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A METHOD FOR THE SITUATION-SPECIFIC EVALUATION OF PRODUCT DEVELOPMENT PROCESS MODELS

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1. Introduction

Models of product development processes (PDP) can help organisations to get a clear view of their product development procedures (analysis) and to improve their performance (optimisation) and thus, to increase their competitiveness. These models may stem from the wide range of existing PDP models that have been published during the last decades. For example, Browning and Ramasesh [2007] compared about 200 papers about Activity Network-Based Process Models. Wynn [2007] states, models "may be constructed for many purposes and should be appropriate to their intended use" [Wynn 2007, p. 3]. According to the purposes, models have different objectives, approaches and/or characteristics. The characteristics may be beneficial or detrimental—depending on the context. As there is a broad range of PDP models available, decision-makers in organisations face the problem, how to identify the best-suited PDP model for the specific situation of their organisation.

The suitablility of existing approaches on how to evaluate/compare PDP models can be examined along the dimensions 'Set of Criteria' (fix, variable) and 'Set of Models' (fix, variable) as follows.

- Criteria fix, models fix: Static comparisons of PDP models (e.g. by [Goh et al. 2003]) can highlight different fashions of the applied set of models but decision-makers need the opportunity to adjust the evaluation criteria to their specific situations.
- Criteria var, models fix: Extractions of PDP model characteristics and properties (e.g. by [Gericke and Blessing 2011]) facilitate a better understanding of several aspects of process modelling—and in particular of the applied models—but the results allow only a comparision among the applied models which limits the usefulness for decision-makers.
- Criteria fix, models var: Definitions of a fixed set of criteria for the comparison of PDP models (e.g. by [Robinson et al. 2005]) depend on the author's perspective which might differ from the decision-makers' perspective and the specific situations of their organisations.
- Criteria var, models var: The following decision-logics do not aim specifically to evaluate PDP models but might be adjustable to a PDP model evaluation. Stetter and Lindemann [2005] focus on 'methods' which facilitate single tasks within the PDP. Birkhofer et al. [2002] also focus on evaluation of 'methods' for specific design tasks whereas the problem at hand requires a broader scope. The methodology by Weber [2008] establishes four criteria which focus on the direct development of a product, not on models for the development process.

This paper presents a method that supports decision-makers in identifying an appropriate model for their specific PDP. In order to develop this method, the following research questions were addressed:

- What are the requirements and influences to be considered for the evaluation of PDP models?
- What are the relevant criteria for the evaluation of PDP models in a concrete industrial development situation?

The result of this paper is intended to contribute to current practice regarding product development. The success criterion of the evaluation method is its applicability in industry, i.e. it fulfils its purpose, produces clear results, follows a clear structure, is easy to use, is adjustable to the unique situation of an organisation, and can be adapted to changing conditions and requirements. However, in this early stage of research, applicability is only tested in two exemplary situations.
The paper is organised as follows. Section 2 summarises requirements of organisations on PDP models, derived from a literature review. Section 3 explains the goal and approach of the evaluation method, presents a questionnaire for the evaluation criteria based on the findings in the former section, and outlines in a step-by-step description how to evaluate PDP models. Section 4 tests the evaluation method, first in expert interviews focusing on the approach and structure, and second, by applying it on three PDP models in two specific situations of organisations, derived from case studies in industry. Section 5 discusses the applicability of the evaluation method, and section 6 concludes by suggesting directions for further research.

2. Literature review of influences on and requirements of PDP models

This section addresses the first research question by exploring the environment and fashion of PDP; from outside the organisation to the inherent feedback-loops within the modelling process itself. By investigating the influences on PDP and deriving requirements of an organisation, it provides the basis for the applied criteria of the evaluation method, outlined in section 3.
The search was executed mainly with the research platform 'Thomson Reuters Web of Knowledge', extended through cross-referencing. The initial search command "product AND development AND process AND model" listed about 35k articles, which were narrowed down by additional commands, a timespan refinement (2000-2012), the selection of domain (science technology) and research areas (engineering OR business economics OR operations research management science), and a selection of 14 source titles. Of the remaining 105 hits 24 were selected, based on their fit to the key terms in the research question. The derived requirements for the models are grouped under the emerging categories

- Adaptability (to changing organisation's characteristics and requirements),
- Performance (with definitions of effectiveness/efficiency, comparing as-is to to-be processes),
- Communication (between organisations, within departments, and among team members),
- Team behaviour (as shared understanding among team members and resulting behaviour),
- Problem solving and learning (supports problem solving and model modification in itself),
- Knowledge handling (information sharing/searching, reuse and de-codification of knowledge),
- Implementation/Application (easy to implement, and applicable in day-to-day business).

