utilization of the MEO is driving us to improve our discipline and causing a culture change”
Outline

- Introduction
- Manufacturing Execution Optimization
- A Case Study
- Research Issues
- Road map to digital supply chain management
Case 3: Kimberly-Clark: Real-time Optimization
Simulation Optimization

\[
\min_{x \in \Theta} f(x) \equiv E[L(x, \omega)],
\]

where \( \Theta \) is the solution space. \( L(x, \omega) \) is available through simulation and \( \omega \) denotes the random factor.

- Many systems are too complicated to be described by mathematical models, and simulation provides a faithful description for them.
- The standard approach to estimate \( f(x) \) is by \( \hat{f}(x) \equiv \frac{1}{n} \sum_{i=1}^{n} L(x, \omega_i) \).
- The ultimate accuracy of the estimate cannot improve faster than \( 1/\sqrt{n} \).

Solving the simulation optimization problem in real-time!
"A New Budget Allocation Framework for the Expected Opportunity Cost"
Accepted by **Operations Research**

---

**EOC Allocation Problem**

\[
\begin{align*}
\text{min} \quad & EOC \\
\text{s.t.} \quad & \sum_{i=1}^{k} \alpha_i = 1, \\
& \alpha_i \geq 0, \quad i = 1, 2, \ldots, k.
\end{align*}
\]

- A major difficulty associated with the EOC allocation problem is that EOC cannot be analytically expressed

---

**FD Allocation Problem**

\[
\text{Problem } P : \quad \max_{\alpha_1, \ldots, \alpha_r} \quad g_\alpha(\alpha_1, \ldots, \alpha_r)
\]

\[
\text{s.t.} \quad \sum_{i=1}^{r} \alpha_i = 1 \\
\alpha_i \geq 0, \quad i = 1, \ldots, r
\]

where

\[
g_\alpha(\alpha_1, \ldots, \alpha_r) = \sum_{i \in S} P(\tilde{X}(n_{\alpha_i}) < \gamma) + \sum_{i \notin S} P(\tilde{X}(n_{\alpha_i}) > \gamma)
\]

---

**Feasibility Determination**

**In real-time!**
FD Allocation Problem

\[ \text{Problem } \mathcal{P} : \quad \max_{\alpha_1, \ldots, \alpha_r} \quad g_n(\alpha_1, \ldots, \alpha_r) \]

\[
\text{s.t. } \sum_{i=1}^{r} \alpha_i = 1 \\
\alpha_i \geq 0, \quad i = 1, \ldots, r
\]

where

\[
g_n(\alpha_1, \ldots, \alpha_r) = \sum_{i \in S} P(\bar{X}_i(n\alpha_i) < \gamma) + \sum_{i \notin S} P(\bar{X}_i(n\alpha_i) > \gamma)
\]
Theorem 1

FLD allocation rule performs no worse than ALD/OCBA rule. Furthermore, if $l_i(\gamma)$'s are not all equal, FLD allocation rule always performs better than ALD/OCBA rule.
Approximation of $g_n$

Suppose $X_{ij}$ is general light tailed distributed

$$g_n(\alpha_1, ..., \alpha_r) = \sum_{i \in S_Y} P(\tilde{X}_i(n\alpha_i) < \gamma) + \sum_{i \in S_N} P(\tilde{X}_i(n\alpha_i) > \gamma)$$

- A major difficulty in general distribution situation is that $g_n$ does not have a closed form expression
- We present an approximation and also a lower bound for $g_n$, 
  $$g_n(\alpha_1, ..., \alpha_r) \approx \sum_{i=1}^{r} (1 - e^{-n\alpha_i l_i(\gamma)})$$
Problem $\mathcal{P}2$: \[
\min_{\alpha_1, \ldots, \alpha_r} \sum_{i=1}^{r} e^{-n\alpha_i I_i(\gamma)}
\]
\[s.t. \sum_{i=1}^{r} \alpha_i = 1\]
\[\alpha_i \geq 0, i = 1, \ldots, r\]

Result: problem $\mathcal{P}2$ is solved by $\alpha_i = p_i^*(1 + \frac{\alpha_i}{n})$, $i = 1, \ldots, r$. 
Outline

- Introduction
- Manufacturing Execution Optimization
- A Case Study
- Research Issues
- Road map to digital supply chain management
5. 航天先进制造中的数字化、智能化制造基础。

主要研究方向：

（1）复杂航天产品数字供应链协同管理理论与方法；
Thank You!
ERP Summary

ERP got the numbers right
Timing related decisions are almost useless
Why?
MES: Manufacturing Execution Systems

Planning and scheduling is based on MRP or APS technologies.

Keep tracking time-related activities.
SCM—Use Inventory to deal with uncertainty