Tools & Trends in
Product Development
Percent of Current Sales Contributed by New Products

Self Reported Standing in Industry
Decay Curve

Ideas Tested Launched Success

1990 1995
Design Processes
NPD Processes in Use in the US

STAGE GATE PROCESSES 56 %

- 3rd Gen. Stage Gate
- Facilitated Stage Gate
- Stage Gate
- Functional, sequential
- Informal
- None
Process Tasks …

- **Product Line Planning**
  - Portfolio, Competition

- **Strategy Development**
  - Target Market, Needs, Attractiveness

- **Idea/Concept Generation**
  - Opportunities and Solutions

- **Idea Screening**
  - Sort, Rank, Eliminate
... Process Tasks

- **Business Analysis**
  - Business Case, Development Contract

- **Development**
  - Convert Concept into Working Product

- **Test & Validation**
  - Product Use, Market

- **Manufacturing Development**
  - Developing and Piloting Manufacturing Process

- **Commercialization**
  - Launch of Full-Scale Production and Sales
Tasks Included in Processes

- Commercialization
- Manufacturing Development
- Test & Validation
- Development
- Business Analysis
- Screening
- Idea Generation
- Project Strategy
- Product Line Planning
Percentage of Projects Using Multifunctional Teams

- New-to-World
- New-to-Firm
- Major Revision
- Cost Reduction
- Repositioning
- Minor Improvement
Tools
Perceived Importance and Use of Marketing Research Tools

- Voice of Customer
- Pre-Test Markets
- Test Markets
- Conjoint Analysis
- Beta Testing
- Concept Tests
- Focus Groups
- Customer Site Visits

Legend:
- Importance
- Degree of Use
Perceived Importance and Use of Engineering Tools
Perceived Importance and Use of Organization Tools

- CPM PERT GANNT
- Champions
- Process Owner
- Team Building Drill
- Heavyweight Manager
- QFD
- Matrix Organization
- Self Directed Teams
- Colocated Teams
- Leaderless Teams

Importance vs. Degree of Use

1. Champions: High Importance, High Degree of Use
2. Process Owner: High Importance, Moderate Degree of Use
3. Team Building Drill: High Importance, Low Degree of Use
4. Heavyweight Manager: High Importance, Low Degree of Use
5. QFD: Moderate Importance, Moderate Degree of Use
6. Matrix Organization: Moderate Importance, Low Degree of Use
7. Self Directed Teams: Low Importance, Low Degree of Use
8. Colocated Teams: Low Importance, Low Degree of Use
9. Leaderless Teams: Low Importance, Low Degree of Use
10. CPM PERT GANNT: Low Importance, Low Degree of Use
Perceived Importance: Top 5

- Voice of the Customer (4.2)
- Customer Site Visits (3.9)
- Rapid Prototyping (3.9)
- Project Scheduling Tools (3.9)
- Product Champions (3.9)
Frequency of Use: Top 5

- Project Scheduling Tools (3.7)
- Voice of Customer (3.6)
- Customer Site Visits (3.5)
- Computer-Aided Design (3.4)
- Matrix Organizations (3.2)
Performance
Past and Future Impact of New Products

- Past 5 Years
- Next 5 Years

New Product Sales and New Product Profits over 5 years.
Product Success

- Successful Products (subjective) 55.9 %
- Profitable 51.7 %
- Still on market after 5 years 74.1 %
Performance Criteria

- Repositioning
- Incremental Improvement
- Next Generation
- New Product Line
- New To World

- Customer Acceptance
- Financial Performance
- Technical Performance

Bar chart showing performance criteria for different types of products or services.
Average Length of Development Projects

- Incremental Improvement
- Next Generation
- New Product Line
- New To World

WEEKS
Further Reading

  - Data Source for preceding slides

- Cooper, Robert G. “Winning at New Products”
  - Stage-Gate Processes
Tools For Innovation: The Design Structure Matrix

Thomas A. Roemer
Spring 06, PD&D
Outline

► Overview
  ▪ Traditional Project Management Tools and Product Development

► Design Structure Matrix (DSM) Basics
  ▪ How to create
  ▪ Classification

► The Iteration Problem:
  ▪ Increasing Development Speed
  ▪ Sequencing, Partitioning and Simulation

► The Integration Problem:
  ▪ DSM Clustering
  ▪ Organizational Structures & Product Architectures
Classical Project Management Tools