Adaptability: The environment of product developing organisations is characterised by a market consisting of customers, other organisations, existing uncertainty and arising competition. Based on the concept of expressed and latent needs of customers [Slater and Narver 1999], the uncertainty becomes clear. Indeed, uncertainty can be composed of not-foreseeable events with even unknown consequences (e.g. [Johnsson et al. 2008]), but Neufville [2004] highlights that also positive and desirable outcomes are possible. Uncertainty just limits organisations to pre-plan their activities and to forecast their results [Galbraith 1974]. Organisations can choose between different strategies on how to deal with this circumstance. They can operate on their environment [Galbraith 1974], attempt to understand it better [Slater and Narver 1999], or just modify their internal processes [Galbraith 1974]. In order to achieve a competitive advantage, the actions of organisations must change, depending on the technology life cycle and the market situation [Adner and Levinthal 2001]. Organisations must be adaptive and have to align their actions to their environment. Being faster than competitors is key to survive [Brookes and Backhouse 1998]. As organisations are partially connected subsystems on several levels [McCarthy 2006], they adapt as a whole when their subsystems adapt. A PDP model has to be adaptable to this changing context.
Performance: The PDP has a significant impact on the organisation's performance [O'Donnell and Duffy 2005], measurable in the dimensions of effectiveness and efficiency. The PDP can be characterised as a knowledge processing activity which "uses resources to transform input into output under the direction of goals and constraints" [O'Donnell and Duffy 2002, p. 1205], [Johnsson et al.

2008] propose a three-staged model at which the variables should be measured even though the measurement of the variables is individually scalable and adjustable.

Communication: Within an organisation, the marketing and the production departments are important knowledge providers. Moenaert et al. [2000] identify requirements that determine the performance of communication: transparency, codification, credibility, cost, and secrecy.

Team behaviour: A clear goal is required to direct the collaboration of all involved parties. If the whole team is divided into several subteams, each of which is responsible for a particular component/ function of the product, the goals have to fit both, within a hierarchical level and between different levels. Nevertheless, a shared terminology is important to ensure efficient information sharing [Heisig et al. 2010]. Shared understanding is a similar individual perception about how the design content is conceptualized [Kleinsmann et al. 2010]. In order to enable an effective/efficient PDP, only the 'right' people need to meet in 'necessary' meetings. Thus, it is important to know 'who does what'.

Problem solving and learning: Bourgeon [2007] identifies new product development projects as learning tools for organisations, whereas the team staffing has a major impact in these projects. Also job rotation of team members and the variation of tasks have a positive influence on collective learning during development projects. Thus, a process model should support people in their period of vocational adjustment. Furthermore, the involvement of several and sometimes temporary team members might be necessary [Purser et al. 1992]. This requires a process model, i.e. learning system, that enables temporary team members to find their way into the work quickly.

Knowledge handling: Technical applications (e.g. the PDP model) should provide people with all the neccessary, yet only the relevant information at the right time [Browning et al. 2006]. Knowledge is invested in different functions and people's 'thought worlds', defined by knowledge boundaries. To overcome these boundaries, three knowledge approaches should be supported by PDP models: the syntactical, the semantical, and the pragmatic approach [Carlile 2002]. In order to capture information and knowledge, a general involvement of electronic representation is necessary which should include the storage, access, concurrency, availability, and searching of information and knowledge. Heisig et al. [2010] summarise the requirements for support systems.

Implementation and applicability: A PDP model should support managerial tasks such as planning and controlling of projects, and indicate the estimated resulting lead time of scheduled activities. Processes can be regarded as systems, and especially the complex behaviour of processes can be better understood by investigating its actions and interactions [Browning et al. 2006]. Cybernetics could help a team to design effectively [Maier et al. 2012]. Both implies the application of cybernetic principles in the modelling process. Both, Wynn et al. [2010] and Browning et al. [2006] highlight advantages of incremental modelling interventions. Regarding the application of a PDP model, Wynn et al. [2010] note that "a model must somehow represent a target system and, in the context of representation is in some sense less than that system" [2010, p. 514]. Thus, process models should be able to adapt to higher-level objectives within the organisation and other modellers [Wynn et al. 2010]. Furthermore, the application of PDP models is determined by cognitive resources of the modellers and model users. But illustrations within model documentations can support the processing of information. If people understand 'why' they should do their work in a specific way, they can act as enablers to the success of process modelling [Browning et al. 2006].

