**New Insights on
Implementing Lean in
Product Development Systems**

**Eric Rebentisch
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## Overview of This Study

- **Part of on-going LAI research on implementing Lean PD systems**
- **Research project from Oct 2008-April 2009**
- **Summary references (available at lean.mit.edu):**
  - **Benchmarking Report: "Efficient Introduction of Lean in Product Development: Results of the Survey"**
  - **Thesis: "The Lean Innovation Roadmap – A Systematic Approach to Introducing Lean in Product Development Processes and Establishing a Learning Organization", June 2009**
- **3 LAI working papers (Lean PD framework; Lean PD Implementation Factors; Lean PD Roadmap Development)**

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## Our Motivation and Focus

- **Motivation:**
  - **Lean PD is a recent, emergent phenomenon**
  - **Base of empirical evidence is still somewhat limited**
  - **Variety of assertions about what Lean PD comprises**
  - **Fundamental question still lingers: What are the attributes of a lean PD system? (independent from Toyota)**
  - **What is actually being done in typical organizations?**
- **Research questions:**
  - **What are the components of a lean PD system?**
  - **How far have typical PD organizations gotten in implementing lean?**
  - **Can we identify patterns or practices that facilitate implementation of lean practices in PD?**

## Our Approach

- **Thorough review of recent publications on Lean PD**
  - **Identified core set of Lean PD components**
- **Identified and collected data from a diverse sample of PD organizations**
  - **Designed and implemented survey based on components identified in publications**
  - **Measured a variety of factors relating to the implementation of Lean PD components**
- **Through analysis derived a framework and roadmap for implementing Lean in PD systems**

**We used a systematic, rigorous, data-based process to assess the state of Lean PD frameworks and practice**

# Literature Review Identified Superset of Lean PD System Components

| Lean PD Component | Clark et al. 1987 | Womack et al. 1991 | Karlsson 1996 | Ward 2001 | Kennedy 2003 | Morgan, Liker 2006 | Brown 2007 | Schuh 2008 |
|---|---|---|---|---|---|---|---|---|
| Workload levelling | | | x | | | x | x | x |
| Strong project manager | x | x | x | x | x | x | | x |
| Specialist career path | | | | x | x | x | | |
| Responsibil.-based plann. and contr. | | | | x | x | x | x | x |
| Cross-project knowledge transfer | | | | | | x | x | |
| Simultaneous engineering | x | x | x | | | x | x | |
| Supplier integration | x | | x | | | x | | |
| Product variety management | | | | | | x | | x |
| Rapid prototyp., simul. and testing | | | | | | x | x | |
| Process standardization | | | | | | x | x | x |
| Set-based engineering | | | | x | x | x | x | x |

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# 11 Lean PD System Components Form Basis for Gathering Data

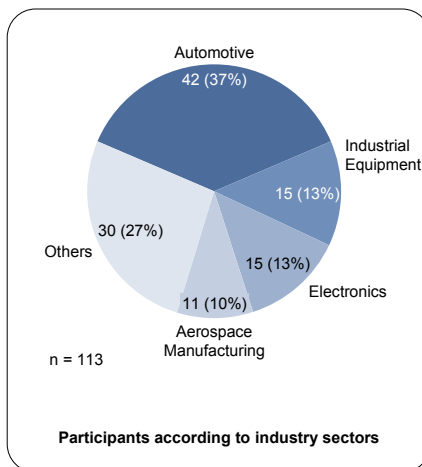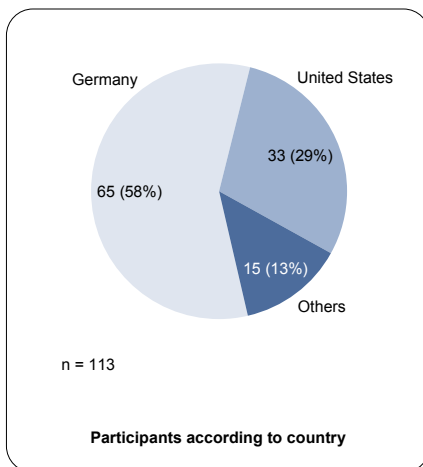| 1 | Workload levelling |
|---|---|
| 2 | Strong project manager |
| 3 | Specialist career path |
| 4 | Responsibility-based planning and control |
| 5 | Cross-project knowledge transfer |
| 6 | Simultaneous engineering |
| 7 | Supplier integration |
| 8 | Product variety management |
| 9 | Rapid prototyping, simulation and testing |
| 10 | Process standardization |
| 11 | Set-based engineering |

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## Two Online Surveys Developed
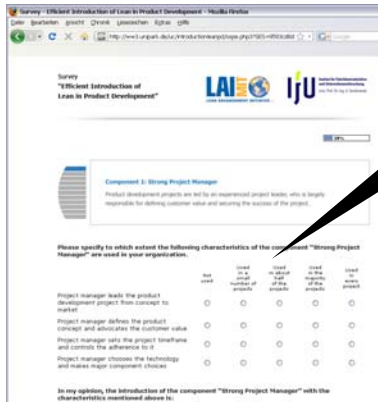


- The hypotheses were translated into two online-surveys (German and English) asking for
  - General information on the introduction process
  - The company's maturity level for each component
  - The perceived usefulness and difficulty of implementation for each component
  - The order of introduction the company has chosen
  - Particular problems experienced when introducing a component (open question)
- The survey announcement was distributed to about 900 product development managers, chief engineers and development engineers using German and US LinkedIn, MIT Alumni Database, contacts of LAI and IFU, ILP, industry associations, chambers of commerce as well as personal contacts
- 113 valid responses

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## Location and Industry Sector of Survey Participants



**Participants according to country**

n = 113

Germany 65 (58%)
United States 33 (29%)
Others 15 (13%)



**Participants according to industry sectors**

n = 113

Automotive 42 (37%)
Industrial Equipment 15 (13%)
Electronics 15 (13%)
Aerospace Manufacturing 11 (10%)
Others 30 (27%)

