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Procedia CIRP 70 (2018) 72–77

www.elsevier.com/locate/procedia

28th CIRP Design Conference, May 2018, Nantes, France

Adaptive Design of Engineering Change Management in Highly Iterative Product Development

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Abstract

Efficient Engineering Change Management (ECM) is an important competency in New Product Development. The increasing use of Highly Iterative Product Development as an agile development paradigm induces substantial time-variability in the requirements of ECM as products progress from early stage development to full series production. As a result, new functional-prerequisites for successful ECM arise in addition to those normally necessary. To address these additional, time-dynamic requirements, this study creates a method for the continuous adaption of ECM using the concept of complexity management.

A heuristic framework combining a detailed literature analysis and expert interviews forms the basis of the method's design. Hereby, complexity drivers and complexity enablers of ECM are identified. The study determines causal relationships between these complexity elements and presents specific measures suitable to allow practitioners to influence the level of complexity inherent in ECM systems. The findings are integrated into complexity-oriented models. Based on these models, a method is presented that permits the adaptive design of ECM to address time-variable management requirements across the product lifecycle.

Peer-review under responsibility of the scientific committee of the 28th CIRP Design Conference 2018.

Keywords: Engineering Change Management; Complexity Management; Agile Development; Highly Iterative Product Development

1. Introduction

Shortening product lifecycles and more stringent customer requirements increasingly require companies to bring novel designs to market quickly to maintain their competitiveness [1-3], a task which has traditionally posed a challenge for most companies [4]. As a result, companies strategically pursuing novel innovations increasingly prefer agile development processes to traditional development processes [2, 5, 6]. By adapting processes from the software industry to hardware design Schuh et al. present the learning-oriented agile development approach of Highly Iterative Product Development (HIPD) [7, 8]. A notable feature of HIPD is a strong reliance on the early production of a vast number of physical prototypes in iteration cycles during the design phase to benefit from the correction of design defects [6]. As a result, the approach induces a high degree of agility and allows an efficient reduction of market and technical uncertainty. At the same time, HIPD poses managerial challenges beyond those induced by traditional management processes, specifically affecting the execution of ECM (ECM) [6].

ECM is the process of managing engineering changes; engineering changes are defined as "changes to parts, drawings or software that have already been released during the product design process, regardless of the scale of the change" [9, p. 104]. ECM is commonly described as a six step process of raising a change request, identifying a set of possible solutions, assessing the risk/impact of those solutions, selecting a solution, implementing the solution, and finally reviewing the change [9] (see Figure 1) and is widely considered to be a critical competence for maintaining competitiveness in New Product Development (NPD) [10]. It is known to influence

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Peer-review under responsibility of the scientific committee of the 28th CIRP Design Conference 2018.
10.1016/j.procir.2018.02.016

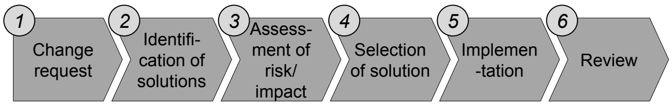

Figure 1: Six step Engineering Change Process (Credit: Jarratt [9])

factors such as the lead time, production cost and productivity of the NPD process [11]. In context of HIPD, the relevance of efficient ECM is amplified by the large number of prototypes and their corresponding design effects as well as pronounced time pressure.

After having introduced the research context in chapter 1, chapter 2 describes a set of functional prerequisites which must be satisfied in order for ECM to be successful. In chapter 3, the "state of the art" of ECM is critically discussed while chapter 4 presents the research methodology to be used. Lastly, chapter 5 presents the research results obtained by the study and in chapter 6 the central content of the paper is summarized in a conclusion.

2. Functional Prerequisites

Literature identifies a large variety of deficiencies in the field of ECM which complicate the design of efficient ECM for product development [9, 12, 13]. Based on empirical observations in a case company and insights from earlier investigations, this work underlines existing problems and illustrates additional ones arising from the new agile paradigm of HIPD [6]. Using these problems as a basis, functional prerequisites for successful ECM are derived. These prerequisites form the basis for both the assessment of existing literature in chapter 3 and the method's design in chapter 5.

