Chapter 10

Process Indicators for Process Engineering (PIPE)

M. Schabacker and M. Gröpper

10.1 Introduction

The campaign Process Indicators for Product Engineering (PIPE) of the companies CONTACT Software, Dassault Systèmes, IBM Software Group, IBM Global Business Services, and Transcat PLM Germany has taken over on the task of evaluating Product Lifecycle Management (PLM) solutions using standardised indicators for the product engineering process. This campaign was supported by VDMA (German Engineering Federation) as a non-materialistic sponsorship and by the Chair of Information Technologies in Mechanical Engineering, Otto-von-Guericke University Magdeburg. The chair provided scientific consulting and monitoring. After studying the literature there was only one reference publication (Alemanni *et al.*, 2008) devoted to the subject of indicators in Product Lifecycle Management. These authors had collected a lot of number indicators (e.g. part list changes number, change issue number). The objective of the PIPE campaign was to create process indicators with an interpretation context through feature cluster analysis of the product life cycle phases, indicating weaknesses in products, processes or business units, or through evaluation of formulas.

10.2 Evaluation Problem of Engineering Processes

In recent years, efforts were at the forefront of predicting the benefit aspects of PLM solutions prior to their introduction and their quantification in monetary terms. Today, the evaluation of PLM solutions after their introduction by characteristic factors is in the focus of attention.

Characteristic factors provide complex subjects in a simple (e.g. the number of engineering change requests in product development) and compressed form (e.g. early warning rate of redundant engineering change request). An *indicator* is a

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characteristic factor that can be interpreted by the user and is based on predefined values (target-actual comparison or target value). The indicator may relate to performance or capacity of the company, its individual organisational units or a machine (Schabacker and Simon, 2012). Therefore, many meaningful indicators have mainly been shown for machinery and equipment in the manufacturing. They were merged for example in the VDMA 66412-1 (VDMA 66412, 2008) and ISO 22400-2:2014 (ISO 22400-2, 2014).

But how can the definition of the indicator be applied to the environment of product development? For example in manufacturing processes, the indicator staff productivity (ratio of productive time to the present time) is fully justified. However, it is pointless in product development to regard the productive work (e.g. to measure the number of created drawings or 3D CAD models per day). There are three important influences within product development:

- the ever-changing customer requirements, which lead only to engineering change requests and after this (economic) evaluation into engineering change orders,
- easy configurable products so that the customers get exactly those products they like,
- effectively organised product development projects in project teams that develop new and complex solutions in less time.

A further influence requires the cooperation of the component-level products between internal and external product development partners to cause comprehensible decisions as quickly as possible.

Therefore, and because of these influences, the project partners of PIPE have developed indicators for the cross-cutting processes in Product Lifecycle Management:

- change management
- requirements management
- configuration management
- project management
- collaboration management

These so-called PIPE processes are described in section 10.3.

10.3 PIPE Processes

Figure 10.1 shows the four parallelly running PIPE processes *change*, *requirements*, *configuration*, and *project management* as well as *collaboration management* as a cross-cutting PIPE process compared to the other four PIPE processes.

