Tools & Trends in Product Development
Decay Curve

Ideas Tested Launched Success

1990 1995
Design Processes
NPD Processes in Use in the US

STAGE GATE PROCESSES 56%
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

- Commerciization
- Manufacturing Development
- Test & Validation
- Development
- Business Analysis
- Screening
- Idea Generation
- Project Strategy
- Product Line Planning
Projects Completing Tasks

- Commercialization
- Manufacturing Development
- Test & Validation
- Development
- Business Analysis
- Screening
- Idea Generation
- Project Strategy
- Product Line Planning
Average Time Spent on Tasks

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

- New-to-World: 80%
- New-to-Firm: 70%
- Major Revision: 60%
- Cost Reduction: 50%
- Repositioning: 40%
- Minor Improvement: 30%
Tools
Perceived Importance and Use of Marketing Research Tools

- **Importance**
  - Voice of Customer
  - Customer Site Visits
  - Concept Tests
  - Focus Groups
  - Beta Testing

- **Degree of Use**
  - Pre-Test Markets
  - Test Markets
  - Conjoint Analysis
Perceived Importance and Use of Engineering Tools

- Rapid Prototyping
- Concurrent Engineering
- Design for Manufacturing
- CAD
- CAE
- FMEA
- Value Analysis
- Virtual Design
- Performance Simulation

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

Percent of Total

New Product Sales

New Product Profits
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
Average Length of Development Projects

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

A | B | C | D | E | F | G | H | I
---|---|---|---|---|---|---|---|---
A | A | X |   |   |   |   |   |   |
B |   | B |   |   |   |   |   | X |
C |   | C | X |   |   |   | D | X |
D |   |   | X | D | X |   |   |   |
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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)

Independent (Parallel)

Interdependent (Coupled)
DSM: Information Exchange Model

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

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Piston- Front Size: 10
Rear Lining Coef of Friction: 11
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**Partitioned DSM: Brake Design**

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Semiconductor Design Example

Set customer target
Estimate sales volumes
Establish pricing direction
Schedule project timeline
Development methods
Macro targets/constraints
Financial analysis
Develop program map
Create initial QHJ matrix
Set technical requirements
Write customer specification
High-level modeling
Write target specification
Develop test plan
Develop validation plan
Build base prototype
Functional modeling
Develop product modules
Lay out integration
Integration modeling
Random testing
Develop test parameters
Finalize schematics
Validation simulation
Complete product layout
Continuity verification
Design rule check
Design package
Generate masks
Verify masks in fab
Run waters
Sort waters
Create test programs
Debug products
Package products
Functionality testing
Send samples to customers
Feedback from customers
Verify sample functionality
Approve packaged products
Environmental validation
Complete product validation
Develop tech. publications
develop service courses
Determine marketing name
Licensing strategy
Create demonstration
Confirm quality goals
Life testing
Intensive testing
Mtg. process stabilization
Develop field support plan
Thermal testing
Confirm process standards
Confirm package standards
Final certification
Volume production
Prepare distribution network
Deliver product to customers

Concurrent Activity Blocks

Generational Learning Feedback

Potential Iterative Loops

Sequential Activities

Parallel Activity Blocks
Task Sequencing Example

Space Shuttle Main Engine
Engine Components
## Dependency Relations in Conceptual Design Block

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Block Decomposition

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

s.t.

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

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

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

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

\[ i,j = \text{index for activities}, \quad i,j = 1,2,\ldots,N; \]

\[ m = \text{index for stages}, \quad m = 1,2,\ldots,M; \]

\[ A = \text{the set of directed arcs in the design graph}; \]

\[ a_{ij} = \text{the level of dependency of activity } i \text{ on } j \]

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

\[ y_{ij} = \begin{cases} 
0 & \text{if arc } ij \text{ is a feed back between stages} \\
1 & \text{otherwise} 
\end{cases} \]

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

| ACTIVITIES                              | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 |
|----------------------------------------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| SSP Engine Balance                     | 4 | 0.1 | 0.15 | 0.1 | |
| CHX Determine Pumping Components       | 10 | 1 | 0.1 | 0.2 | 0.2 | |
| CST Compare Design Impeller Tip Speed  | 9 | 1 | |
| PT Make Preliminary Material Selections | 2 | 0.1 | 1 | 0.1 | 0.1 | 0.1 | |
| CAX Determine Optimum Turbine Staging  | 7 | 1 | 0.1 | 0.1 | 0.1 | 0.1 | |
| ST Compare Design Pitchline Velocities | 8 | |
| CDE Design Turbine                     | 17 | 0.2 | 1 | 0.3 | 0.1 | |
| CDE Design Pumping Elements            | 11 | 1 | 0.5 | 8 | 0.3 | 0.1 | |
| CST Evaluate Rotor Sizing              | 12 | 1 | 1 | 1 | |
| CST Compare Design Annulus Area        | 6 | 1 | 1 | |
| CDE Position Bearings and Selection    | 16 | 1 | 0.2 | 1 | 3 | 0.2 | |
| CSL Define Seal System                 | 20 | 1 | 0.2 | 1 | 2 | 0.3 | 0.1 | |
| CSL Define Individual Sealing Elements | 21 | 0.1 | 1 | 2 | 0.1 | 0.2 | 0.1 | |
| CDE Incorporate Seal Dimensions        | 19 | |
| BR Determine Bearing Geometry          | 15 | 1 | 1 | 4 | 0.1 | 0.1 | 0.2 | 0.1 | |
| CDE Incorporate Bearing Dimensions     | 13 | |
| Design Pump Housing                    | 4 | 1 | 0.5 | 1 | 1 | 4 | 0.2 | 0.1 | 0.1 | |
| CST Assess Pump Housing                | 3 | |
| Design Turbine Housing                 | 27 | 0.5 | 1 | 1 | 1 | 4 | 0.2 | 0.1 | 0.1 | |
| CDE Design Rotor                       | 14 | 0.2 | 1 | 1 | 2 | 0.1 | 0.2 | 0.1 | 0.1 | |
| CDE Integrate Rotor and Structure Layout | 18 | 1 | 1 | 8 | 0.1 | |
| CDE Develop Thrust Balance             | 22 | 0.2 | 1 | 6 | |
| CST Assess Turbine Housing             | 5 | 1 | 4 | |
| CRD Build Finite Element Model         | 23 | 0.1 | 1 | 0.3 | 1 | |
| CRD Define Linear Rotordynamic Behavior | 24 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | |
| CRD Evaluate Design                    | 25 | |
| CDE Analyze Weight                     | 26 | 1 | 0.2 | 4 | |
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

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Pilot Project Performance

As-Is

9d  39 days  68 days

To-Be

20 days  25 days  40 days

27% Savings

Project Completion Time [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

<table>
<thead>
<tr>
<th>Task</th>
<th>A</th>
<th>X</th>
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<tbody>
<tr>
<td>Task B</td>
<td>R2</td>
<td></td>
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<tr>
<td>Task C</td>
<td>X</td>
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</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Task A</th>
<th>Task B</th>
<th>Task C</th>
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</table>

\[ I = 0.0 \] : 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

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

No Dependency  Low  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

<table>
<thead>
<tr>
<th>Component</th>
<th>Team 1</th>
<th>Team 2</th>
<th>Team 3</th>
<th>Team 4</th>
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</thead>
<tbody>
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<td>Engine Block</td>
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<td>Crankshaft</td>
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**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  

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