11 responses from LAI member firms

## Annual Revenue of Survey Participants

**Revenue in \$ (2007)**

| Revenue | Number of respondents | Percentage |
|---|---|---|
| 0 - 10 M | 10 | 8.8 % |
| 10 - 100 M | 17 | 15.0 % |
| 100 M - 1 BN | 29 | 25.7 % |
| 1 BN - 10 BN | 27 | 23.9 % |
| 10 BN - 100 BN | 21 | 18.6 % |
| >100 BN | 9 | 8.0 % |

n = 113

**Number of respondents**
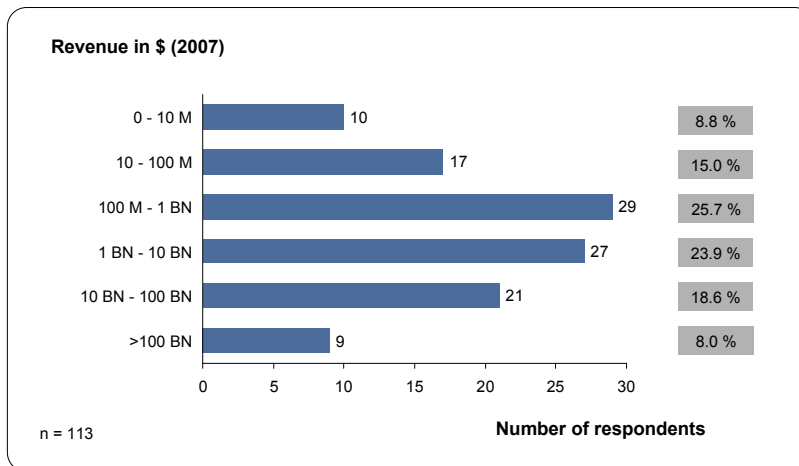
## Primary Areas of Measurement

- **The company's maturity level for each component (level of use of a lean PD component)**

- **The perceived benefit and ease of implementation for each component**

- **The order of introduction the company has chosen (rank order)**

- **Others (not addressed here)**
  - **General information on the introduction process**
  - **Particular problems experienced when introducing a component (open question)**

**Implementation of Lean PD Components**

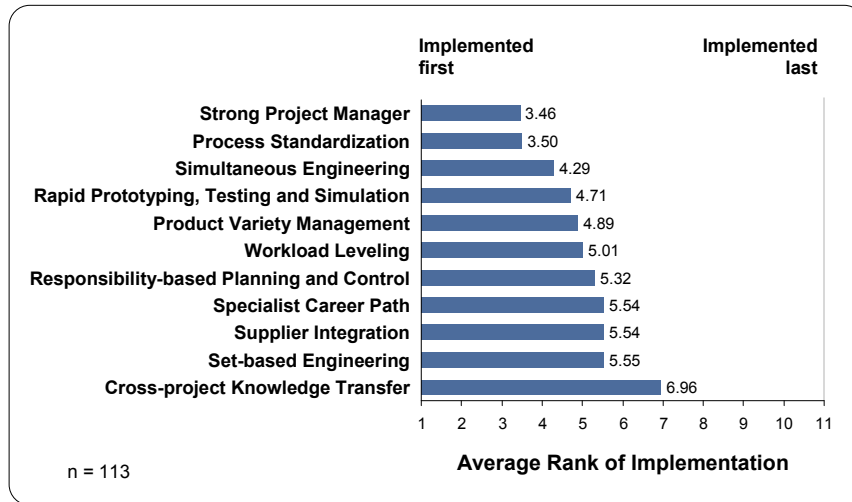| | Not used | Used in about half of the projects | Used in every project |
|---|---|---|---|
| Process Standardization | | | 3.62 |
| Simultaneous Engineering | | | 3.36 |
| Strong Project Manager | | | 3.34 |
| Workload Leveling | | | 3.33 |
| Specialist Career Path | | | 3.31 |
| Product Variety Management | | | 3.20 |
| Supplier Integration | | | 3.12 |
| Rapid Prototyping, Testing and Simulation | | | 3.05 |
| Responsibility-based Planning and Control | | | 3.02 |
| Set-based Engineering | | | 2.71 |
| Cross-project Knowledge Transfer | | | 2.46 |

Average Rating Use

n = 113

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**Each Component Comprises 4 Characteristics (Indicators)**

| | Not used | Used in about half of the projects | Used in every project |
|---|---|---|---|
| Process Standardization | | | 3.62 |
| Simultaneous Engineering | | | 3.36 |

| | Average Rating Use | |
|---|---|---|
| Standard milestones define a sequence in which the development tasks are conducted | 4.09 | σ=1.09 |
| Standardized tools are used for project planning and control | 3.81 | σ=1.16 |
| Standardized tools and procedures are used for design tasks | 3.51 | σ=1.04 |
| Standardized documents are used for capturing knowledge and lessons learned | 3.07 | σ=1.29 |

n = 113

**Rank Order of Implementation**

| | Implemented first | | | | | | Implemented last | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|

Strong Project Manager — 3.46
Process Standardization — 3.50
Simultaneous Engineering — 4.29
Rapid Prototyping, Testing and Simulation — 4.71
Product Variety Management — 4.89
Workload Leveling — 5.01
Responsibility-based Planning and Control — 5.32
Specialist Career Path — 5.54
Supplier Integration — 5.54
Set-based Engineering — 5.55
Cross-project Knowledge Transfer — 6.96

n = 113

**Average Rank of Implementation**

**Perceived Benefits From Implementation of the Component**

| | Very low | Somewhat low | Somewhat high | Very high |
|---|---|---|---|---|

Simultaneous Engineering — 5.14
Process Standardization — 4.96
Product Variety Management — 4.85
Workload Leveling — 4.83
Cross-project Knowledge Transfer — 4.79
Supplier Integration — 4.78
Strong Project Manager — 4.77
Rapid Prototyping, Testing and Simulation — 4.62
Set-based Engineering — 4.42
Specialist Career Path — 4.38
Responsibility-based Planning and Control — 4.34

n = 113

**Average Rating Benefits of Implementation**

# Ease of Implementation

| | Very difficult | Somewhat difficult | Somewhat easy | Very easy |
|---|---|---|---|---|

| Component | Average Rating |
|---|---|
| Specialist Career Path | 3.48 |
| Simultaneous Engineering | 3.35 |
| Process Standardization | 3.29 |
| Rapid Prototyping, Testing and Simulation | 3.16 |
| Responsibility-based Planning and Control | 2.99 |
| Supplier Integration | 2.82 |
| Strong Project Manager | 2.68 |
| Workload Leveling | 2.68 |
| Set-based Engineering | 2.58 |
| Product Variety Management | 2.50 |
| Cross-project Knowledge Transfer | 2.39 |

n = 113

**Average Rating Ease of Implementation**

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# General Observations: Lean PD Components Form a Highly Interwoven System