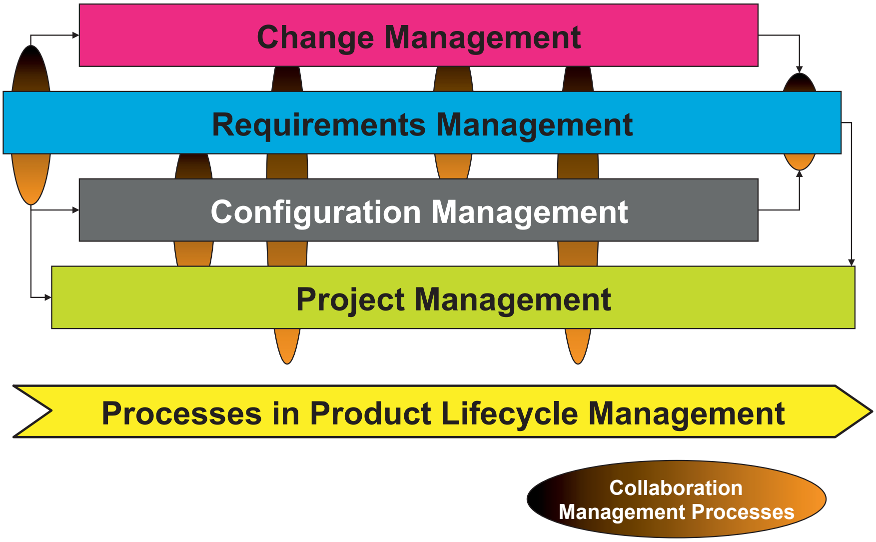

Figure 10.1. Flow of the PIPE processes in Product Lifecycle Management

10.3.1 Change Management

The change management supports all activities for the acquiring, collecting, evaluating, deciding, planning, and adding of product changes. Change management includes five sub-processes:

- identifying the reason for change
- specifying the engineering change request
- evaluating the engineering change request in the departments
- bringing together reviews and documenting decisions
- evaluating change alternatives with defining milestones

10.3.2 Requirements Management

Requirements management supports target-oriented development of products which meet specifications. It involves collecting, processing , structuring, and verifying of customer and internal requirements. Requirements management includes five sub-processes:

- collecting customer and internal requirements
- specifying requirements
- structuring and classifying requirements
- monitoring the implementation of the requirements
- reviewing requirements after the implementation

10.3.3 Configuration Management

Configuration management is a management discipline which encompasses organisational and behavioural rules to the product life cycle of a configuration unit via its development through manufacturing and support. A configuration unit is any combination of hardware, software, or services. A configuration is a set of objects that describe the product for a certain time. The status of each configuration are retained as baselines and can be built up for several views (as designed, as built, as maintained) (DIN ISO 10007, 2004).

The objective of configuration management is to document the fulfillment of physical and functional requirements of a configuration unit and to achieve full transparency referring to this. Besides, it is intended that everyone who is interested in a configuration unit uses the correct and accurate documentation (DIN ISO 10007, 2004).

Therefore, configuration management is not bound per se to a specific application context. The application and implementation of configuration management result in a configuration management process. This requires the organisation and planning. In addition to this conceptual section of configuration management four sub-processes of configuration management are to be distinguished (DIN ISO 10007, 2004):

- identifying the configuration(s)
- executing the documentation in configuration management (the so-called configuration record keeping)
- monitoring the configuration(s)
- executing the configuration auditing

10.3.4 Project Management

Project management comprises, in accordance with DIN 69901 (DIN 69901, 2009), the entirety of managerial functions, organisation, techniques, and means for the execution of a project. The project management includes four sub-processes:

- initialising the project
- planning the project
- monitoring the project
- completing the project

10.3.5 Collaboration Management

Collaboration Management controls the collaboration on component-level between internal and external partners to bring about as quickly as possible comprehensible decisions. Collaboration Management is a cross-section process to change, requirements, configuration, and project management.

10.4 PIPE Indicators

To assist companies in the identification of optimisation potentials in the product creation process using standardised process indicators, the focus of this campaign is therefore based on the Continuous Improvement Process (Schabacker and Simon, 2012). This can be reached by reorganisation, improved processes and methods as well as tools (IT systems such as CAx or PDM systems) in product development. Methods to improve training can also make a valuable contribution because for example unified modeling methods at the 3D CAD workstation improve the cooperation. A process indicator supports in

- making decisions (problem identification, representation, information extraction),
- the control of processes (target-actual comparison),
- the documentation of processes (traceability and transparency of processes) and/or
- coordination (behaviour control) of important facts and relationships in the product creation process of a company.

10.4.1 Description of the Process Indicators

The description of the process indicators is based on the VDMA 66412-1 (VDMA 66412, 2008) which includes characteristic factors for Manufacturing Execution Systems (MES).