2.1. Functional Prerequisite a): Measure-Based Design of a Socio-Technical ECM System

As ECM is a socio-technical system, existing literature exhibits substantial deficiencies in both social and technical sub-systems [6, 14, 15] such as static, inflexible change processes [9] and insufficient data management respectively [6]. Particularly, information technology (IT) factors supporting organizational aspects are neglected due to a lack of transparency about the mutual dependency of design factors of ECM. To guarantee a comprehensive approach to ECM design, an overview of design elements, their interdependencies and specific measures to qualify ECM systems are needed.

2.2. Functional Prerequisite b): Consideration of the Requirements of ECM Systems

Adequate design of socio-technical ECM systems must take into consideration all relevant requirements within companies such as product complexity or the role of suppliers [16]. Additionally, knowledge of requirements' effect on the design elements of ECM is needed. Due to a lack of knowledge about relevant requirements and their effect on ECM, the design of ECM often does not meet these specific requirements in reality. This fact leads to the need for an identification of the relevant influencing factors and of cause-effect relationships between influencing factors and design elements.

2.3. Functional Prerequisite c): Continuous Adaption of the ECM System

The increasing relevance of agile product development is the main driver for the need to develop a method of adaptive ECM design. This results from additional requirements imposed by HIPD. The requirements placed on ECM as mentioned in b) are now subject to pronounced time-variability. Hence, an easy-to-use method for the highly adaptive design of ECM through the fast implementation of adequate measures is required.

3. State of the Art

Though ECM is known to exhibit a low level of process maturity, several notable ECM frameworks exist [17, 18].

Huang (2001) proposes a web-based framework which provides computerized support to log, file, evaluate and issue EC's, though the method fails to integrate Product Lifecycle Management (PLM) and Enterprise Resource Planning (ERP) data [19]. Chen (2002) proposes a framework to support the activities required by allied concurrent engineering, another commonly employed agile development paradigm [20]. Chen's framework emphasizes dynamic configurability, flexibility heterogeneity and complexity as well as inter-enterprise communication and information consistency and is intended to integrate value-added activities by assigning them to the most qualified possible teams [20]. Rouibah (2003) proposes a workflow based ECM method to reflect the needs of customer order driven engineering [21]. Hamraz (2013) proposes a requirements-based framework using a literature based set of 25 key ECM requirements which focus on information consistency and flexibility [12]. This framework employs a linkage method to predict the effects of change implementation [12].

Analysis of the above frameworks reveals that functional prerequisite a) "socio-technicality" is generally addressed by existing frameworks, though some shortcomings exist such as lacking PLM and ERP integration [19, 21-23]. Functional prerequisite b), "consideration of the requirements of an ECM system", is incompletely addressed by existing literature; only three frameworks providing a listing of influencing factors were identified by Hamraz (2013) and none provided information about ECM design elements [12]. Likewise only two known papers present comprehensive listings of ECM design elements and neither do so in consideration of integration with an influence model [17, 24]. To date, no known paper has presented influence or design models suitable for integration with a cause relationship model and no such relationship model is known to exist. Due to the resulting inability to alter ECM frameworks as their requirements change, no easy to use adaptive ECM model is known to exist; academically developed ECM frameworks in general have historically performed poorly in industrial contexts [12, 21]. Furthermore, no known paper considers the issue of ECM in the context of HIPD, though proprietary implementations of such ECM systems are known to exist in industry. As such, functional prerequisite c) "need for an easy-to-use adaptive ECM framework" is not satisfied by existing literature. Therefore, while functional prerequisite a) is somewhat satisfied by existing literature, much work remains to satisfy prerequisites b) and c). This paper focuses on addressing these functional requirements, especially where existing literature has been deficient.

4. Methodology

A comprehensive literature review forms the basis of the method's design. Literature from the fields of ECM, Complexity Management and Systems Theory were analyzed and other fields were referenced where necessary. Direct literature quotations were catalogued and used to establish presented models and relationships. Literature was searched during the period of March to August, 2017 with an emphasis on keywords such as 'Engineering Change Management', 'New Product Development', 'Complexity Management', and others. Findings from literature were continuously validated through intensive interaction with industry experts as well as observations in a case company which designs electric vehicles using HIPD. Details about the case study are not included in this paper due to space constraints.