- **Significant positive correlations between nearly all Lean PD components for implementation/use**

- **Strong Project Manager component not correlated with implementation of other components**
  - **Consistent high use across sample—a given for PD?**
    - **Spread in *Strong PM* characteristics scores suggest difference between traditional PM and Lean Strong PM (more later)**
  - **Strong PM concept emphasizes effectiveness; Other components emphasize efficiency?**

- **Data doesn't address impact of partial implementation of Lean PD components on overall system performance**
  - **Analysis highlights interdependencies in implementation of components, however**

## Commonly Cited Lean Change Elements Seen to Have Limited Relation to Implementation

- **Weak but positive correlation between existence of Lean vision/goals and implementation levels**
- **Use of Value Stream Mapping (VSM) not significantly correlated with component implementation levels**
  - **Generally not used or limited use in pockets of lean activity**
- **Use of lean specialists not significantly correlated with implementation maturity**
  - **Designation of internal lean champion**
  - **Use of external change agents (*sensei*)**

## Developing an Implementation Roadmap

- **<u>Current state</u>: Build from what we know now: how firms are, on average, implementing Lean practices in PD**
- **Current state approximation: use average use of the 44 characteristics to define the overall order of implementation (~practice maturity measure)**

# Lean PD components and characteristics

| 11. | Process Standardization | 1. | Standard milestones define a sequence in which the development tasks are conducted |
| | | 2. | Standardized tools are used for project planning and control |
| | | 3. | Standardized tools and procedures are used for design tasks |
| | | 4. | Standardized documents are used for capturing knowledge and lessons learned |
| 10. | Simultaneous Engineering | 5. | Representatives from manufacturing, quality assurance and purchasing are integrated in the concept definition phase |
| | | 6. | There are frequent review meetings with development, manufacturing, quality assurance and purchasing |
| | | 7. | There is a formalized process for evaluating design proposals regarding manufacturing and assembly compatibility |
| | | 8. | Development and testing of production facilities is done in parallel to product development |
| 9. | Strong Project Manager | 9. | Project manager leads the product development project from concept to market |
| | | 10. | Project manager defines the product concept and advocates the customer value |
| | | 11. | Project manager sets the project timeframe and controls the adherence to it |
| | | 12. | Project manager chooses the technology and makes major component choices |
| 8. | Workload Leveling | 13. | Product development resources are planned on a cross-project basis |
| | | 14. | Development activities are scheduled and prioritized |
| | | 15. | Actual and planned capacity utilization are compared frequently |
| | | 16. | Resources are flexibly adapted in case of occurring bottlenecks |

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# Current State: Average Implementation of Lean PD Components
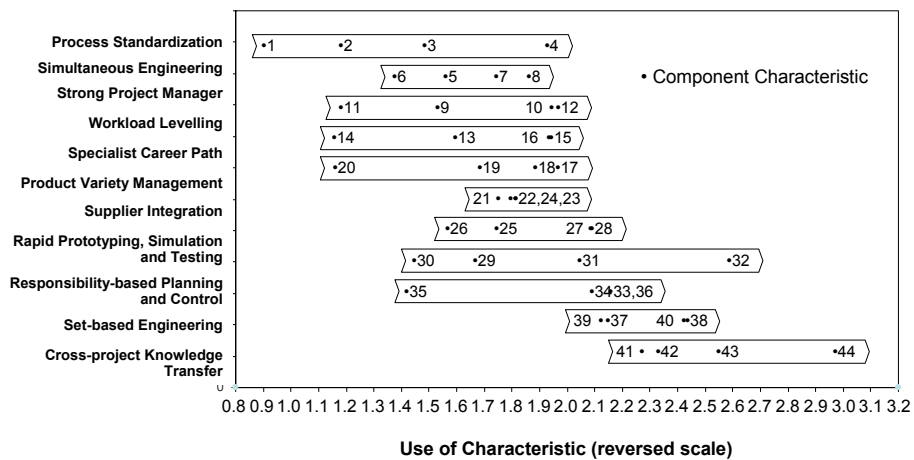


Use of Characteristic (reversed scale)

• Component Characteristic

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## Developing an Implementation Roadmap, cont.

- **Future state prediction: Adjust implementation timing for each characteristic reflecting insights from analysis of all components**
  - **Logical and evidence-based precedence (i.e., does use of a specific component correlate with the perceived ease of implementing other Lean PD components?)**
  - **Degree of interdependence between components (i.e., components with a high mutual dependency should be implemented concurrently)**
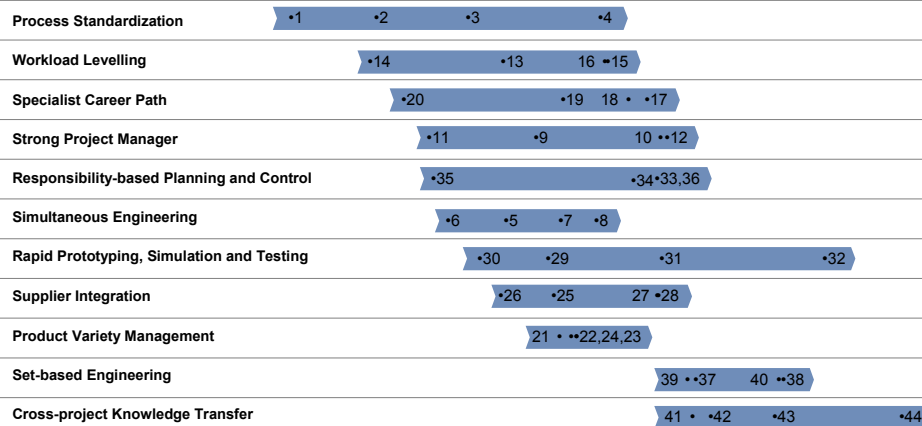
> **Use data-based insights to develop an idealized *future state* implementation roadmap**