- Gantt Charts
- Graph-based: PERT, CPM, IDEF
Characteristics

- Complex Depiction
- Focus on Work Flows
  - DSM focuses on Information Flows
- Ignore Iterations & Rework
  - Test results, Planned design reviews, Design mistakes, Coupled nature of the process
- Decomposition & Integration
  - Assume optimal Decomposition & Structure
  - Integration of Tasks not addressed
Design Iteration

- **Iteration**: The repetition of tasks due to new information.
  - Changes in input information (upstream)
  - Update of shared assumptions (concurrent)
  - Discovery of errors (downstream)

- **Fundamental in Product development**
  - Often times hidden

- **Understanding Iterations requires**
  - Visibility of information flows
A Graph and its DSM

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td></td>
<td></td>
<td></td>
<td>D</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>F</td>
<td></td>
<td></td>
<td></td>
<td>F</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>G</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>H</td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>I</td>
<td></td>
</tr>
</tbody>
</table>
Creating a DSM

- Design manuals
- Process sheets
- Structured expert interviews
  - Interview engineers and managers
  - Determine list of tasks or parameters
  - Ask about inputs, outputs, strengths of interaction, etc
  - Enter marks in matrix
  - Check with engineers and managers
- Questionnaires
Four Types of DSMs

- Activity based DSM
- Parameter based DSM
- Team based DSM
- Product Architecture DSM

Iteration
- Sequencing
- Partitioning
- Simulation

Integration
- Clustering
Iteration Focused Tools

Concepts, Examples, Solution
Approaches
Sequencing Tasks in Projects

Possible Relationships between Tasks

- **Dependent (Series)**
  - A → B

- **Independent (Parallel)**
  - A
  - B

- **Interdependent (Coupled)**
  - A
  - B
**DSM: Information Exchange Model**

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
<th>K</th>
<th>L</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>J</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Interpretation:**

- **Rows: Required Information**
  - D needs input from E, F & L.

- **Columns: Provided Information**
  - B transfers info to C, F, G, J & K.

**Note:**

- Information flows are easier to capture than work flows.
- Inputs are easier to capture than outputs.
DSM: Partitioned or Sequenced

Task Sequence

Series

Parallel

Coupled
Sequencing Algorithm

- Step 1: Schedule tasks with empty rows first
- Step 2: Delete the row and column for that task
- Step 3: Repeat (Go to step 1)
- Step 4: Schedule tasks with empty columns last
- Step 5: Delete the row and column for that task
- Step 6: Repeat (Go to step 4)
- Step 7: All the tasks that are left unscheduled are coupled. Group them into blocks around the diagonal
### Example: Brake System Design

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer_Requirements</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wheel Torque</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pedal Mech. Advantage</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>System_Level_Parameters</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rotor Diameter</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ABS Modular Display</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Front_Lining_Coef._of_Friction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Piston-Rear Size</td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Caliper Compliance</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Piston- Front Size</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rear Lining Coef of Friction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Booster - Max. Stroke</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Booster Reaction Ratio</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>13</td>
</tr>
</tbody>
</table>
## Partitioned DSM: Brake Design

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>4</th>
<th>2</th>
<th>10</th>
<th>8</th>
<th>3</th>
<th>11</th>
<th>7</th>
<th>13</th>
<th>5</th>
<th>12</th>
<th>9</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Customer_Requirements</strong></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td></td>
<td></td>
<td>5</td>
<td>13</td>
<td>7</td>
<td>12</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td><strong>System_Level_Parameters</strong></td>
<td>4</td>
<td>X</td>
<td>X</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td></td>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Wheel Torque</strong></td>
<td>2</td>
<td></td>
<td>X</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td>6</td>
<td></td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Piston- Front Size</strong></td>
<td>10</td>
<td>X</td>
<td>X</td>
<td>10</td>
<td>X</td>
<td></td>
<td></td>
<td>6</td>
<td></td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Piston-Rear Size</strong></td>
<td>8</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>8</td>
<td></td>
<td>6</td>
<td></td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Pedal Mech. Advantage</strong></td>
<td>3</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>3</td>
<td></td>
<td></td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Rear Lining Coef. of Friction</strong></td>
<td>11</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>11</td>
<td>X</td>
<td>X</td>
<td></td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Front_Lining_Coeff. of Friction</strong></td>
<td>7</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>7</td>
<td>X</td>
<td>X</td>
<td></td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Booster Reaction Ratio</strong></td>
<td>13</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>13</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Rotor Diameter</strong></td>
<td>5</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Booster - Max. Stroke</strong></td>
<td>12</td>
<td>X</td>
<td></td>
<td>12</td>
<td>X</td>
<td></td>
<td></td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Caliper Compliance</strong></td>
<td>9</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>ABS Modular Display</strong></td>
<td>6</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6</td>
</tr>
</tbody>
</table>
Task Sequencing Example