3. Evaluation method

This section develops the evaluation method of PDP models. First, the goal and approach of the evaluation method are explained, second, the evaluation criteria are derived from the literature review in section 2 and embedded in a questionnaire, and third, the evaluation method is described step by step. Thus, the second research question can be addressed.

3.1 Goal and approach

The goal of the evaluation method is to identify the PDP model—out of an open set of models—with the greatest fit to the specific situation of the organisation. The approach of the evaluation method is to identify relevant criteria in order to describe the specific situation of the organisation adequately, to evaluate the PDP models against these criteria, and to compare the evaluation results identifying the model with the greatest fit. This approach requires a logical procedure 'how to decide' whether and how well a model fits. Therefore, each criterion unfolds into two parts: one part for the situation and the other for the models. The logic can be depicted in a 2x2-matrix (Figure 1 on the left):

- If a situational criterion is considered to be important in/for the development process, the criterion is fulfilled ('yes'). Thus, the potentially picked PDP model should provide particular properties or characteristics which reflect this requirement.
  - If the corresponding criterion for the model is fulfilled ('yes'), it will fit the situation.
  - If the model does not fulfil the criterion ('no'), the model is not suitable for the situation regarding this criterion.
- If the situational criterion is not important/relevant ('no'), the models do not need to fit this criterion. A model that contains more features than required is over-engineered. In best case, it does not matter, otherwise it could even hamper its users.

For instance, an organisation is operating in a market with heterogeneous or even contradicting customer requirements. Thus, the situational criterion "Does the organisation operate on a market with heterogeneous customer requirements?" would be fulfilled in that situation ('yes'). From this follows that the organisation should apply a PDP model which is able to reflect different customer needs and requirements, i.e. the corresponding criterion "Is the model able to reflect different customer needs and requirements?" should be fulfilled ('yes').

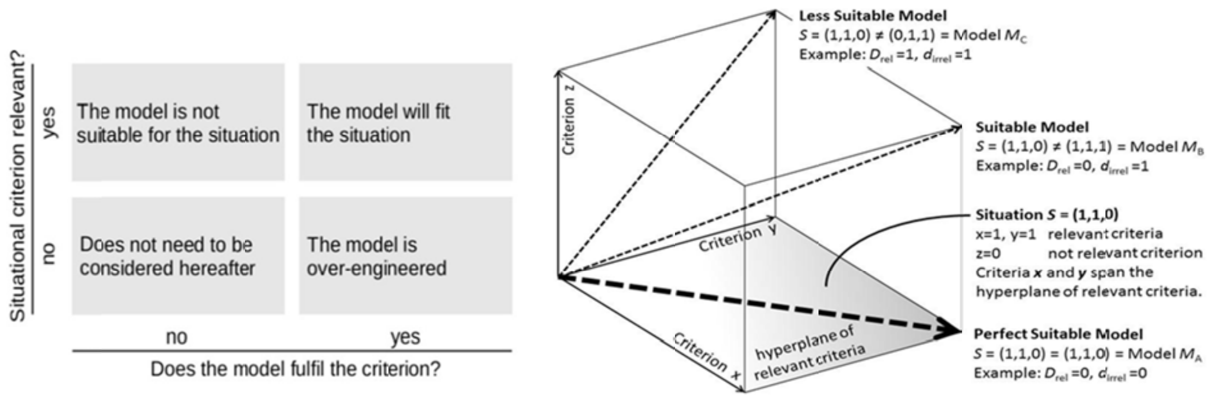

Figure 1. Logic "how to decide" (left), and hyperplane of relevant criteria (right)

3.2 Evaluation criteria

Both parts of each criterion are formulated as questions to facilitate users to figure out whether the criterion is fulfilled or not. The whole set of 33 criteria is derived from the requirements outlined in section 2. Table 1 lists exemplarily the five criteria regarding "adaptability".

Table 1. Criteria for "adaptability" as example for 5 criteria out of 33 criteria

Questions for the Situation	Questions for the Model
Does the organisation operate on a market with heterogeneous customer requirements?	Is the model able to reflect different customer needs and requirements?
Do customer requirements change over time?	Is the model able to reflect customer requirements which need to be changed/adjusted during the model application?
Does the organisation operate on a competitive (or contestable) market or is it crucial to develop products within a short time-to-market?	Does the model explicitly explain how a short time-to-market is ensured, or can a short time-to-market be derived from a general consideration of time?
Does the technological life cycle on the market change rapidly over time?	Does the model satisfy at least the needs for this state of the technology life cycle?
Do already (partly) existing solutions for the support of the development process need to be extended in order to completely satisfy its requirements?	Is the model (and its computational implementation) adaptable/adjustable to these existing solutions?