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## Future State: Adjusted Lean PD Component Implementation

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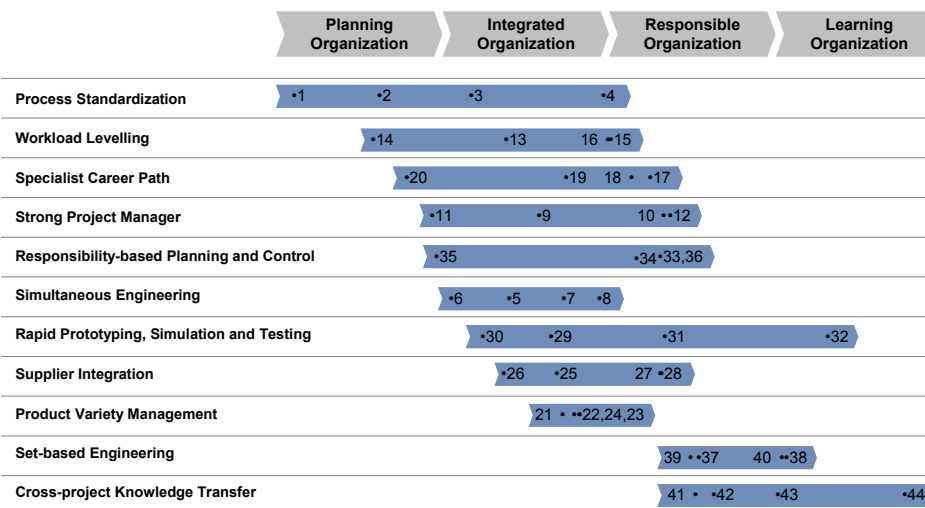## Gaining Insights From the Future State Roadmap

- **Roadmap divided into four major Implementation phases**
  - **Names induced from groupings of similar characteristics, from general themes in each group, and represent increasing levels of system lean maturity**
- **Lean PD components are implemented in concurrent and overlapping implementation streams of considerably differing lengths—some elements are harder than others**
- **Relatively large gaps between the implementation of single characteristics—not everything happens at once**
- **Arrows showing the implementation streams for the Lean PD components have a clear beginning and end— implementation isn't complete at the end of the arrow, with on-going opportunities for continuous improvement**

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## Lean PD implementation stages

| | Planning Organization | Integrated Organization | Responsible Organization | Learning Organization |
|---|---|---|---|---|
| Process Standardization | •1  •2 | •3          •4 | | |
| Workload Levelling | •14 | •13      16 •15 | | |
| Specialist Career Path | •20 | •19   18 •  •17 | | |
| Strong Project Manager | •11 | •9      10 ••12 | | |
| Responsibility-based Planning and Control | •35 | •34•33,36 | | |
| Simultaneous Engineering | •6 | •5   •7  •8 | | |
| Rapid Prototyping, Simulation and Testing | •30 | •29      •31 | •32 | |
| Supplier Integration | •26 | •25   27 •28 | | |
| Product Variety Management | 21 • ••22,24,23 | | | |
| Set-based Engineering | | 39 ••37   40 ••38 | | |
| Cross-project Knowledge Transfer | | 41 •  •42   •43 | •44 | |

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# Phase 1: Planning Organization

- **Establish structure and discipline to enable more stable and predictable PD system operations**
- **Build the necessary capabilities for planning and scheduling product development projects. e.g.:**
  - Standard milestones define the sequence of development tasks (no.1)
  - Development activities clearly scheduled and prioritized (no.14)
  - Standardized planning and control (no.2)
  - The project manager sets the project timeframe and controls adherence (no.11)
  - Performance of development engineers regularly evaluated and discussed in feedback meetings (no. 20 and 35)
- **While at first, the planning of PD projects may be done by designated planners, this task should be delegated to the project managers by the end of phase one**

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# Phase 2: Integrated Organization

- **Establish tighter control over coordination of activities, and reduce variation and unpredictability in task execution, in part through rationalization of the product architecture.**
- **Enhance internal design capabilities through tools and product optimization**
  - Standardized tools and procedures for design tasks (no.3), computer-aided modeling and simulation (no.30) and quick physical modeling (no.29)
  - Clear goals for the use of off-the-shelf components within a product (no.21) and the reuse of product parts among different modules, products and product families (no.22)
- **Important internal stakeholders (e.g., manufacturing and quality assurance) are integrated into the design process to ensure goals are well aligned**
  - Integration of development, manufacturing, quality assurance and purchasing into the concept definition phase (no.5) and evaluating design proposals for manufacturing and assembly compatibility (no.7), with frequent review meetings (no.6)
- **Phase 2 activities help prepare for phase 3, the responsible organization.**
  - Small number of high-capability, critical parts suppliers used (no.26)
  - A mentoring system for junior engineers (no.19)
  - Standardized documents capture best practices and lessons learned (no.4)

## Phase 3: Responsible Organization

- **Establish a sense of ownership among all participants**
- **Develop PD culture that rewards responsibility and personal commitment**
  - Project manager directly involved in defining the product concept and advocating customer value (no.10), and choosing key technologies (no.12)
  - Developers check their own performance with formalized feedback process (no.34), set their own goals, negotiate deadlines for their tasks (no.33), and are given the opportunity to experiment with new approaches to improve efficiency (no.36)
  - Engineers' promotions based on functional experience and knowledge (no.18), advancing in their functional areas without losing their technical focus (no.17)
  - Critical suppliers integrated early in the conceptual design process (no.27) and mentored/developed similar to internal employees (no.28)
- **The resulting innovative potential enables the organization to explore a larger number of ideas and conserve the generated knowledge for reuse, e.g.,**
  - Product solutions intensively tested using rapid prototyping technology (no.31), with decisions in favor of a particular solution delayed until objective data are available (no.39)
  - Implement methods to collect information on successful procedures, tools and designs across projects (no.41), with best practices and lessons learned reviewed and reused in subsequent projects (no.42)