Space Shuttle Main Engine
Engine Components

- Controller
- LPFTP turbine drive duct
- LPFTP discharge duct
- LPFTP turbine discharge duct
- LPX fuel duct
- Fuel bleed valve
- HP fuel duct
- Main fuel valve
- Hot gas manifold
- HP LOX duct
- Main oxidizer valve
- High-pressure oxidizer turbopump
- Nozzle
- Low-pressure oxidizer turbopump
- Low-pressure oxidizer duct
- Pneumatic control assembly
- Preburner fuel supply ducts
- Preburner LOX supply duct
- Main combustion chamber
- Chamber coolant valve
- Low-pressure fuel turbine turbopump
- Oxidizer preburner
- Oxidizer bleeder valve
- LPFTP BLEED VALVE
- LPFTP BLEED VALVE
- LPFTP BLEED VALVE
Dependency Relations in Conceptual Design Block

<table>
<thead>
<tr>
<th>ACTIVITIES</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
<th>20</th>
<th>21</th>
<th>22</th>
<th>23</th>
<th>24</th>
<th>25</th>
<th>26</th>
<th>27</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSP Engine Balance</td>
<td>1</td>
<td>4</td>
<td>0.15</td>
<td>0.1</td>
<td>0.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CMT Make Preliminary Material Selection</td>
<td>2</td>
<td>1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CST Assess Pump Housing</td>
<td>3</td>
<td></td>
<td>8</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design Pump Housing</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td>0.5</td>
<td>0.2</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td>0.1</td>
<td>1</td>
<td>0.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CST Assess Turbine Housing</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CST Compare Design Annulus Area</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CST Compare Design Tip Speed</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CST Compare Design Tip Speed</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CST Compare Design Tip Speed</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CST Compare Design Tip Speed</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CST Compare Design Tip Speed</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CST Compare Design Tip Speed</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CST Compare Design Tip Speed</td>
<td>13</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CST Compare Design Tip Speed</td>
<td>14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CST Compare Design Tip Speed</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CST Compare Design Tip Speed</td>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CST Compare Design Tip Speed</td>
<td>17</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CST Compare Design Tip Speed</td>
<td>18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CST Compare Design Tip Speed</td>
<td>19</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CST Compare Design Tip Speed</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CST Compare Design Tip Speed</td>
<td>21</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CST Compare Design Tip Speed</td>
<td>22</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CST Compare Design Tip Speed</td>
<td>23</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CST Compare Design Tip Speed</td>
<td>24</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CST Compare Design Tip Speed</td>
<td>25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CST Compare Design Tip Speed</td>
<td>26</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CST Compare Design Tip Speed</td>
<td>27</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Block Decomposition

\[
\min \sum_{ij \in A} a_{ij} n_{ij} y_{ij}
\]

s.t.

\[
\sum_{m=1}^{M} x_{im} = 1, \quad \forall \ i
\]

\[
\sum_{i=1}^{N} x_{im} \leq C, \quad \forall \ m
\]

\[
x_{im} - \sum_{h=m+1}^{M} x_{jh} - y_{ij} \leq 0, \quad \forall \ i, j, m
\]

\[
x_{im}, y_{ij} \in \{0,1\}, \quad \forall \ i, j, m
\]

\(i,j = \) index for activities, \(i,j = 1,2,\ldots,N;\)

\(m = \) index for stages, \(m = 1,2,\ldots,M;\)

\(A = \) the set of directed arcs in the design graph;

\(a_{ij} = \) the level of dependency of activity \(i\) on \(j\)

\(x_{im} = \begin{cases} 
1 & \text{if activity } i \text{ is assigned to stage } m \\
0 & \text{otherwise}
\end{cases}\)

\(y_{ij} = \begin{cases} 
0 & \text{if arc } ij \text{ is a feedback between stages} \\
1 & \text{otherwise}
\end{cases}\)

\(n_{ij} = \begin{cases} 
W & (\text{a large number}) \text{ if } a_{ij} = 1 \\
1 & \text{otherwise}
\end{cases}\)
Resulting Structure for Conceptual Design Block

