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# DIMENSIONS OF PRODUCT DEVELOPMENT SUCCESS

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## 1. Introduction

Successful product development (PD) is indispensable for the competitiveness of a company and thus of strategic relevance. Not only inventions as such but also their successful conversion into marketable products are of major importance for long-term success. Still there is no generally applicable measurement for development success [Fixson and Marion 2012], [Taylor and Kristensen 2013], [Bender and Steven 2015]. The contribution focuses this problem from an interdisciplinary perspective combining engineering and business administration points of view.

From an engineering point of view PD can cover a wide range of purposes and activities and accordingly contributes from a managerial point of view in fundamentally different ways to a company's success [Hahn and Häusler 2013], [Taylor and Ahmed-Kristensen 2014]. This again requires different evaluation methods. Therefore in this paper a tool for a classification of PD acitivities is introduced as key prerequisite for context appropriate performance evaluation.

The innovative tool for analysis is a four-quadrant matrix which classifies PD activities in two dimensions named "object orientation" and "application orientation". The four resulting quadrants are evaluated according to their accessibility to evaluate PD success. We then focus the discussion on one selected quadrant which represents development activities related to basic research, applied to developing new PD competences or strategies. This quadrant is chosen because we consider "success" evaluation for this case most challenging. Illustrated by an example, performance indicators are discussed concerning their potential to measure PD success in this quadrant.

The paper is organised as follows: section 2 gives an answer to the question what PD is and how successful PD can be characterised. In section 3 performance indicators are introduced as a tool for measuring PD success. Based on this, in section 4 a contribution to the measurement of PD success in quadrant I of the matrix is presented. The paper closes with an outlook on further investigations to be done.

## 2. What is successful product development?

PD activities must be managed and monitored like any other business function. But as activities and results in PD are determined by rather specific conditions, performance evaluation is much more sophisticated than e.g. for the production department. These specific conditions are adressed in the following sections: Why measure PD success? What are characteristic PD tasks and processes? What is PD success?

### 2.1 Why measure product development success?

From a business administration point of view, successful PD must contribute to achieving the company's strategic and operational goals. So undoubtedly there should be methods to evaluate to what extent PD

activities have been successful. However compared to other departments measuring the success of PD activities in terms of efficiency or effectiveness is often more difficult.
This can be explained with characteristic tasks and results of engineering design as such (see following section), as well as the wide range of heterogeneous activities covered by functions related to PD in a company. PD can cover for instance the elaboration of engineering design drawings for a physical product, or defining a roadmap for the development of a product service system with integrated modularisation strategy, or developing a company specific PD process with integrated design methods or even identifying qualification requirements for specific product development activities. Accordingly, from an organisational perspective PD can take place in various functional areas of a company depending on design object on the one hand or level of application orientation on the other hand [Schröder 2003]. Moreover, to convert design concepts into (economically) successful products requires co-operation of several functions in a company, which should also not be neglected when measuring overall PD performance.
Considering the fact how PD contributes to both operational as well as strategic objectives of every company the evaluation of its success including the integration of all relevant PD activities in various functional allocations must be of highest priority.