## Phase 4: Learning Organization

- **Maximize organizational learning**
  - **Alternative solutions for a product module are designed and tested simultaneously (no.38), narrowed, and retained once a particular concept has been selected (no.40)**
  - **Quickly generate and test products using lean methods for prototype build and tool manufacturing (no.32)**
  - **The existing knowledge base is continuously updated (no.43)**
  - **Knowledge abstracted and simplified to yield generalizable conclusions on how to improve the company's products and processes (no.44)**

**General Observations**

- **Lean PD implementation stages based on analysis are consistent with our general understanding of the attributes of these systems**
  - **Solid foundation: well-defined structure of disciplined practices and execution**
  - **Focus on the big picture: key stakeholders, tools, and products work together in harmony**
  - **Engage everybody's full capabilities: develop distributed leadership and responsibility ("*everybody everyday*") across the enterprise**
  - **Exploit the capabilities: continuous learning, rapid experimentation, widespread knowledge sharing and diffusion**
    - **Implication: increased capacity and quicker turns requires growth of the business to sustain**

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**Study Summary**

- **Study contributes significant new benchmark data to Lean PD knowledge base**
- **Coherent set of Lean PD components defined based on broad review of competing ideas**
- **Relationships between components of a Lean PD system explored using empirical evidence**
- **Roadmap developed that identifies specific steps in the Lean PD journey, as well as high-level insights into the evolution of PD systems**
- **Caveat: analysis based on existing framing of Lean PD (no radical new concepts developed)**

# Questions?

# Backup Slides

## Workload Leveling

| | |
|---|---|
| 1 | Workload leveling |
| 2 | Strong project manager |
| 3 | Specialist career path |
| 4 | Responsibility-based planning and control |
| 5 | Cross-project knowledge transfer |
| 6 | Simultaneous engineering |
| 7 | Supplier integration |
| 8 | Product variety management |
| 9 | Rapid prototyping, simulation and testing |
| 10 | Process standardization |
| 11 | Set-based engineering |

Resources and capacities are planned on a project and cross-project basis. In the course of the project, required resources are controlled frequently and flexibly adapted in the case of occurring bottlenecks.

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## Strong Project Manager

| | |
|---|---|
| 1 | Workload leveling |
| 2 | Strong project manager |
| 3 | Specialist career path |
| 4 | Responsibility-based planning and control |
| 5 | Cross-project knowledge transfer |
| 6 | Simultaneous engineering |
| 7 | Supplier integration |
| 8 | Product variety management |
| 9 | Rapid prototyping, simulation and testing |
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| 11 | Set-based engineering |

Product development projects are led by an experienced project leader, who is largely responsible for defining customer value and securing the success of the project from concept to market.

**Specialist Career Path**

| | |
|---|---|
| 1 | Workload leveling |
| 2 | Strong project manager |
| 3 | Specialist career path |
| 4 | Responsibility-based planning and control |
| 5 | Cross-project knowledge transfer |
| 6 | Simultaneous engineering |
| 7 | Supplier integration |
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**Engineers are given the opportunity to advance in their technical domain, based on personal coaching and frequent feedback by their superiors.**

**Responsibility-based Planning and Control**

| | |
|---|---|
| 1 | Workload leveling |
| 2 | Strong project manager |
| 3 | Specialist career path |
| 4 | Responsibility-based planning and control |
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| 6 | Simultaneous engineering |
| 7 | Supplier integration |
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| 10 | Process standardization |
| 11 | Set-based engineering |

**Development engineers are locally responsible for planning, execution and control of detailed product development activities.**

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## Cross-project Knowledge Transfer

| | |
|---|---|
| 1 | Workload leveling |
| 2 | Strong project manager |
| 3 | Specialist career path |
| 4 | Responsibility-based planning and control |
| 5 | Cross-project knowledge transfer |
| 6 | Simultaneous engineering |
| 7 | Supplier integration |
| 8 | Product variety management |
| 9 | Rapid prototyping, simulation and testing |
| 10 | Process standardization |
| 11 | Set-based engineering |

**Successful methods, designs and tools as well as areas for improvement are documented on a cross-project basis and actively used and refined in subsequent projects.**

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## Simultaneous Engineering

| | |
|---|---|
| 1 | Workload leveling |
| 2 | Strong project manager |
| 3 | Specialist career path |
| 4 | Responsibility-based planning and control |
| 5 | Cross-project knowledge transfer |
| 6 | Simultaneous engineering |
| 7 | Supplier integration |
| 8 | Product variety management |
| 9 | Rapid prototyping, simulation and testing |
| 10 | Process standardization |
| 11 | Set-based engineering |

**Production, quality assurance and purchasing departments are integrated into development activities at an early stage. The design of production processes and facilities is conducted in parallel to the development of the product.**

**Supplier Integration**

| | |
|---|---|
| 1 | Workload leveling |
| 2 | Strong project manager |
| 3 | Specialist career path |
| 4 | Responsibility-based planning and control |
| 5 | Cross-project knowledge transfer |
| 6 | Simultaneous engineering |
| 7 | Supplier integration |
| 8 | Product variety management |
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| 11 | Set-based engineering |

**Suppliers of critical parts are identified early in the project, integrated into the development process and actively supported to improve their performance.**

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**Product Variety Management**

| | |
|---|---|
| 1 | Workload leveling |
| 2 | Strong project manager |
| 3 | Specialist career path |
| 4 | Responsibility-based planning and control |
| 5 | Cross-project knowledge transfer |
| 6 | Simultaneous engineering |
| 7 | Supplier integration |
| 8 | Product variety management |
| 9 | Rapid prototyping, simulation and testing |
| 10 | Process standardization |
| 11 | Set-based engineering |