5. Findings

Using the methodology presented in chapter 4, models addressing the functional prerequisites outlined in chapter 2 were developed through analytical desktop research and empirical investigations. The overall aim of the research work is to provide a method that supports companies in the design of a fast and high quality change process. Accordingly, the rapid shift of requirements in agile development processes is a particularly relevant consideration of the model.

To develop the model, the systems theory based concept of complexity management is invoked. Applied in the context of ECM, complexity enablers present design factors of the ECM system which promote the ability to handle EC's efficiently through an increased amount of design complexity. In contrast, complexity drivers constitute the influencing factors of ECM, and constitute elements of of the company system which complicate the handling of EC's with increasing amount of influence complexity.

A design model is presented in section 5.1 consisting of a set of relevant complexity enablers. Interdependencies between complexity enablers and practical measures suitable to influence complexity enablers are identified. Similarly, section

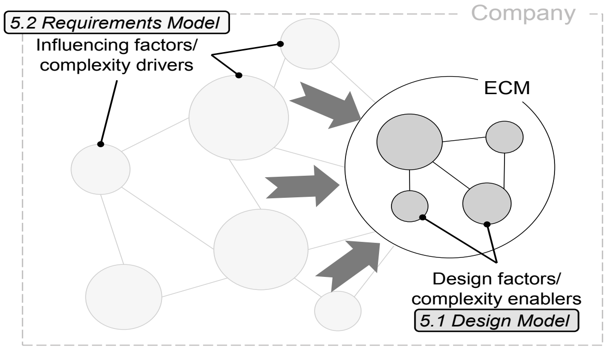

Figure 2: ECM System within Company System

5.2 presents a requirements model consisting of a set of relevant complexity drivers [25]. Using a model similar to that employed by Gartzen (2012), a relationships matrix is developed which allows the selection of an appropriate level of design complexity as required by a given influence complexity level [26]. The interaction of complexity drivers and complexity enablers is depicted in Figure 2.

A method is presented in section 5.3 which considers influence complexity as a function of relevant factors outside of the control of ECM practitioners; the method considers influence complexity to be responded to by design complexity. Though higher design complexities are known to exhibit greater capability in responding to the challenges induced by influence complexities [25], the model strives to limit design complexity to the degree strictly necessary, as any complexity is known to exhibit a negative effect on corporate performance [27].

5.1 Design Model

As input variables to the complexity model, a number of ECM design factors are identified from relevant literature sources. As aforementioned, these factors represent complexity enablers of ECM. The list of 23 complexity enablers and the literature from which they are sourced is presented in Table 1.

Table 1: List of ECM Complexity Enabler Categories

#	Enabler Category	Sources
1	Resource Allocation	*Tavcar (2006) [28], Lundqvist (2013) [29]*
2	Qualifications	*Lee (2007) [22]*
3	Team Composition	*Bosch-Rekveldt (2011) [30], Loch (1999) [31], Hood (1998) [32] , Tavcar (2006) [28]*
4	Organizational Interfaces	*Langer (2016) [14], Kahn (1996) [33], Tavcar (2006) [28]*
5	Individual Motivation	*Caruana (1998) [34], Loch (1999)[31]*
6	Directives and Control	*Kieser (1992) [35], Schreyögg (2016) [36], Caruana (1998) [34]*
7	Accountability	*Saeed (1993) [37], Peg (2002) [38], Tacvar (2006) [28], Kieser (1992) [35]*
8	Structural Formalization	*Tavcar (2006) [28], Kahn (1996) [33], Kieser (1992) [35], Rouibah (2003) [21]*
9	Contextual Support	*Lee (2006) [22], Lee (2011) [39], Alemanni (2011) [40]*
10	Document Availability	*Lee (2006) [22], Tavcar (2006) [28]*
11	Data Structure Ubiquity	*Tavcar (2006) [28], Lee (2011) [39], Huang (2001) [19]*
12	Data Structure Utility	*Tavcar (2006) [28], Rouibah (2003) [21]*
13	Experiential Knowledge Storage	*Lee (2006) [22], Pemberton (2000) [41]*
14	Process Flexibility	*Schonenberg (2008) [42], Tavcar (2006) [28]*
15	Process Support for Experiential Learning	*Lee (2006) [22], Pemberton (2000) [41]*
16	Organic Processes	*Rouibah (2003) [21]*
17	Breadth of Approval Requirements	*Saeed (1993) [37]*
18	Serial vs. Parallel Process	*Ström (2013) [24], Wickel (2015) [43], Rouibah (2003) [21]*
19	Diversity of Simultaneous Tasks	*Loch (1999) [31], Aral (2007) [44]*
20	Communication Intensity	*Tavcar (2006) [28], Yan (2013) [45]*
21	Communication Institutionalization	*Tavcar (2006) [28], Yan (2013) [45]*
22	Communication Formalization	*Tavcar (2006) [28], Prahinski (2004) [46]*