### 2.2 What are characteristic product development tasks and processes?

In general, engineering design describes the transformation process from goals or input requirements into a (technical) problem solution [Ehrlenspiel and Meerkamm 2013], [Feldhusen and Grote 2013]. From a cognition psychology point of view this is denominated as "problem solving", which indicates the existence of a barrier between problem and solution [VDI 2221 1993]. This means that lack of transparency concerning (some) requirements, objectives, subtasks to be performed and properties of the solution to be developed are caused inherently by characteristics of the task to be performed, not by e.g. deficient problem definition or ill performance of the engineer [von der Weth and Frankenberger 1995]. More specifically, the solution to an engineering design problem by definition represents a trade-off between heavily conflicting objectives [O'Donnell and Duffy 2005], [Gericke et al. 2013]. A design solution can usually not simultaneously be the first on the market, of highest technical value, easy to handle, cost efficient to manufacture and maintain, perfect to recycle, best value-for-money and winner of an industrial design price, too. There is no "one best solution" to an engineering design problem. On the contrary: if no reasonable objectives are given along with the problem to be solved, the engineer might not even find any solution to the problem at all or design one of the famous "over-engineered" purely technical solutions nobody needs or wants. Again, this is not necessarily the engineer's fault, but could also be attributed to the characteristics of problem solving with conflicting objectives as such.
The effects of these characteristics are demonstrated by the following example: When looking at the alleged straight-forward, purely physical solution to a simple engineering-design problem such as designing a gear-box, it becomes immediately obvious that there can be no single best solution. Depending on specific technical requirements like input torque or gear rate, interfaces to other sub-systems, standardisation requirements, preferred manufacuring or procurement arrangements, batch size (maybe depending on modularisation strategy), timeline as well as target costs, completely different solutions will be evaluated "best". Additionally the evaluation of the solution will be different depending on the level of detail of the solution at hand since specific product features and requirements only emerge in advanced design stages (e.g. required production accuracies) but contribute strongly to the cost, timeline or quality of the product.
To tackle this obvious complexity caused by the variety of potential solutions several approaches have been made to find a generally applicable procedure for engineering design activities. In the German guideline VDI 2221 [1993] for example, the engineering design process is subdivided in several design phases with characteristic work results each. The widely accepted English translation for these major design phases are [Pahl et al. 2007]:

- planning and task clarification,
- conceptual design,
- embodiment and detailed design.

Main goal during the first phase of planning and task clarification is - in addition to the elicitation of the input requirements - the identification of relevant boundary conditions and interfaces with other systems or the environment.
Conceptual design aims at finding solution principles on a higher level of abstraction. On the one hand this phase explicitly facilitates finding the essential (technical) problems which are often caused by contradictory requirements in terms of cost, timeline or quality. On the other hand during conceptual design the input requirements must be complemented with additional requirements derived from the specific solution at hand (e.g. related to concrete dimensions or weight, material or production conditions). Not until the last phases, embodiment and detailed design, the actual CAD models and layout-drawings accompanied by parts lists and production documents, are generated as well-defined results of the engineering design process.
However, the procedure as described in VDI 2221 is suited to explain the general logic of the design process, but does not (intend to) provide a task organisation which would allow for measuring concrete results at defined points in time against a standard procedure. This again is caused by the fact that there are so many influencing context factors to the design process that no generally applicable procedure can be defined [Bender et al. 2001], [Meißner et al. 2005], [Roelofsen and Lindemann 2010], for an overview over design processes see Andreasen 2005, context factors influencing the design process are summarized in [Gericke et al. 2013]. The three-dimensional solution space as visualised by Ponn gives a good impression of the number of potential solutions as well as different approaches to a design problem [Ponn 2007].
In conclusion, characteristics of the design task as well as the engineering design process are that there is neither one best solution nor one best process which could serve as baseline for measuring PD success. Still, the evaluation of engineering design activities must be made possible for pure management reasons.

### 2.3 What is product development success?

Successful PD can be measured against a large number of indicators [VDMA 2013], [Schabacker and Gröpper 2015]. Obvious success factors are for instance the market acceptance of the developed product or the compliance of the specific solution found to the problem at hand. But also project management driven indicators can, depending on the task, provide precious information on product development success. Many attempts have been made to define and measure successful PD [Hauschildt 2002], [Corsten et al. 2006], [Hansmann 2006], but due to the characteristic boundary conditions related to problem solving in combination with the heterogeneity of PD activities and potential functional allocations the solution to the problem is obviously context sensitive.
Against the background of these characteristic difficulties, typically the performance of PD departments in a company is evaluated by indicators refering to input quantities, e.g. number of workforce, working hours, material used or even more aggregated, money spent on PD activities. This is remarkable because no distinct relation between resource consumption and quality of the problem solution has ever been shown.
From a controlling point of view, the ratio of output and input refers to the productivity of a PD process and thus allows to evaluate its efficiency. In order to avoid developing, with a considerable amount of money, things nobody needs it is important to also evaluate the effectivity respectively the outcome of PD in terms of contributing to the strategic objectives of the enterprise.
However, depending on the variety of objects and their application level, successful PD must be defined differently depending on the strategic and/or operational relevance [Linnhoff 1996], [Hauschildt 2002], [Schröder 2003], [Hahn et al. 2013]. For instance developing a successful longterm strategy for component standardisation will be measured against different indicators compared to designing a gearbox or the completion of an R&D project on time, cost, and budget.