The applied set of criteria could satisfy the features of collective exhaustiveness and mutual exclusiveness. Collective exhaustiveness is almost impossible to prove. The set of criteria has to be realistically assumed as not collectively exhaustive, even if the literature review covered a broad range of published topics. Thus, a mechanism is required ensuring that all important criteria are considered for the method application, i.e the method itself has to be adaptable. Mutual exclusiveness is relatively easy to examine with a paired comparison due to the manageable amount of criteria. But even if the amount would rise, the method needs to be applicable. Thus, a mechanism is required ensuring that additional criteria are pairwise disjoint with all existing criteria.

3.3 The evaluation method step-by-step

Stating prerequisites for the method application: the specific situation of the organisation, an initial set X of PDP models, and a list of criteria L, whereas each criterion in L is applicable for the situation and the models. Both, the set of models and the list of criteria might be extended. First, if none of the models fulfil the minimum requirements, additional models have to be examined. Second, if list L is not 'exhaustive', the list needs to be complemented with further criteria which are considered to be important. It has to be ensured that the additional criteria are mutually exclusive to the existing ones.

Determining relevant criteria for the situation followed by a binary description with the vector S. This kind of description forces one to distinguish between 'relevant' and 'not relevant' criteria. The evaluation of the specific situation is done by answering the situation-related questions of the criteria (on the left-hand side). Establish a situational vector S, coding the'yes'-answers with a '1' and 'no'-answers with a '0', and sort all relevant criteria together in order to get a better overview (see the 'hyperplane of relevant criteria' in Figure 1 on the right). The vector S is needed to calculate the deviation from the vectorial description of the model characteristics at a later step.

Evaluating PDP models against relevant criteria followed by a binary description of each model in set X with the vector M_i. The evaluation of the models is conducted similar to the description of the situation. Mark the 'yes'-answers with a '1', and the 'no'-answers with a '0' respectively. The criteria in each vector M_i must have the same order as in S, i.e. the whole list of criteria is applied.

Determining PDP models' deviation from relevant criteria. The deviation $D_i = \text{Sum}_{\text{relevant}}\ (S–M_i)$ will be calculated by counting the different criteria evaluations for each relevant criterion, i.e. the failed criteria on the model-side are counted. The smaller the deviation, the better the fit. The vectorial description of the situation S and each model M_i supports conducting this step.

Evaluating PDP models against requirements leads to set Y, comprising all models with a deviation smaller than a certain threshold T. Even if none of the models is 'perfect', some might be sufficiently applicable. Their deviation is smaller than the threshold T (an 80%-fulfilment of the relevant criteria is suggested), and should be put on the 'shortlist' (set Y) for further examination. If none of the models has a deviation smaller than T, additional models have to be examined. In order to avoid an infinity loop, T gets doubled. Thus, the deviations of the models in set X and the threshold T converge.

Ranking PDP models identifies the model(s) with the minimal deviation $D^* = \min_Y D_i$. Set Y contains at least one model, and all models in Y satisfy sufficiently the relevant criteria of S. The larger the distance between the first and second best model, the more unambiguous is the result. A 10%-distance of relevant criteria should be enough to consider the result as 'clear-cut'. If so, the calculations terminate here (jump to step 'reflecting'). Otherwise, there might be ambiguity, especially if a lot of models are evaluated, if the models are similar, or only a few criteria are relevant.

Evaluating PDP models against irrelevant criteria leads to the final decision. It is assumed that the fulfilment of irrelevant criteria binds modelling capacities and increases the model's complexity. Thus, a model that just fulfils the relevant criteria, is 'better' than a model that additionally fulfils some irrelevant criteria. First, we calculate the deviations $d_i = \text{sum}_{\text{irrelevant}}\ (S–M_i)$. Second, the minimal deviation $d^* = \min_Y d_i$ is identified. And third, the model with the smallest deviation is chosen, as it fits the specific situation best! The calculation terminates here.

Reflecting about the result (single-loop learning), the method application (double-loop learning), and the result of the implementation of the method result (follow-up).