**There are targets for the use of off-the-shelf components and reuse of parts as well as standardized modules and product platforms.**

## Rapid Prototyping, Simulation and Testing

| | |
|---|---|
| 1 | Workload leveling |
| 2 | Strong project manager |
| 3 | Specialist career path |
| 4 | Responsibility-based planning and control |
| 5 | Cross-project knowledge transfer |
| 6 | Simultaneous engineering |
| 7 | Supplier integration |
| 8 | Product variety management |
| 9 | Rapid prototyping, simulation and testing |
| 10 | Process standardization |
| 11 | Set-based engineering |

**For a fast and reliable evaluation of concepts and drafts, rapid prototyping technologies, computer aided simulation, methods for fast physical modeling and flexible manufacturing are used.**

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## Process Standardization

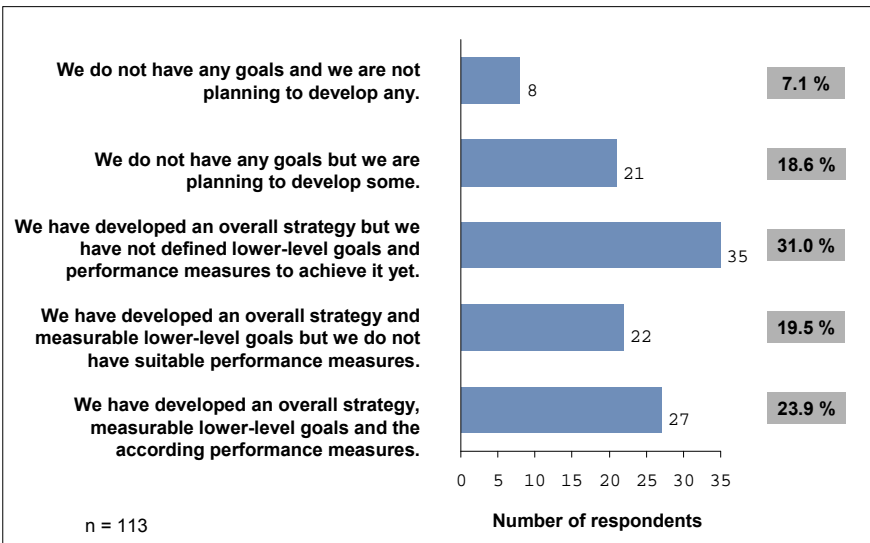| | |
|---|---|
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| 6 | Simultaneous engineering |
| 7 | Supplier integration |
| 8 | Product variety management |
| 9 | Rapid prototyping, simulation and testing |
| 10 | Process standardization |
| 11 | Set-based engineering |

**For planning, executing and documenting projects, standardized processes, tools and methods are used.**
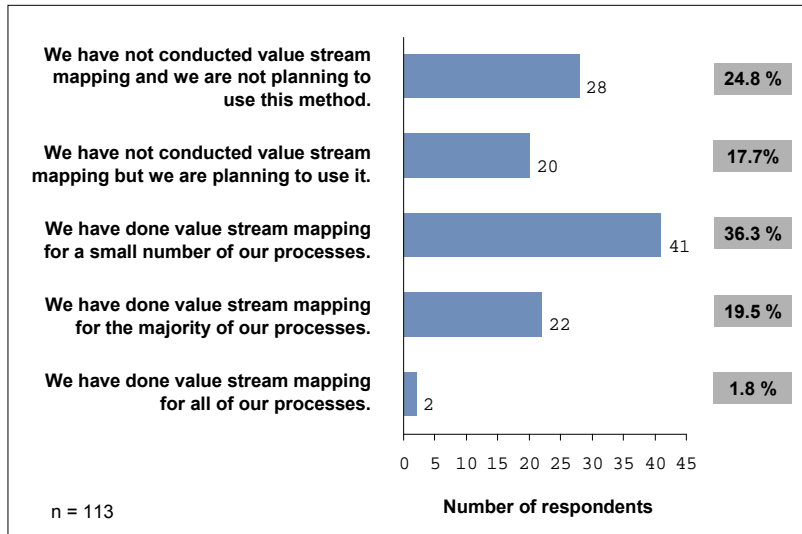
**Set-based Engineering**

| | |
|---|---|
| 1 | Workload leveling |
| 2 | Strong project manager |
| 3 | Specialist career path |
| 4 | Responsibility-based planning and control |
| 5 | Cross-project knowledge transfer |
| 6 | Simultaneous engineering |
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**When developing a product module, a large number of alternative solutions are considered early in the process. The set of solutions is subsequently narrowed based on simultaneous development and testing of the alternatives.**

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**Existence of Lean PD Vision/Goals**



We do not have any goals and we are not planning to develop any. — 8 — **7.1 %**

We do not have any goals but we are planning to develop some. — 21 — **18.6 %**

We have developed an overall strategy but we have not defined lower-level goals and performance measures to achieve it yet. — 35 — **31.0 %**

We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measures. — 22 — **19.5 %**

We have developed an overall strategy, measurable lower-level goals and the according performance measures. — 27 — **23.9 %**

n = 113

**Number of respondents**

22

**Use of Value Stream Mapping**

We have not conducted value stream mapping and we are not planning to use this method. — 28 — **24.8 %**

We have not conducted value stream mapping but we are planning to use it. — 20 — **17.7%**

We have done value stream mapping for a small number of our processes. — 41 — **36.3 %**

We have done value stream mapping for the majority of our processes. — 22 — **19.5 %**

We have done value stream mapping for all of our processes. — 2 — **1.8 %**

0 5 10 15 20 25 30 35 40 45

n = 113

**Number of respondents**

**Use of Dedicated Change Agents**

**Has your organization declared a person responsible for implementing Lean principles in product development?**

**Is your organization planning to use or already using external help (e.g. consultants, sensei, etc.) to implement Lean principles in product development?**

Yes 46%

No 54%

Yes 37%

No 63%

n = 113

**Pairwise interdependencies of the components were described qualitatively using a cause-effect matrix**

... require this component.

To what extent does this component ...