For each complexity enabler presented in Table 1, low and high complexity ideal types were identified from relevant literature. These ideal types allow qualification of the complexity level for each enabler category separately for each individual step in the six step ECM process. Though space constraints prevent a complete presentation of all ideal types, examples of these ideal types are given in the following paragraph.

The low and high ideal types of #7 - Accountability were found to be centralized decision making, external responsibility and decentralized decision making, individual responsibility respectively [28, 38]. Likewise, Yan (2013) identifies the low and high ideal types of #21 - Communication Institutionalization as all written and all face to face respectively [45]. By estimating the position of the actual value between these ideal types, practitioners are effectively able to qualify the complexity value of any of these elements.

Additionally, literature review revealed a number of interdependencies between complexity enablers in the ECM system. In other words, modifying a particular set of complexity enablers has the effect of modifying others outside that set. These interdependencies were investigated through literature review and recorded qualitatively in a 23x23 correlation matrix which preserves the direction of causality. Two examples of interrelations are given below.

Thoms notes that "a worker who feels accountable to coworkers as well as to a supervisor may find work more motivating" indicating that increasing the complexity of Accountability (#7) would also lead to an increase of the complexity of Individual Motivation (#5) [38, p. 309]. Additionally, this implies were an increase in Motivation (#5) required, the complexity of Accountability (#7) would need to be increased by implementing a relevant measure. In another example, Chen notes that decentralizing decision making is likely to increase communication frequency, indicating a positive correlation between Directives and Control (#6) and Communication Intensity (#20) [47]. Likewise, were increased Communication Intensity communication required, Directives and Control complexity would also need to be increased to increase the complexity level of those design factors.

Measures vary widely in their form and are only intended to be implemented in the steps of the ECM process for which they are necessary (as determined by the step-wise consideration of influence-design relationships discussed at the beginning of chapter 5). Examples of several measures are presented in Table 2.

Table 2: Sample of ECM Measures

Measure	Effect on Design Factors	Step	Source
Allowing Employees to Make Decisions	7. Accountability (+)	1-6	*Lindemann (1998) [48]*
Clarifying EC Ownership	8. Structural Formalization (+)	1-6	*Lindemann (1998) [48]*
Implement Inter-disciplinary Teams	3. Team Composition (+)	1-6	*Lindemann (1998) [48]*

5.2 Requirements Model

As referenced in chapter 4, an extensive literature based requirements analysis was conducted. Though this analysis was similar to those conducted by Hamraz (2013), Lee (2006) and Rouibah (2003), the need to identify specific ECM complexity drivers of ECM resulted in a different (though related) set of categories [12, 21, 22]. The complete listing of 10 complexity drivers and the literature from which they are sourced is presented in Table 3.