3.4 Additional instructions for use

There are two additional instructions for the method application. First, be honest to yourself! The decision-maker has to gather all relevant information about the current situation (there might be information that cannot be displayed in the suggested binary vector), the currently applied PDP model (if existent), and all possibly introduced other models. And second, if it is not possible to examine whether a situational criterion is relevant or not (or to which extent it is relevant), its application is a 'political' decision of the decision-maker. It has to be taken into consideration that the organisation might be able to fulfil situational criteria with models, methods or tools beyond the examined PDP models. Thus, the criterion would be relevant for the situation, but not for the examined models.

4. Testing

This section evaluates the approach and structure of the evaluation method and investigates its applicability. This was achieved by challenging the method in expert interviews (section 4.1), and by applying the method to three PDP models based on the relevant criteria of two specific situations. These situations had been derived from interviews with practitioners working in manufacturing organisations (section 4.2). Thus, the second research question was addressed situation-specifically.

4.1 Testing in expert interviews

The first objective was the evaluation of the method approach, aiming to figure out whether it is sensible and promisingly effective, and whether its description is comprehensible. An evaluation by experts in semi-structured interviews was conducted, allowing them to give their own suggestions.
The interviewed experts were (1) a research associate at the EDC at the University of Cambridge, UK, who worked for about a decade as management consultant and in a business role, (2) a senior lecturer in the design group at the Open University in Milton Keynes, UK, and (3) a management consultant who completed his PhD at the EDC, focussing on the impact of interaction on process behaviour and management support through process modelling. These experts were not biased, as neither of them had been involved in the method development, nor was any of them author of the applied PDP models (in section 4.2.), nor did they know the details of the research questions, or hold an interest in the method.
The results of the interviews: (1) Regarding the criteria, there is a need for unambiguity in the relationship between both parts of each evaluation criterion. The linkages between both parts should neither be obvious nor inexplicable, even if they are explained somewhere else. Furthermore, all applied terms and concepts should be made clear for the method user. Regarding the step-by-step description, considering each possible loop, the method is "reasonable", "applicable" and "I am happy with it!" (2) Each of the method steps should have an informative heading. Nobody wants to 'mindlessly' follow an algorithm, but would appreciate having guidance during the evaluation process and the decision taking. As the consistency of the method is provided, the loose estimation of the threshold *T* catch one's eye considering all the concise formulations in the method description. As also partial process models can be supportive during the PDP, a weighting of the criteria might be helpful for the evaluation of potential process models. (3) The approach and structure of the evaluation method is "sensible" and "comprehensible". The method is applicable "by all means" even though the the derivation of the evaluation criteria should be scrutinised beforehand. Especially the clear and short step-by-step description is considered as supportive.
Having confirmed the sensibleness and general applicability of the evaluation method by three experts, the method was exemplarily applied in two specific situations, based on case studies in industry.

4.2 Testing with case study based applications

The second objective was the investigation of the method's applicability. By applying the evaluation method on 3 PDP models and 2 specific situations, it was examined (whether and) how the method works. As it is scarcely to be expected that an organisation will exchange its PDP model without any economic constraints, the testing focused on the descriptions of specific situations, on the method's applications, and on the deriving of recommendations which models fit the situations best.

In the application, the two case studies—of an automotive supplier ("Auto"), and a manufacturer of craftmen tools ("Tool") – result in situational descriptions of the organisations, derived from each one semi-structured interview (ca. one hour long) with an employee in a relevant department. This interview technique allowed to systematically investigate the situations with the list of criteria *L*, and additionally, the employees had the chance to bring in their several years' working experiences and own perspectives. In both cases, the list *L* got extended (in step 1) with the criteria stated in the Tables 2 and 3.

Table 2. Additional criteria for the automotive supplier (Auto)

Questions for the Situation	Questions for the Model
Is the quantity of products predictable?	Is the model designed for the predicted quantity of products?
Does the organisation need suppliers involved in the product development process?	Does the model provide interfaces to suppliers and support their involvement in the product development process?

Table 3. Additional criteria for the manufacturer of craftmen tools (Tool)

Questions for the Situation	Questions for the Model
Does the organisation want to develop complex product?	Is the model able to reflect the complexity of products?
Does the organisation need to develop several products at the same time?	Does the model support a simultaneous development of products and provides a tool for the scheduling of production starts?

The set of applied PDP models comprised here exemplarily the 3-Cycle-Model of product engineering ("3Cycles") by Gausemeier et al. [2011, 2012], the Muenchener Vorgehensmodell ("MVM") by Lindemann [2009], and the Integrated Product Engineering Model ("iPeM") by Albers [2010], [Albers et al. 2010], [Albers and Braun 2011]. All of these models are selected as they claim to be 'integrated models' with an holistic approach. The evaluation of the models was based on the above stated literature only.