<table>
<thead>
<tr>
<th>ACTIVITIES</th>
<th>1</th>
<th>10</th>
<th>9</th>
<th>2</th>
<th>7</th>
<th>8</th>
<th>17</th>
<th>11</th>
<th>12</th>
<th>6</th>
<th>16</th>
<th>20</th>
<th>21</th>
<th>19</th>
<th>15</th>
<th>13</th>
<th>4</th>
<th>14</th>
<th>18</th>
<th>22</th>
<th>5</th>
<th>23</th>
<th>24</th>
<th>25</th>
<th>26</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSP Engine Balance</td>
<td>4</td>
<td></td>
<td>0.1</td>
<td>0.15</td>
<td>0.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHX Determine Pumping Components</td>
<td>10</td>
<td></td>
<td>0.1</td>
<td>0.1</td>
<td>0.2</td>
<td>0.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CST Compare Design Impeller Tip Speeds</td>
<td>9</td>
<td></td>
<td>0.1</td>
<td>0.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IT Make Preliminary Material Selections</td>
<td>2</td>
<td></td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAX Determine Optimum Turbine Staging</td>
<td>7</td>
<td>1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.2</td>
<td>0.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ST Compare Design Pitchline Velocities</td>
<td>8</td>
<td></td>
<td></td>
<td>0.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CDE Design Turbine</td>
<td>17</td>
<td></td>
<td>0.2</td>
<td>1</td>
<td>0.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CDE Design Pumping Elements</td>
<td>11</td>
<td></td>
<td>1</td>
<td>0.5</td>
<td>0.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CST Evaluate Rotor Sizing</td>
<td>12</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CST Compare Design Annulus Area</td>
<td>6</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CDE Position Bearings and Selection</td>
<td>16</td>
<td></td>
<td>1</td>
<td>0.2</td>
<td>0.1</td>
<td>0.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CSL Define Seal System</td>
<td>20</td>
<td></td>
<td>1</td>
<td>0.2</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CSL Define Individual Sealing Elements</td>
<td>21</td>
<td></td>
<td>0.1</td>
<td>1</td>
<td>2</td>
<td>0.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CDE Incorporate Seal Dimensions</td>
<td>19</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CBR Determine Bearing Geometry</td>
<td>15</td>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CDE Incorporate Bearing Dimensions</td>
<td>13</td>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
<td>0.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design Pump Housing</td>
<td>4</td>
<td>1</td>
<td>0.5</td>
<td>1</td>
<td></td>
<td>0.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CST Assess Pump Housing</td>
<td>3</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design Turbine Housing</td>
<td>27</td>
<td></td>
<td>0.5</td>
<td>1</td>
<td></td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CDE Design Rotor</td>
<td>14</td>
<td>0.2</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DE Integrate Rotor and Structure Layout</td>
<td>18</td>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CDE Develop Thrust Balance</td>
<td>22</td>
<td>0.2</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CST Assess Turbine Housing</td>
<td>5</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CRD Build FE Model</td>
<td>23</td>
<td></td>
<td>0.1</td>
<td>1</td>
<td>0.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CRD Define Linear Rotordynamic Behavior</td>
<td>24</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CRD Evaluate Design</td>
<td>25</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CDE Analyze Weight</td>
<td>26</td>
<td></td>
<td></td>
<td>1</td>
<td>0.2</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
STC’s Existing Process

- Conceptual Design
- Negotiation
- Detail Design
- Manufacturing & Testing

Program Office  Project Team  Functional Departments
Proposed Process

Conceptual Design

Negotiation

Detail Design

Manufacturing & Testing

Core Design Team

Program Office

Functional Departments
Pilot Project Performance

As-Is

To-Be

Conceptual Design

Detail Design

Fabrication & Test

Project Completion Time [days]

27% Savings

9d

39 days

68 days

20 days

25 days

40 days

20 days

25 days

40 days
DSM Simulation

- Task A requires input from task C
- Perform A by assuming a value for C’s output
- Deliver A’s output to B
- Deliver B’s output to C
- Feed C’s output back to A
  - Check initial assumption (made by A)
- Update assumption and repeat task A.
Simulating Rework

R is the probability that Task A will be repeated once task C has finished its work.

\[ R = 0.0 \]: There is 0 chance that A will be repeated based on results of task C.

\[ R = 1.0 \]: There is 100% probability that A will be repeated based on results of task C.
Simulating 2\textsuperscript{nd} Order Rework

Second Order rework is the rework associated with forward information flows that is triggered by feedback marks.