The data for a process indicator can be collected for the actual recording either manually or read from existing IT systems (e.g. PDM systems) in a time period to be determined beforehand (monthly, quarterly, fiscal year, per project). The process indicators are designed so that the two cases are considered. Some process indicators include correlations of variables formula (indicated by the formulation for example ...ratio, ...degree), others include values based on an accumulated number of features or feature clusters (e.g. reason for change, product component, corporate responsibility). Besides, a process indicator includes

- the product creation phase (e.g. pre-design, design, manufacturing, production support),
- its benefits and/or identification of improvement potentials and/or application,
- evaluation using a trend statement (e.g. the higher, the better) and further evaluation instructions and explanations as well as
- its mapping to corporate responsibilities or departments of a company or corporate level managers, the indicator relates to this, and
- its mapping to the PIPE processes.

An example of the description of a process indicator is shown in Figure 10.2.

Name of the Indicator:	**Early Warning Rate of Redundant Engineering Change Requests**
Description of the Indicator	
Phase of the Product Creation Process:	Unnecessary process steps sooner redundant requests are detected, the sooner and avoided other processes continue or be terminated.
Benefit/ Potential for Improvement Application:	The proportion of early detected redundant requests should tend to increase due to the learning curve over time.
Time Behaviour:	continuous
Definition and Calculation of the Indicator	
Formula:	$NoECR_{RED\ err\ pre}$ = Number of Engineering Change Requests$_{\text{RED err pre}}$ $NoECR_{RED\ err}$ = Number of Engineering Change Requests$_{\text{RED err}}$ $EWRoECR_{RED\ err}$ = Early Warning Rate of Engineering Change Requests$_{\text{RED err}}$ $$EWRoECR_{RED\ err} = \frac{NoECR_{RED\ err\ pre}}{NoECR_{RED\ err}} * 100\%$$
Unit/ Dimension:	%
Evaluation:	Trend: the higher, the better
Analysis:	Due to a learning curve, the proportion of early warnings should continuously improve. The smaller the percentage, the greater the improvement in rate should be. Early detection rate close to 100% can only be seriously improved.
Notes	
Hints/ Explanations:	-
Corporate Responsibility:	☑ Marketing ☑ Development/Design ☐ Manufacturing ☐ Service ☐ Purchase
Company Level:	Middle management: development management / design management, portfolio management, product managers, controlling
PIPE Process:	☑ Change Management ☐ Requirements Management ☐ Configuration Management ☐ Project Management ☐ Collaboration Management

Figure 10.2. Sample description of a process indicator

All process indicators are described in the VDMA guideline *Process Indicators for Product Engineering (VDMA, 2013)*. Table 10.1 shows 24 process indicators for the five PIPE processes.

Table 10.1. Process indicators for change management

Name of PIPE Process	**Name of Process Indicator**
1. Change Management	1.1 Number of Engineering Change Requests (ECR) 1.2 Number of Engineering Change Orders (ECO) 1.3 Abnormality Degree (change cluster) 1.4 Throughput Time of ECR 1.5 Throughput Time of ECO 1.6 Early Warning Rate of Redundant ECR
2. Requirements Management	2.1 Approval Rate of Requirements 2.2 Processing Status of Requirements 2.3 Degree of Coverage of Acceptance Criteria
3. Configuration Management	3.1 Carry-Over of Parts Degree of Standard Parts 3.2 Carry-Over of Parts Degree of Product Components 3.3 Configuration Items Ratio 3.4 Structured Configuration Items Ratio 3.5 CAD Documents Configuration Items Ratio 3.6 Historicised Configuration Items Ratio 3.7 Synchronised Configuration Item Ratio
4. Project Management	4.1 Adherence to Delivery Dates 4.2 Cost Efficiency 4.3 Project Status 4.4 Number of Duration of Missed Deadlines (internal/external partner)
5. Collaboration Management	5.1 Knowledge Management Degree of Maturity 5.2 Automation Level of Processes supported by automated Workflows 5.3 Partner Evaluation Status 5.4 Part of Search Time per Employee

Table 10.2 shows the process indicators for requirements management with their variables and formulas. Two of these process indicators have one interpretation context and reporting option, respectively; the process indicator *Degree of Coverage of Acceptance Criteria* has two reporting options. The process indicators for the other four PIPE processes are described in a similar way. In total, the campaign developed 24 process indicators with 37 reporting options.