The evaluation results of each criterion are depicted in Table 4. Both situations were characterised with the boolean description of 34 criteria each, whereof 25 and 22 respectively were relevant. The three PDP models were characterised with the same criteria. The following comments refer to Table 4 (a) 'Auto' can delay product launches due to its market power whereas 'Tool' depends on a early time-to-market. Only iPeM provides a module for the scheduling of activities. (b) The iPeM implementation in form of a wiki-based software application allows to tick both boxes. Software implementations of the other models are not described in the applied literature. (c) Both employees did not know enough about the informal network to answer the question. Thus, this criterion was not considered further. (d) iPeM fails the criterion due to the reported problems identified during the implementation in an industrial context [Albers et al. 2010, p. 23]. Eventually, the iPeM is the model with the smallest deviation from the required characteristics ($D_{\text{Auto,iPeM}} = 5$, $D_{\text{Tool,iPeM}} = 4$, compared to $D_{\text{Auto,3Cycles}} = 15$, $D_{\text{Tool,3Cycles}} = 17$ and $D_{\text{Auto,MVM}} = 14$, $D_{\text{Tool,MVM}} = 14$), and the only model that fulfils the relevant criteria sufficiently. Thus, iPeM fits best the situations' descriptions of both case studies.

5. Discussion

Regarding the success criterion, the evaluation method fulfils its purpose as demonstrated in section 4. Its application results are defined on $\mathbb{N}_0$, and thus, easy to compare. The method follows a clear structure (as supported in expert interviews), and it is easy to use (as the describing of the organisation's situations took one hour each). It is adjustable to these situations as only a portion of the criteria were considered as relevant (the examination of the two case study situations exemplarily demonstrates that the situations of two organisations can vary tremendously), and thus it is able to learn (on the one hand there are mechanisms to adapt certain values during the method application, e.g. the threshold *T* or the set *X*, and on the other hand there are opportunities to learn between two applications, e.g. by reflecting about the result, the application, and the consequences of the model implementation) even if the value of threshold T could be confirmed.

Table 4. Matching the criteria with 2 organisation's situations and with 3 PDP models

Situation	Auto	Tool	3Cycle	MVM	iPeM	**Models**
Adaptability						
Heterogeneous customers	1	1	1	1	1	Different customer needs
Change requirements	1	0	1	1	1	Adjust customer needs
Time-to-market (a)	0	1	0	0	1	Time-to-market
Techonology life cycle	1	0	1	1	1	Technology life cycle
Partly existing solutions	1	1	1	1	1	Adjustable to existing sol.
Performance						
Effectivness	1	0	0	1	1	Effectiveness
Efficiency	1	1	1	0	1	Efficiency
Performance on diff. levels	1	1	0	1	1	Performance on diff levels
Continuous improvement	1	1	0	0	1	As-is and to-be processes
Communication						
Knowledge of diff. funct.	1	1	1	0	0	Involvem. of departments
Need to communicate	1	1	0	0	1	Transparency
Frequent and direct commun.	0	1	0	0	0	Frequent and direct comm.
Secrecy	0	0	0	0	0	Secure channels
Team behaviour						
Shared understanding	1	1	1	1	1	Shared understanding
Development goal	0	1	0	1	1	How to divide goals
Comm. bet. team members	1	1	0	0	1	(b) Component responsib.
Who does what	1	1	0	0	1	(b) Who is working on…
Cross-functional interaction	1	1	0	0	0	Climate
Problem solving & learning						
Job rotation	1	0	0	1	0	Facilitate working in
Spontaneous problems	1	1	0	1	1	How to solve problems
Model improvement	0	1	0	0	1	Detect errors in the model
Knowledge handling						
Process predictable	1	0	0	0	0	Relevant information
Informal network of people (c)			-	-	-	Information sharing
Codify tacit knowledge	1	0	0	0	1	Codification of knowledge
Knowledge management	1	0	0	0	1	Storage, access, searching
Reuse of knowledge	1	1	0	0	1	Reuse of knowledge
Implementation & application						
Planning and controlling	1	0	1	1	1	Planning and controlling
Change mgmt. proj. difficult	0	0	0	1	0	Incremental impleme.
Model implementation	0	0	0	0	0	Feedback-effects
System of objectives	0	1	0	1	1	Target alignment
Insights in complex behaviour	1	1	0	0	1	Cybernetic principles
Cognitive support systems	0	0	1	1	0	(d) Cognitive processes
Motivation by reasoning	1	1	0	1	1	Why specific tasks

Automotive-case specific						
Quantity of products	1	-	1	0	0	Design for predicted qua.
Involvment of suppliers	1	-	1	0	1	Interfaces for suppliers
Manufacturing-case specific						
Product complexity	-	1	0	0	1	Complexity of products
Simultaneous development	-	1	0	0	0	Simult. devel. & schedul.