## 3. Performance indicators for product development success

From the wide range of controlling instruments for PD [Steven 2016], we concentrate on performance indicators. In management, performance indicators (on the operational level) respectively key performance indicators (KPIs, on the strategic level) are an important and valuable tool for measuring and

controlling conditions as well as performance of various entrepreneurial subsystems [Küpper 2005], [Meyer 2011], [Reichmann 2011], [Gladen 2014]. A performance indicator is a figure which represents economic facts or conditions that are subject to quantitative measurement [Steven 2007].
In addition to management purposes, (key) performance indicators provide adequate information for decision makers. Proper evaluation of the results of former plans is a valuable tool for future decisions as well as for setting future performance targets. Furthermore, KPIs can be used as objective evidence for incentive schemes. Popular financial performance indicators are profit, sales volume, market share etc. which cannot be used in PD because they only have an indirect relation to PD performance.
Several approaches have been made to find appropriate methods and tools which evaluate PD performance with regard to the specific conditions to be considered in engineering design [Linnhoff 1996], [Schröder 2003], [Hahn et al. 2013], [Dziobczenski et al. 2013], [VDMA 2013], [Taylor and Ahmed-Kristensen 2014], [Schabacker and Gröpper 2015]. They represent valuable contributions to selective PD tasks but mostly do not adress the attributes needed for a systematic evaluation of PD problems in general from a controlling point of view.
This section gives a systematic overview and a classification of performance indicators that will be used for evaluation of PD success in section 4.

### 3.1 Specific conditions for product development controlling

Production controlling for instance has access to a great variety of controlling instruments [Corsten and Friedl 1999]. Nevertheless, most of them are not suitable for the evaluation of PD success [Steven 2016]. The difficulties in measuring PD success arise not only from the specific field of activities (see section 2), but also from the longterm orientation and the indirect, time-lagged correlation of input and output. The main challenges resulting from these discrepancies are the following:

- Although PD activities take place in everyday business, their focus is often on strategic issues and their strategic value subject to individual interpretation [Hahn et al. 2013].
- Even if it is possible to measure PD output, the outcome of PD activities is by far more relevant for the company's longterm success which leads to difficulties when measuring results in relation to actual allocated ressources.
- Results of PD can often be rated only on a qualitative level whereas for instance production results can be measured by quantitative standards [Hopp et al. 2009].
- In a production environment efficiency respectively productivity is an important objective. For PD activities, efficiency is hard to measure and, even worse, effectiveness is far more important but can hardly be measured at all [Hopp et al. 2009].
- Subjective assessments are prevailing in evaluation of PD activities because there is a lack of consistent evaluation criteria due to conflicting requirements [von der Weth and Frankenberger 1995].

### 3.2 Classification of performance indicators

Measurement of performance is essential for all functions in an industrial organisation in order to be able to plan, control and assess each activity in relation to the overall objectives of the enterprise. This is obviously also valid for functions related to PD.
In order to fulfil their management support function, performance indicators have to satisfy the principle of controllability. This means that they have to be defined unambiguously and constantly over time, determined regularly, in a traceable way, and based on current data. Furthermore, they have to describe the underlying facts adequately and last but not least their provision has to be cost effective. Figure 1 shows the most important criteria by which performance indicators can be classified [Bender and Steven 2015].
To ensure PD success it is crucial to select appropriate, problem-specific KPIs. This can only be done if the relations between the underlying factors and their impact on the strategic targets are revealed [Taylor and Ahmed-Kristensen 2014]. This implies to break down the highly aggregated strategic KPIs into manageable objectives for the operational level. This is usually done in a cascading manner [Bremser and Barsky 2004].