Columns:
11 Lean PD components

Rows:
11 Lean PD components

Matrix entries:
How does component in row require component in column

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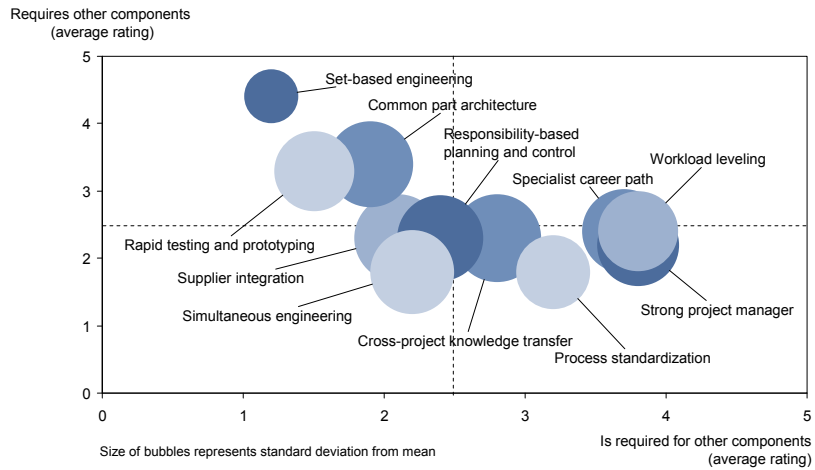**After the qualitative analysis the interdependencies were rated on a scale from 0 to 5**

| | Strong Project Manager | Specialist career path | Workload levelling | Responsibility-based planning and control | Cross-project knowledge transfer | Simultaneous engineering | Supplier integration | Product Variety Management | Rapid testing and prototyping | Process standardization | Set-based concurrent engineering | Average | Std. Deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Strong Project Manager | X | 4 | 5 | 3 | 1 | 1 | 1 | 1 | 1 | 4 | 1 | 2.20 | 1.54 |
| Specialist career path | 2 | X | 5 | 5 | 3 | 1 | 1 | 1 | | | | | |
| Workload levelling | 4 | 3 | X | 2 | 2 | 2 | 2 | 1 | | | | | |
| Responsibility-based planning and control | 4 | 5 | 4 | X | 3 | 1 | 1 | 1 | | | | | |
| Cross-project knowledge transfer | 4 | 3 | 5 | 2 | X | 1 | 1 | 1 | 1 | 4 | 1 | 2.30 | 1.49 |
| Simultaneous engineering | 4 | 2 | 2 | 1 | 1 | X | 1 | 3 | 1 | 2 | 1 | 1.80 | 0.98 |
| Supplier integration | 5 | 4 | 2 | 2 | | 1 | X | 3 | 1 | 2 | 1 | 2.30 | 1.27 |
| Product Variety Management | 4 | 5 | 5 | 1 | 5 | | 4 | X | 1 | 4 | 1 | 3.40 | 1.62 |
| Rapid testing and prototyping | 4 | 4 | 3 | 3 | 3 | 5 | | | | | | | |
| | | | | 1 | 3 | 1 | | | | | | | |
| | | | 4 | 5 | 5 | | | | | | | | |
| | | | 2.4 | 2.8 | 2.2 | | | | | | | | |
| Std. Deviation | 0.98 | 1.10 | 1.17 | 1.28 | 1.33 | 1.66 | 1.51 | 1.14 | 1.20 | 1.08 | 0.40 | | |

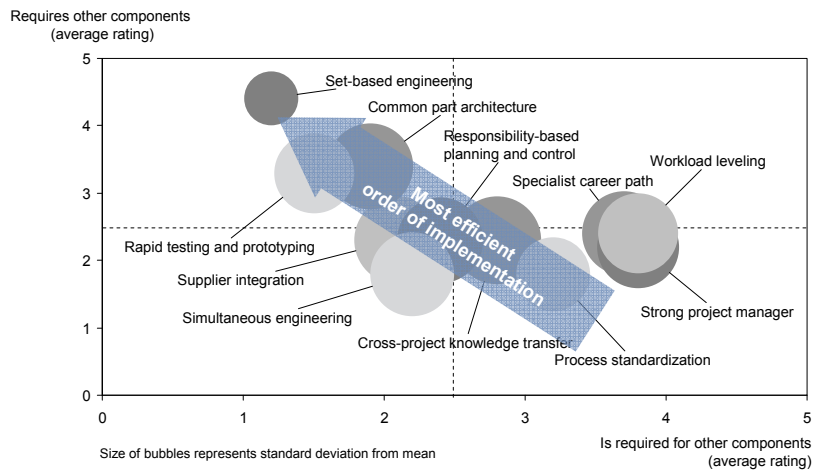Columns:
11 Lean PD components

Matrix entries:
To what extent does component in row require component in column on a scale from 0 to 5

Rows:
11 Lean PD components

24

The quantitative analysis was translated into a graphical representation of the interdependencies

Requires other components (average rating)

Set-based engineering
Common part architecture
Responsibility-based planning and control
Workload leveling
Specialist career path
Rapid testing and prototyping
Supplier integration
Simultaneous engineering
Cross-project knowledge transfer
Process standardization
Strong project manager

Size of bubbles represents standard deviation from mean

Is required for other components (average rating)

Based on the interdependencies hypotheses on the most efficient order of implementation were derived

Requires other components (average rating)

Set-based engineering
Common part architecture
Responsibility-based planning and control
Workload leveling
Specialist career path
Most efficient order of implementation
Rapid testing and prototyping
Supplier integration
Simultaneous engineering
Cross-project knowledge transfer
Process standardization
Strong project manager

Size of bubbles represents standard deviation from mean

Is required for other components (average rating)

## Using API to identify the future state

$$POS_{new,i} = POS_{old,i} - x \cdot CF_i$$

- **Task: adjust relative position (POS$_{new,i}$) of characteristics along implementation timeline using empirical insights about interdependencies, challenges**
- **Use DSM assumption: minimize distance between highly interdependent characteristics**
  - **Measure interdependence by assessing degree to which use of one practice aids/hinders the implementation of another (using correction factor—CF$_i$)**
  - **Interdependence is dimensionless—need to scale to units of measurement to make its impact meaningful (using correction coefficient—x)**