Regarding the method application: 33 criteria were suggested, and both practitioners added two criteria each. However, one of the 33 initial criteria (compare comment 'c') could not be applied so that the remaining 34 criteria were used for the situational descriptions. Of these criteria, 15 were relevant in both cases, 15 relevant in one case each, and 4 not relevant in either case. Especially the 15 'single-relevant' criteria—that is almost half of all criteria—highlight the need to adjust the criteria for the PDP model evaluation to the specific situation at hand. Besides the situational examination, the evaluation of the models shows that 'capable' models—i.e. models which fulfil a lot of criteria—are not preferred a priori above specific models regarding a specific situation, i.e. iPeM is not the 'best' model in general. However, these 'capable' models might have an advantage if the situation changes.
Regarding benefits and costs: As it is neither possible to label the costs of the method application with a 'price sticker' nor to calculate the exact benefit of the method application's result—due to the uniqueness of each application situation there is no 'baseline' for a comparison—only the most important influencing factors are discussed. The costs of the method application are caused by (1) the method application itself, depending on (1.a) the specific situation which has to be examined, i.e. the amount of criteria as well as the size and structure of the organisation influence the effort which is needed, and (1.b) the amount of process models which are examined, and (2) the process model implementation within the manufacturing organisation, including different departments, functions, locations, a lot of people—and maybe also suppliers and customers. On the contrary, the benefits depend on (1) the effectiveness and impact of the decision's result. The confidence of the result of the decision making does not have a direct financial impact for the organisation, however the implementation of the chosen model might influence the viability of the whole organisation, and (2) the efficiency and clarity during the application. The concise description minimises ambiguity for the decision-makers and facilitates the opportunity for a software implementation.

6. Conclusion and outlook

This paper highlights that influences on and requirements for PDP models can vary in industrial product development situations. Furthermore, this paper presents a method that supports decision-makers in identifying an appropriate PDP model for the specific situation of their organisation. However, in this early stage of research, its applicability is only tested in two exemplary situations.
Four directions for further research may be suggested: (1) The value for threshold *T* should be validated and might be complemented with weighting factors for the criteria. (2) The method might include the specific implementation costs for each PDP model, calculating the relation of the model's utility versus these costs. (3) Regarding the method application: A database for the evaluation results of situations and PDP models would be interesting (3.a) for decision-makers in industry as it would save the effort to evaluate the models against at least a part of the criteria, and (3.b) for the research community as it would provide insights into the relevant requirements of organisations in order to develop PDP models. (4) Practical experience has to validate whether the model implementation – based on the method's result – has the intended impact on the competitiveness of an organisation.

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References

Adner, R., Levinthal, D., "Demand Heterogeneity and Technology Evolution: Implications for Product and Process Innovation", Management Science, Vol. 47, No. 5, 2001, pp. 611–628.

Albers, A., Braun, A., "A generalised framework to compass and to support complex product engineering processes", International Journal of Product Development, Vol. 15, Nos. 1/2/3, 2011, pp. 6-25.

Albers, A., "Five Hypotheses about Engineering Processes and their Consequences", TMCE 2010.

Albers, A., Braun, A., Muschik, S., "Uniqueness and the Multiple Fractal Character of Product Engineering Processes", in: Heisig P, Clarkson JP, Vanja S (eds.), Proceedings of the MMEP 2010, Springer, London, 2010.

Birkhofer, H, Kloberdanz, H, Berger, B, Sauer, T, "Cleaning up design methods – describing methods completely and standardised", International Design Conference, DESIGN'02, 2002, pp. 17-22.

Bourgeon, L, "Staffing approach and conditions for collective learning in project teams: The case of new product development projects", International Journal of Project Management, Vol. 25, 2007, pp. 413–422.

Brookes, N. J., Backhouse, C. J., "Measuring the performance of product introduction", Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, Vol.212, No.1, 1998, pp.1-11.

Browning, T. R., Fricke, E., Negele, H., "Key Concepts in Modeling Product Development Processes", Systems Engineering, Vol. 9, No. 2, 2006, pp. 104–128.

Browning, T. R., Ramasesh, R. V., "A Survey of Activity Network-Based Process Models for Managing Product Development Projects", Production and Operations Management, Vol.16, No. 2, 2007, pp. 217–240.