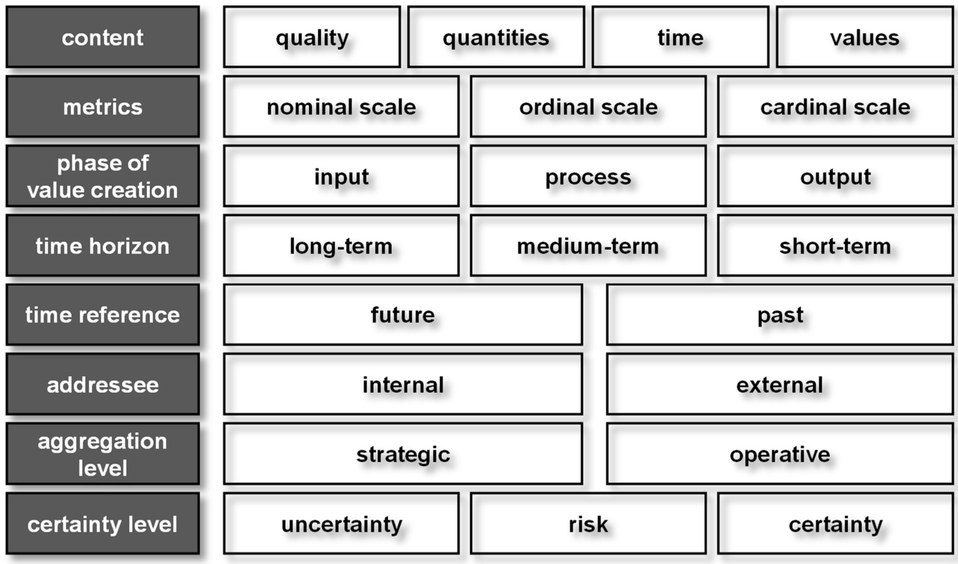


**Figure 1. Classification of (key) performance indicators**

## 4. Dimensions of product development success

Due to the different types and levels of activities, the contribution of PD activities to the overall company's success is difficult to capture not only for complexity, lack of transparency or conflicting requirements, but also for simple reasons of heterogeneity (see section 2). In order to bring some structure into the abundance of PD activities and performance indicators (see section 3), a classification is needed that allows to assign success criteria to differend kinds of PD activities and to use specific performance indicators for certain situations. As we have shown in the previous sections, appropriate measurement of PD success is not mainly hindered by a lack of available performance indicators but by their appropriate application to the specific PD case.

### 4.1 Classification of product development activities

Since there will be no generally applicable method to appropriately evaluate PD success, we suggest the "divide and conquer" approach. To improve the hit-rate of performance measurement, a rough classification of PD activities with regard to their type of result is introduced by Bender and Steven [2015]. Two key dimensions must be distinguished: application orientation and object orientation.

Application orientation: This dimension addresses how far PD solves a practical problem (applied research) as opposed to providing general insight as in basic research. In the first case the result can be tested against dedicated customer or internal requirements and the solution clearly either does solve the problem at hand or it does not. In basic research however, the result might be revolutionary from scientific point of view, but probably of no practical application (yet). This kind of PD activitiy has to be measured against an (anticipated) market or innovation potential which is difficult since the success is often a subject of individual interpretation (or depending on the business model of the company involved).

Object orientation: Regardless of application orientation, the subject of PD can address solving a concrete engineering problem as opposed to developing a competency or strategy suitable for solving engineering problems (meta-level). Solving a concrete problem by means of developing a product or service can for success evaluation be tested against (internal) customer requirements, whereas working out a strategy or a competency to improve PD performance is much more difficult to evaluate. Even a long-term assessment on how a specific design strategy or more competent employees contribute to PD success will be difficult to assess due to the large number of influencing factors in the process.