Table 3: List of ECM Complexity Drivers

#	Driver Category	Sources
1	Stakeholder Complexity	*Bosch-Rekveldt (2011) [30], Hertrampft (2008)[49]*
2	Goal Complexity	*Bosch-Rekveldt (2011) [30], Peg (2002)[38]*
3	Quality Requirements	*Bosch-Rekveldt (2011) [30]*
4	Vertical Integration	*Größler (2006) [50], Gartzen (2012) [26], Bosch-Rekveldt (2011) [30]*
5	Culture	*Bosch-Rekveldt (2011) [30], Loch (1999) [31]*
6	Product Technical Complexity	*Damanpour (1996) [51], Hobday (1998) [52], Hertrampft (2008) [49], Langer (2016) [14], Gartzen (2012) [26]*
7	Product Innovation and Novelty	*Gartzen (2012) [26], Hobday (1998) [52], Damanpour (1996) [51], Bosch-Rekveldt (2011) [30]*
8	Product Variety	*Hobday (1998) [52], Thomas (2017) [53]*
9	Process Scope	*Perona (2004) [27], Hobday (1998) [52]*
10	Company Features	*Bosch-Rekveldt (2011) [30], Pemberton (2000) [41], Pulkkinen (2013)[54]*

In a method identical to that used in the complexity enabler categories, the complexity level of complexity driver categories is qualified by judging the actual level of complexity against provided ideal types of each category.

Ideal types were developed for each category in a way identical to that presented in section 5.1 for the complexity enablers.

In addition, through an extensive literature analysis, observations at a case company and expert interviews, qualitative relationships were identified between complexity drivers and enablers. These multidimensional relationships were tabulated in a 23x10 relationships matrix assessed for relevance in each step of the ECM process. The latter distinction allows design complexities to be increased only in the process steps for which they are necessary, keeping overall design complexity to a minimum. A 5x3 excerpt is presented in Table 4.

Table 4: Excerpt of 23x10 Relationships Matrix (Steps for Which Relationship is Valid are Given in Brackets)

Design Model/ Influence Model	Stakeholder Complexity	Goal Complexity	Quality Re-quirements
Resource Allocation		+ (all)	+ (all)
Structural Formalization	+ (all)	+ (all)	+ (2-5)
Team Composition	+ (4)	+ (1,4)	
Organizational Interfaces		+ (2-3)	
Directives and Control	+ (2-5)	+ (2-5)	

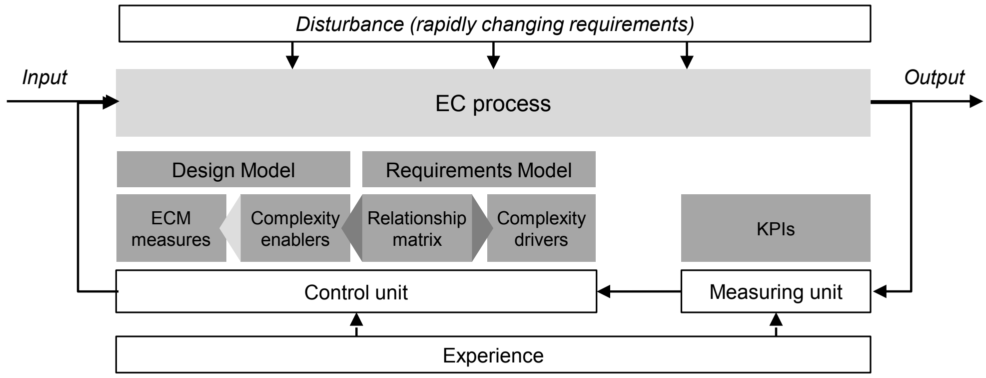

Figure 3: Method for the Adaptive Design of Engineering Change Management

5.3 Method for the Continuous Adaption of ECM

According to Winkler (2007), control circuits represent appropriate means to design and adapt complex systems [55]. ECM has been characterised as a socio-technical system in this article, thus a control system is the basis of the complexity-oriented method presented in Figure 3. As a result of complex causalities in ECM, the method possesses a heuristic character; control of the system requires profound experience in the field of ECM on the part of the method's applicant.

To implement the presented method, practitioners continuously assess the current state of the ECM system using KPI's such as the number of active EC's and process lead as suggested by Jarratt (2011) [9]. KPI's will tend to change as the performance of the system decreases over time as a result of both dynamic corporate needs (inputs) as well as changing requirements (disturbances). Once a predefined performance limit is reached, the method triggers an adaption of the ECM system within the control unit. Here, the Design Model and the Requirements Model allow for the derivation of suitable measures to stabilize the EC system: A systematic assessment of the complexity levels of the complexity drivers is followed by an evaluation of the compatible complexity enablers as indicated by the Relationship Matrix. If a discrepancy is detected, first interdependencies between complexity enablers are examined avoiding the risk of neglecting complexity aspects. Finally, practical measures suitable to influence all complexity enablers in need of modification are selected in order to regain complexity control.