Table 10.2. Process indicators for requirements management

Name of Process Indicator	Name of Variables with Formula Context
2.1 Approval Rate of Requirements	*NoACR* = Number of Approved Consistent Requirements *NoR* = Number of Requirements *ARoR* = Approval Rate of Requirements $ARoR = \frac{NoACR}{NoR} * 100\%$
2.2 Processing Status of Requirements	*NoRR* = Number of Raw Requirements *NoR* = Number of Requirements *DoCoRwS* = Degree of Coverage of Requirements with Solutions $DoCoRwS = \frac{NoRR}{NoR} * 100\%$
2.3 Degree of Coverage of Acceptance Criteria	*NoDAC* = Number of Defined Acceptance Criteria *NoRR* = Number of Reworked Requirements *NoR* = Number of Requirements $DoCoAC_{complete}$ = Degree of Coverage of Acceptance $\text{Criteria}_{complete}$ $DoCoAC_{range}$ = Degree of Coverage of Acceptance Criteria_{range} • Completeness of Acceptance Criteria: $DoCoAC_{complete} = \frac{NoDAC}{NoR} * 100\%$ • Scope of Post of Requirements: $DoCoAC_{range} = \frac{NoRR}{NoR} * 100\%$

10.4.2 Evaluation of the Process Indicators

To demonstrate the feasibility of the results the project partner developed a PIPE tool based on Microsoft Excel.

One possibility for the visualisation of results is the use of evaluation graphs over the entire product lifecycle for the process indicators in change and project management. For example, by summing up the change requests, an accumulation can be detected in a cluster analysis of the product life cycle phases, indicating weaknesses in products, processes or business units. This is used with the Pivot method using tables as table data in different cases can be represented and analysed in a condensed, summarised form (Figure 10.3).

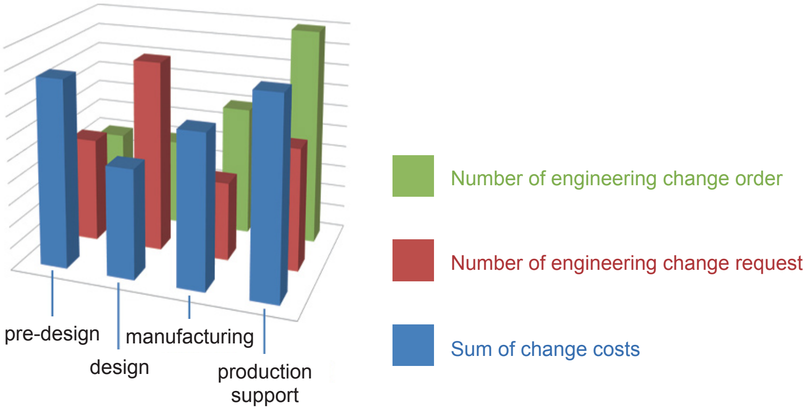

Figure 10.3. Cluster analysis of change management with Pivot tables (Schabacker and Simon, 2012; Schabacker, 2013)

The PIPE tool also allows visual evaluation of the process indicators using a traffic light system. After the company-specific values (target-actual values) are summarised and defined for each process indicator, the comparison with the results for the respective process indicator is carried out:

- The traffic light color *green* indicates that the calculated value for the corporate responsibility (responsibilities) and the phases of the product creation process moves within the permissible range, so no continuous improvement must necessarily take place in the process.
- The traffic light color *yellow* indicates that the calculated value is **within** a tolerance range outside the company-specific value for the corporate responsibility (responsibilities) and the phases of the product creation process; here, a continuous improvement for the respective corporate responsibility and respective phases of the product creation process should be planned.
- The traffic light color *red* indicates that the calculated value is **far beyond** the tolerance range of company-specific value for the company responsibility (responsibilities) and the phases of the product creation process; here it must be planned a continuous improvement for the respective corporate responsibility and respective phases of the product creation process.