Using these two dimensions allows for a classification of PD activities by creating a four-field matrix. The four quadrants address the areas of PD activities shown in Figure 2.

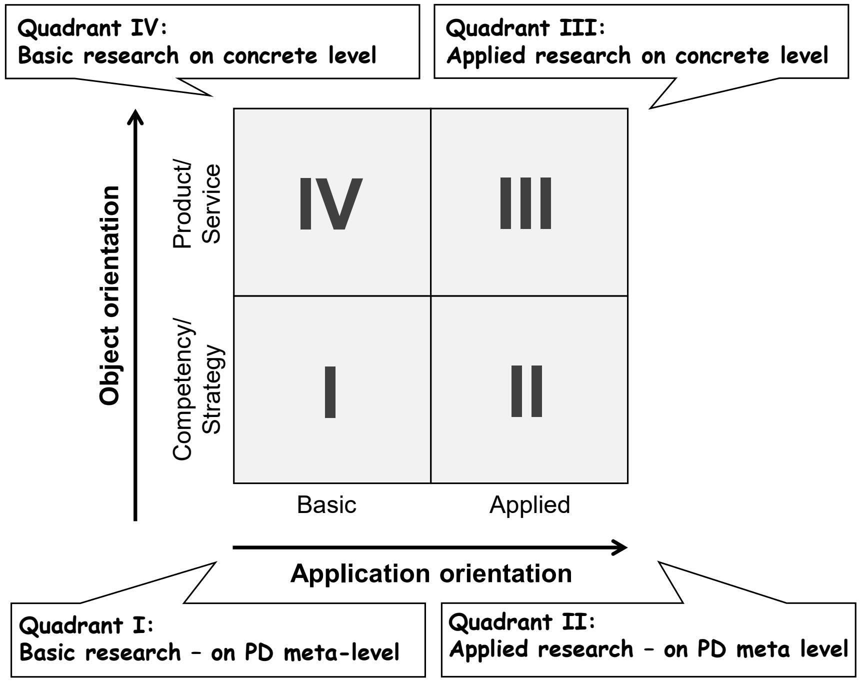


**Figure 2. Classification of product development activities**

- Quadrant I: Basic research on PD meta level resulting in new competencies or strategies. Example: development of general or specific process models, procedures, methodologies to increase PD success.
- Quadrant II: Applied research on the meta level of PD resulting in new competencies or strategies. Example: company-specific calculation methods, modularisation or size range strategies for defined product platforms.
- Quadrant III: Applied research on the concrete level of PD in terms of products or services Example: development of a single tool, but also of a complete process plant.
- Quadrant IV: Basic research on the concrete level of PD in terms of products or services Example: development of new materials for specific applications or of a new type of power engine.

Depending on the two dimensions forming the four quadrants for PD contexts as shown in Figure 2, PD success must be measured using appropriate indicators.

### 4.2 Measurement of product development success

The classification matrix allows for some general tendencies for measuring PD success in the two dimensions (see Figure 3). Firstly, to measure success of applied PD acitivities (quadrants II and III) it is possible to look at the concrete result of the specific problem. So an output and quality oriented performance indicator would be a reasonable starting point, since it is obvious whether or not the applied problem has been solved. This works regardless of object orientation, i.e. whether the object is an applied product or service or a competency or strategy.

On the other hand, focussing on products or services in the object dimension (quadrants III and IV) allows to evaluate or anticipate market success against defined criteria. So in these cases performance indicators would need to be related to (potential) market needs or success.

Quadrant III, overlapping both cases discussed above (applied PD problems and concrete products or services, see Figure 3) is the quadrant with the most unambiguous performance evaluation: PD projects. In PD projects concrete problems are solved against distinct criteria - usually defined by time, cost, and quality requirements. Therefore typical PD project performance indicators as for instance standardised in [VDMA 2013] can be applied and appropriately support the management with relevant information.