Carlile, P. R., "A Pragmatic View of Knowledge and Boundaries: Boundary Objects in New Product Development", Organization Science, Vol. 13, No. 4, 2002, pp. 442–455.

Galbraith, J. R., "Organization Design: An Information Processing View", Interfaces, Vol. 4, No. 3, 1974, pp. 28-36.

Gausemeier, J., Dumitrescu, R., Kahl, S., Nordsiek, D., "Integrative development of product and production system for mechatronic products", Robotics and Computer-Integrated Manufacturing, Vol. 27, 2011, pp. 772–778.

Gausemeier, J., Lanza, G., Lindemann, U., "Produkte und Produktionssysteme integrativ konzipieren – Modellbildung und Analyse in der frühen Phase der Produktentstehung", Carl Hanser Verlag, Munich, 2012.

Gericke, K, Blessing, L., "Comparisions of design methodologies and process models across disciplines: a literature review", ICED'11, 2011.

Goh, Y. M., Booker, J. D., McMahon, C. A., "Evaluation of process modelling approaches to support probabilistic design analysis", ICED'03, 2003.

Heisig, P., Caldwell, N. H. M., Grebici, K., Clarkson, P. J., "Exploring knowledge and information needs in engineering from the past and for the future – results from a survey", Design Studies, Vol.31, 2010, pp. 499–532.

Johnsson, S., Eriksson, J., Olsson, R., "Modeling Performance in Complex Product Development – A Product Development Organizational Performance Model", Proceedings of the International Association for Management of Technology, IAMOT, 2008.

Kleinsmann, M., Buijs, J., Valkenburg, R., "Understanding the complexity of knowledge integration in collaborative new product development teams: A case study", J. Eng. Technol. Manag., Vol.27, 2010, pp. 20–32.

Lindemann, U., "Methodische Entwicklung technischer Produkte – Methoden flexibel und situationsgerecht anwenden", 3., korrigierte Auflage, Springer-Verlag Berlin Heidelberg, 2009.

Maier, A. M., Wynn, D. C., Andreasen, M. M., Clarkson, P. J., "A Cybernetic Perspective on Methods and Process Models in Collaborative Designing", International Design Conference, DESIGN'12, 2012, pp. 233–240.

McCarthy, I. P., Tsinopoulos, C., Allen, P., Rose-Anderssen, C., "New Product Development as a Complex Adaptive System of Decisions", Journal of Product Innovation Management, Vol. 23, 2006, pp. 437–456.

Moenaert, R. K., Caeldries, F., Lievens, A.,Wauters, E., "Communication Flows in International Product Innovation Teams", Journal of Product Innovation Management, Vol. 17, 2000, pp. 360–377.

Neufville, R., "Uncertainty Management for Engineering Systems Planning and Design", MITesd, Engineering Systems Monograph, March 2004.

O'Donnell, F. J., Duffy, A. H. B., "Modelling design development performance", International Journal of Operations & Production Management, Vol. 22, No. 11, 2002, pp. 1198–1221.

O'Donnell, F. J., Duffy, A. H. B., "Design Performance", Springer, London, 2005.

Purser, R. E., Pasmore, W. A., Tenkasi, R. V., "The influence of deliberations on learning in new product development teams", Journal of Engineering Technology Management, Vol. 9, 1992, pp. 1–28.

Robinson, M. A., Sparrow, P. R., Clegg, C., Birdi, K., "Design engineering competencies: future requirements and predicted changes in the forthcoming decade", Design Studies, Vol. 26, 2005, pp. 123–153.

Slater, S. F., Narver, J. C., "Market-Oriented Is More Than Being Customer-Led", Strategic Management Journal, Vol. 20, No. 12, 1999, pp. 1165-1168.
Stetter, R., Lindemann, U., "The transfer of methods into industry", in: Clarkson JP, Eckert CM: Design process improvement – A review of current practice, pp. 436–549, Springer, London, 2005.
Weber, C., "How to derive application-specific design methodologies", International Design Conference, DESIGN'08, 2008, pp. 69-80.
Wynn, D. C., "Model-Based Approaches to Support Process Improvement in Complex Product Development", PhD-Thesis at the University of Cambridge, UK, 2007.
Wynn, D. C., Maier, A. M., Clarkson, P. J., "How can PD Process Modelling Be Made More Useful? An Exploration of Factors which Influence Modelling Utility", International Design Conference, DESIGN'10, 2010, pp. 511–522.

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