An example for an evaluation is shown in Figure 10.4 for requirements management (for the calulation see formulas in Table 10.2).

Result for PIPE Indicators
Period
Begin: 31.01.13
End: 15.03.14
Period Length: 408 days

PIPE Process	PIPE Indicator	Result	Company-specific Values	Unit
Requirements Management				
	2.1 Release Degree of Requirements	80,00%	70%	%
	2.2 Processing Status of Requirements	80,00%	82%	%
	2.3 Degree of Coverage of Acceptance Criteria	20,00%	70%	%
		30,00%	70%	%

Figure 10.4. Process indicators for the evaluation of requirements management (VDMA, 2013)

10.4.3 Evaluation of Maturity of the PIPE Processes

An overall evaluation of all process indicators in the PIPE processes is based on the achieved number of traffic light colors *green*, *yellow*, and *red* (Figure 10.5).

PIPE Compass	Number (green)	Number (yellow)	Number (red)	Overall Evaluation Indicators	Maturity
Change Management	6	2	5	13	53,8%
Requirements Management	1	1	2	4	37,5%
Configuration Management	0	1	6	7	7,1%
Project Management	5	0	3	8	62,5%
Collaboration Management	2	0	3	5	40,0%
Overall Traffic Analysis	14	4	19	37	43,2%

Figure 10.5. Example of the evaluation of the traffic light functions for all process indicators and PIPE processes (VDMA, 2013)

A maturity level is calculated based on the number of traffic light colors of indicators for each PIPE process and represented in a spider web diagram (Figure 10.6).

This reflects the current state of a company. However, this does not mean that, irrespective of the costs, a 100% state (i.e. company-specific values are exceeded at all process indicators) must be achieved by using the methods of the continuous improvement process.

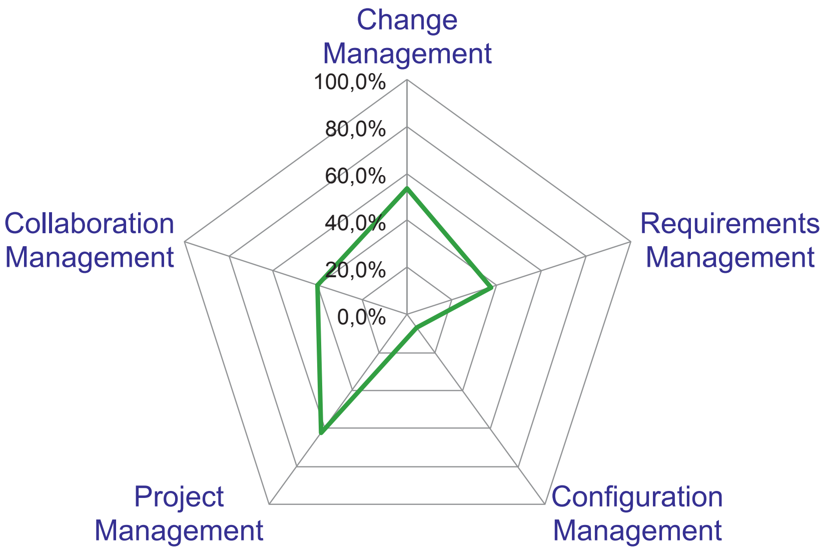

Figure 10.6. Example of the maturity level for all PIPE processes (VDMA, 2013)

10.5 Conclusions

After the successful project completion of this campaign 24 process indicators with 37 reporting options are available in the VDMA guideline *Process Indicators for Product Engineering (PIPE)* that consider all relevant PLM disciplines and are already being used by customers. The benefit of PIPE lies in a uniform evaluation methodology. The identified process indicators have been tested with companies using the PIPE tool with respect to their applicability and feasibility.

10.6 References

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