6. Conclusion

As an agile development paradigm, HIPD represents a promising approach for the creation of novel innovations. Relying heavily on pronounced time-varying ECM requirements to reduce market uncertainties, HIPD poses a unique challenge for ECM practitioners.

To address this time variability, the presented research introduces an easy-to-use method which supports the continuous adaption of ECM in industrial practice. To accomplish this, the method relies on complexity-based design, influence, interdependence, relationship and measures models. This work presents relevant categories to describe all of these models and an industrially practicable iterative method to use them in ECM design.

Acknowledgements

The authors would like to thank the German Research Foundation (DFG) for funding this work in the research and development project "Cluster of Excellence – Integrative Production Technology for High Wage Countries".

References

[1] G. Schuh, T. Gartzen, F. Basse, and E. Schrey, "Enabling radical innovation through highly iterative product expedition in ramp up and demonstration factories," *Procedia CIRP,* vol. 41, pp. 620-625, 2016.

[2] C. M. McDermott and G. C. O'Connor, "Managing radical innovation: an overview of emergent strategy issues," *Journal of product innovation management,* vol. 19, no. 6, pp. 424-438, 2002.

[3] G. C. O'connor and M. P. Rice, "Opportunity recognition and breakthrough innovation in large established firms," *California Management Review,* vol. 43, no. 2, pp. 95-116, 2001.

[4] C. M. Christensen, *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*. Vahlen, 2011.

[5] P. G. Smith, "Change: Embrace It, Don't Deny It," *Research-Technology Management,* vol. 51, no. 4, pp. 34-40, 2008.

[6] G. Schuh, T. Gartzen, S. Soucy-Bouchard, and F. Basse, "Enabling agility in product development through an adaptive engineering change management," *Procedia CIRP,* vol. 63, pp. 342-347, 2017.

[7] G. Schuh, S. Rudolf, M. Riesener, and J. Kantelberg, "Application of Highly-Iterative Product Development in Automotive and Manufacturing Industry," in *ISPIM Innovation Symposium*, 2016, p. 1: The International Society for Professional Innovation Management (ISPIM).

[8] F. Diels, S. Rudolf, and G. Schuh, "Highly iterative product development process for engineering projects," *Applied Mechanics & Materials,* vol. 794, 2015.

[9] T. A. W. Jarratt, C. M. Eckert, N. H. M. Caldwell, and P. J. Clarkson, "Engineering change: an overview and perspective on the literature," *Research in Engineering Design,* vol. 22, no. 2, pp. 103-124, 2010.

[10] R. G. Boznak and A. K. Decker, *Competitive product development: a quality approach to succeeding in the'90s and beyond*. Irwin Professional Pub, 1993.

[11] K. R. Reddi and Y. B. Moon, "System dynamics modeling of engineering change management in a collaborative environment," *The International Journal of Advanced Manufacturing Technology,* vol. 55, no. 9-12, pp. 1225-1239, 2011.

[12] B. Hamraz, N. H. M. Caldwell, D. C. Wynn, and P. J. Clarkson, "Requirements-based development of an improved engineering change management method," *Journal of Engineering Design,* vol. 24, no. 11, pp. 765-793, 2013.

[13] N. Ahmad, D. C. Wynn, and P. J. Clarkson, "Change impact on a product and its redesign process: a tool for knowledge capture and reuse," *Research in Engineering Design,* vol. 24, no. 3, pp. 219-