First order rework: Output of task C causes task A to do some rework
2\textsuperscript{nd} order rework: Consequently there is a chance tasks depending on A (e.g. task B) will also be repeated.
Simulating Rework Impact

\(I = 0.0\) : If task A is reworked due to task C results, then 0\% of task A’s initial duration will be repeated.

\(I = 1.0\) : If task A is reworked due to task C results, then 100\% of task A’s initial duration will be repeated.
Simulation Results

- DSM contains rework probabilities and impacts
- Cost and time add up
- Many runs produce a distribution of total time and cost
- Different task sequences can be tried

Gantt Chart with Iteration

- Typical Gantt chart shows monotone progress
- Actual project behavior includes tasks stopping, restarting, repeating and impacting other tasks

Lessons Learned: Iteration

- Development is inherently iterative
- Understanding of coupling is essential
- Iterations improve quality but consumes time
- Iteration can be accelerated through
  - Information technology (faster iterations)
  - Coordination techniques (faster iterations)
  - Decreased coupling (fewer iterations)

- Two Types of Iteration
  - Planned Iterations (getting it right the first time)
  - Unplanned iterations (fixing it when it’s not right)
Integration Focused Tools

Concepts, Examples, Solution Approaches
Team Selection

- Team assignment is often opportunistic
  - “We just grab whoever is available.”
- Not easy to tell who should be on a team
- Tradition groups people by function
- Info flow suggests different groupings
- Info gathered by asking people to record their interaction frequency with others
Clustering a DSM

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>D</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>F</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>G</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

No Dependency

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>F</th>
<th>E</th>
<th>D</th>
<th>B</th>
<th>C</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>F</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>D</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>G</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Low

|   |   |   |   |   |   |   |   |
|---|---|---|---|---|---|---|
| E | E |   |   |   |   |   |
| D | D |   |   |   |   |   |
| B | B |   |   |   |   |   |
| C | C |   |   |   |   |   |

Hi
Alternative Arrangement

Overlapped Teams

No Dependency  Low  Hi
GM’s Powertrain Division

- 22 Development Teams into four System Teams
  - Short block: block, crankshaft, pistons, conn. rods, flywheel, lubrication
  - Valve train: cylinder head, camshaft and valve mechanism, water pump and cooling
  - Induction: intake manifold, accessory drive, air cleaner, throttle body, fuel system
  - Emissions & electrical: Exhaust, EGR, EVAP, electrical system, electronics, ignition
# Existing PD System Teams

| Engine Block | A | F | G | D | E | I | B | C | J | K | P | H | N | O | Q | L | M | R | S | T | U | V |
| Crankshaft   | F |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Flywheel     | G |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Pistons      | D |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Connecting Rods | E |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Lubrication  | I |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Cylinder Heads | B |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Camshaft/Valve Train | C |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Water Pump/Cooling | J |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Intake Manifold | K |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Fuel System  | P |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Accessory Drive | H |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Air Cleaner | N |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| A.I.R. | O |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Throttle Body | Q |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Exhaust | L |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| E.G.R. | M |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| EVAP | R |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Ignition | S |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| E.C.M. | T |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Electrical System | U |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Engine Assembly | V |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |

**Level of Dependence**
- ● High
- ○ Average
- △ Low
Proposed PD System Teams

Crankshaft
Flywheel
Connecting Rods
Pistons
Lubrication
Engine Block
Camshaft/Valve Train
Cylinder Heads
Intake Manifold
Water Pump/Cooling
Fuel System
Air Cleaner
Throttle Body
EVAP
Cylinder Heads
Intake Manifold
A.I.R.
Exhaust
E.G.R.
Accessory Drive
Ignition
E.C.M.
Electrical System
Engine Assembly

Level of Dependence
- High
- Average
- Low

Team 1
Team 2
Team 3
Team 4
System Integration Team
Lessons Learned: Integration

- Large development efforts require multiple activities to be performed in parallel.
- The many subsystems must be integrated to achieve an overall system solution.
- Mapping the information dependence reveals an underlying structure for system engineering.
- Organizations and architectures can be designed based upon this structure.
Conclusions

- The DSM supports a major need in product development:
  - documenting information that is exchanged
- It provides visually powerful means for designing, upgrading, and communicating product development activities
- It has been used in industry successfully
Additional Material