Examples for these indicators are working time, investment/depreciation of equipment, number of prototypes, customer satisfaction. This quadrant is well-covered in literature [Bassioni et al. 2004], [Gräf and Langmann 2011], [Taylor and Ahmed-Kristensen 2014].
Quadrant I (basic research on PD competencies or strategies, see Figure 3) sketches the field of PD activities, which is most difficult to evaluate with regard to success and performance. This is due to the fact that the problem solution is neither marketable nor can be made subject to simple cause-and-effect considerations when it comes to assessing the contribution of the acitivities to the strategic goals of the company.

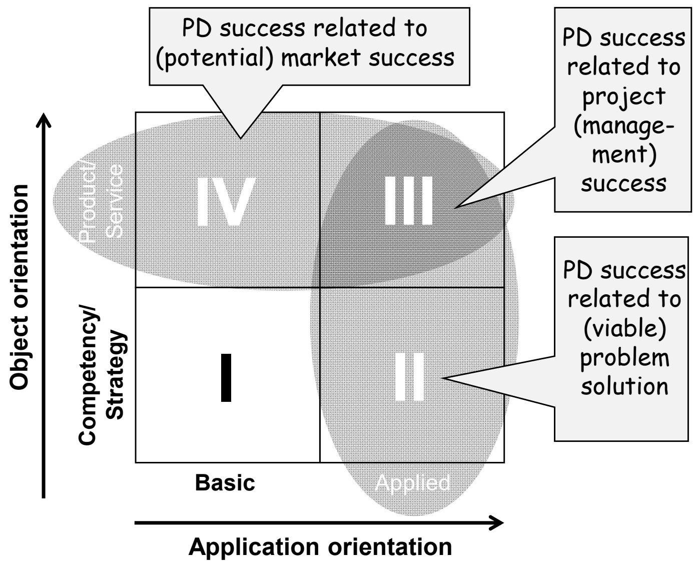


**Figure 3. Complexity of measurement of product development success**

### 4.3 Classification matrix - exemplary application for quadrant I

In this quadrant, PD is done on a generic or meta level and instead of practical solutions only the potential of later results can be evaluated. The results of PD activities in this quadrant are general approaches for the development of competencies or strategies as discussed in the subsequent example. Nevertheless, over time the results of PD in quadrant I may be concretised in one or both dimensions.
An example for a setting could be an assumed lack of design methodology competency in an advanced engineering department in the railway industry. The head of department probably suggests using scenario techniques and the application of VDI 2221 design methodology to be able to better predict future market developments and look more systematically for potential engineering solutions. The board of management would probably object to an extensive training for all the engineers due to high effort and time consumption with no immediate effect on the ROI. The head of the advanced engineering department would then contact a research institute to verify the use of design methods with regard to the goals at hand.
Applying the classification strategy as presented in section 4.1 works as follows:
1. Classification of the exemplary PD activity context "Development of research design to verify the use of design methods" according to four-field matrix shown in Figure 2:

- Object of the PD activity is a competency or process
- Application level of the PD activity is basic research since there would be no methodology available yet in the scenario described
- Classification result: quadrant I

2. Relation of quadrant I PD activity to appropriate performance indicators as generally explained in section 3.2 and specifically applied to quadrant I in Figure 2:

- Content: quality related, since the effect of more competent product developers is of strategic nature and its contribution to PD success cannot be evaluated in isolation with regard to quantitative, value-related or time-related effects. Example for appropriate KPI: quality of solution
- Metrics: the success of the PD activity would have to be measured on a nominal (yes – approach makes sense or no – does not make sense) or ordinal scale (degree of completion of project), a cardinal scale such as increase in ROI would not make sense.
- Phase of value creation: the responsibility of PD performance would be input oriented (man hours or expenses for training, number of staff involved)
- Time horizon: success would have to be measured long-term (more than one year)
- Time reference: the reference figures for PD performance would need to be future oriented such as quality of solution
- Addressee: the PD activities would address internal performance indicators (market hit-rate of developments)
- Aggregation level: the aggregation level would be high since measuring successful application of design methods would require a number of different performance indicators due to strategic relevance.
- Certainty level: potential KPIs would be on "uncertainty level" since there are no singular cause-and-effect principles for this kind of activity.