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## CF$_i$: Correlation Between Use and Ease of Implementation

| | Ease of Implementation Strong Project Manager | Ease of Implementation Set-based Engineering | Ease of Implementation Process Standardization | Ease of Implementation Specialist Career Path | Ease of Implementation Product Variety Management | Ease of Implementation Workload Leveling | Ease of Implementation Supplier Integration | Ease of Implementation Responsibility-based Planning and Control | Ease of Implementation Cross project Knowledge Transfer | Ease of Implementation Rapid Prototyping, Simulation and Testing | Ease of Implementation Simultaneous Engineering |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Use of Strong Project Manager | .212** | -.044** | -.034 | -.095 | -.191* | -.000 | -.140 | -.000 | -.252** | -.077 | -.097 |
| Use of Set-based Engineering | .091 | .201** | -.023 | .209* | -.144 | -.114 | -.000 | .144 | -.006 | .022 | -.039 |
| Use of Process Standardization | .197* | .155 | | | | | | | | .007 | .080 |
| Use of Specialist Career Path | -.025 | .170 | | | | | | | | -.070 | -.103 |
| Use of Product Variety Management | -.046 | .184 | | | | | | | | .064 | -.068 |
| Use of Workload Leveling | .100 | .220* | | | | | | | | .117 | -.052 |

| Component | | Correction Factor (CF) |
|---|---|---|
| 11. | Process Standardization | 0.053 |
| 10. | Simultaneous Engineering | 0.018 |
| 9. | Strong Project Manager | -0.086 |
| | ...ng | 0.051 |
| | ...Path | -0.034 |
| | ...Management | 0.027 |
| | ...ion | 0.035 |
| | ...g, Simulation and Testing | -0.009 |
| | ...sed Planning and Control | 0.088 |
| | ...eering | -0.017 |
| | ...owledge Transfer | 0.088 |

- Assumption: components which have a positive impact on the perceived ease of implementing others should be introduced earlier; those which do not facilitate the introduction of other components should be implemented later.
- The role each of the component plays with regard to the implementation of others is reflected in the average correlation coefficient for each row in the table

## Scaling the correction coefficient

- **Use DSM assumption: minimize distance in time between implementation of highly interdependent characteristics**
  - **Iterate to minima using empirical data and numeric methods**
  - **Use value of x (1.3) to calculate new positions for characteristics along implementation timeline**
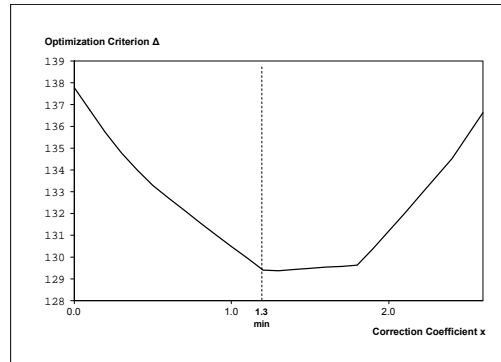
$$POS_{new,j} = POS_{old,j} - x \cdot CF_i$$

Minimize the distance between correlated characteristics:

$$\frac{|POS_{new,i} - POS_{new,j}|}{COR_{i,j}}$$

$$\min \Delta = \sum_{i=1}^{11} \sum_{j=1}^{11} \frac{|POS_{new,i} - POS_{new,j}|}{COR_{i,j}}$$

$$\min \Delta = \sum_{i=1}^{11} \sum_{j=1}^{11} \frac{|POS_{old,i} - POS_{old,j} - x \cdot (CF_i - CF_j)|}{COR_{i,j}}$$



Optimization Criterion Δ — plot vs. Correction Coefficient x, minimum at 1.3

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## Lean PD components and characteristics

| 7. | Specialist Career Path | 17. | There is a designated career path for technical specialists in their functional areas |
| | | 18. | Promotion is based on functional experience and knowledge |
| | | 19. | More experienced employees are responsible for mentoring and supporting junior engineers |
| | | 20. | Performance of individuals is regularly evaluated and discussed in feedback meetings |
| 6. | Product Variety Management | 21. | There are clear goals for the use of off-the-shelf components within a product |
| | | 22. | There are clear goals for the reuse of product parts among different modules, products and product families |
| | | 23. | There are modular components with standardized interfaces |
| | | 24. | There are common product platforms encompassing several product lines |
| 5. | Supplier Integration | 25. | Parts are evaluated according to their criticality before making outsourcing decisions |
| | | 26. | A small number of high-capability suppliers are used for critical parts |
| | | 27. | Critical suppliers are integrated in the concept definition phase |
| | | 28. | Suppliers are mentored to improve their performance |
| 4. | Rapid Prototyping, Simulation and Testing | 29. | Designs are quickly modeled and tested using physical models |
| | | 30. | Computer-aided modeling and simulation are used |
| | | 31. | Rapid prototyping technology is used |
| | | 32. | Methods of Lean Production are used in prototype build and tool manufacturing |

# Lean PD components and characteristics

| 3. | Responsibility-based Planning and Control | 33. | Developers are given the opportunity to set their own goals and negotiate deadlines for their tasks |
| | | 34. | Developers are given the opportunity to check their own performance based on a formalized feedback process |
| | | 35. | Developers are evaluated based on their performance |
| | | 36. | Developers are given the opportunity to experiment with new approaches to improve efficiency |
| 2. | Set-based Engineering | 37. | A large number of possible solutions for a product module are considered early in the process |
| | | 38. | Alternative solutions for a product module are designed and tested simultaneously |
| | | 39. | Decisions are delayed in favor of a particular solution until objective data are available |
| | | 40. | A concept for a product module is not revised once it has been selected |
| 1. | Cross-project Knowledge Transfer | 41. | There are methods and devices to collect information on successful procedures, tools and designs across projects |
| | | 42. | Best practices and lessons learned from previous projects are reviewed |
| | | 43. | Documented knowledge is continuously updated by the engineers |
| | | 44. | The collected knowledge is frequently simplified and generalized |