Figure 4 illustrates which types of performance indicators from Figure 1 are typical for PD activities in contexts allocated to quadrant I.

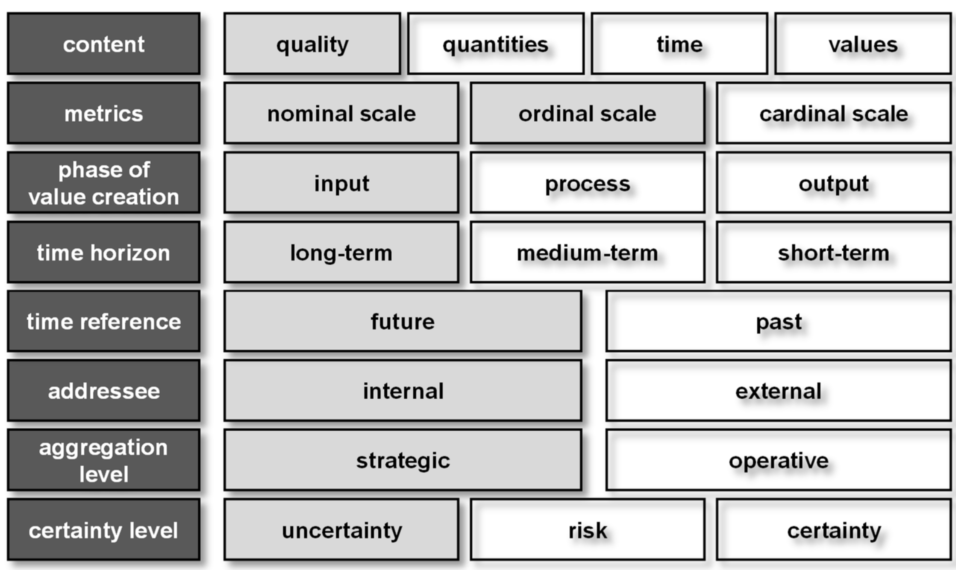


**Figure 4. Performance indicators for quadrant I of the classification matrix**

An application example from academia for quadrant I is the scientific investigation of the use of design methodologies for improving the quality of engineering design solutions [Bender 2004].
For quadrants II, III, and IV of the classification matrix, appropriate types of performance indicators are shown in [Bender and Steven 2015].

## 5. Summary and conclusions

Product Development is one of the critical factors contributing to longterm business success. And performance management of PD is important to support adequate business attention. However, due to specific tasks and processes in engineering design it is difficult to make this information available to management by means of appropriate performance indicators. In addition, the use of inappropriate indicators leads to suboptimal decisions based on misinterpretations with regard to PD performance. Against the

background of a wide range of different kinds of PD activities as well as a vast number of known performance indicators, the approach presented here aims at finding the most suitable combination of both for the specific PD context at hand.
Starting from a discussion of the definition, the necessity and possibilities of PD performance measurement, we have shown the major shortfalls in this field. We then defined performance indicators as an useful measurement tool. By the help of a classification matrix separating application oriented and product oriented PD activities, we have identfied four quadrants with different characteristics of PD activities with regard to success definition. Also existing approaches for these four quadrants differ fundamentally. Success definition in quadrant III (applied research on products and services) can be defined by means of classical project related indicators. PD results from quadrants II and IV can have the potential to be measured against (anticipated) market needs or (anticipated) contribution to the solution of the PD problem at hand.
Most ambiguous to access from business administration point of view is quadrant I, addressing basic reseach on the meta level of PD, since neither input nor output nor mere process related indicators support understanding "success" in this area. Additionally the time lag between PD acitivities and success is usually very long. Therefore concentrating on the most difficult quadrant we have shown for a practical example which kinds of performance indicators provide useful information for PD management. These generic results can be transferred to other problems in quadrant I.
Future research will concentrate on analysing how other controlling instruments can be assigned to or adapted for the specific tasks prevailing in the different quadrants.

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