244, 2013.
[14] S. Langer, "Änderungsmanagement," in *Handbuch Produktenwicklung*, U. Lindemann, Ed.: Carl Hanser Verlag GmbH Co Kg, 2016.
[15] A. Sharafi, "Knowledge Discovery in Databases," in *Knowledge Discovery in Databases*: Springer, 2013, pp. 51-108.
[16] F. B. G. Schuh, B. Franzkoch, F. Harzenetter, M. Luckert, J. Prote, J. Reschke, S. Schmitz, V. Stich, G. Tücks, J. Weißkopf, "Change Request im Produktionsbetrieb," presented at the AWK Aachener Werkzeugmaschinen Kolloquium 2017 – Internet of Production für agile Unternehmen, 2017.
[17] S. H. Storbjerg, T. D. Brunoe, and K. Nielsen, "Towards an engineering change management maturity grid," *Journal of Engineering Design,* vol. 27, no. 4-6, pp. 361-389, 2016.
[18] G. Huang, W. Yee, and K. Mak, "Current practice of engineering change management in Hong Kong manufacturing industries," *Journal of Materials Processing Technology,* vol. 139, no. 1, pp. 481-487, 2003.
[19] G. Huang, W. Yee, and K. Mak, "Development of a web-based system for engineering change management," *Robotics and Computer-Integrated Manufacturing,* vol. 17, no. 3, pp. 255-267, 2001.
[20] Y.-M. Chen, W.-S. Shir, and C.-Y. Shen, "Distributed engineering change management for allied concurrent engineering," *International Journal of Computer Integrated Manufacturing,* vol. 15, no. 2, pp. 127-151, 2002.
[21] K. Rouibah and K. Caskey, "A workflow system for the management of inter-company collaborative engineering processes," *Journal of Engineering Design,* vol. 14, no. 3, pp. 273-293, 2003.
[22] H. J. Lee, H. J. Ahn, J. W. Kim, and S. J. Park, "Capturing and reusing knowledge in engineering change management: A case of automobile development," *Information Systems Frontiers,* vol. 8, no. 5, pp. 375-394, 2006.
[23] V. Kocar and A. Akgunduz, "ADVICE: A virtual environment for Engineering Change Management," *Computers in Industry,* vol. 61, no. 1, pp. 15-28, 2010.
[24] M. Ström, "Improving engineering change processes by using lean principles," 2013.
[25] R. Kirchhof, *Ganzheitliches Komplexitätsmanagement: Grundlagen und Methodik des Umgangs mit Komplexität im Unternehmen*. Springer-Verlag, 2013.
[26] T. Gartzen, "Discrete Migration als Anlufstrategie für Montagesysteme," PhD, WZL, RWTH Aachen University, Aachen, Germany, 2012.
[27] M. Perona and G. Miragliotta, "Complexity management and supply chain performance assessment. A field study and a conceptual framework," *International journal of production economics,* vol. 90, no. 1, pp. 103-115, 2004.
[28] J. Tavcar and J. Duhovnik, "Engineering Change Management in Distruted Environment with PDM/PLM Support," in *Manufacturing the Future*: InTech, 2006.
[29] M. Lundqvist and A. Masson, "Improvement of an Engineering Change Process: A Case Study at ASCOM Wireless Solutions," Masters, Chalmers University of Technology, Gothenburg, Sweden, 2013.
[30] M. Bosch-Rekveldt, Y. Jongkind, H. Mooi, H. Bakker, and A. Verbraeck, "Grasping project complexity in large engineering projects: The TOE (Technical, Organizational and Environmental) framework," *International Journal of Project Management,* vol. 29, no. 6, pp. 728-739, 2011.
[31] C. Terwiesch and C. H. Loch, "Managing the process of engineering change orders: the case of the climate control system in automobile development," *Journal of product innovation management,* vol. 16, no. 2, pp. 160-172, 1999.
[32] C. Hood, "The Art of the State. Culture, Rhetoric, and Public Management," ed: Oxford, 1998.
[33] K. B. Kahn, "Interdepartmental integration: a definition with implications for product development performance," *Journal of product innovation management,* vol. 13, no. 2, pp. 137-151, 1996.
[34] A. Caruana, M. H. Morris, and A. J. Vella, "The effect of centralization and formalization on entrepreneurship in export firms," *Journal of Small Business Management,* vol. 36, no. 1, p. 16, 1998.
[35] A. Kieser and H. Kubicek, *Organisation*. Walter de Gruyter GmbH & Co KG, 1992.
[36] A. Schreyögg, "Der Organisationale Kontext im Coaching," *Handbuch Schlüsselkonzepte im Coaching,* pp. 1-11, 2016.
[37] B. I. Saeed, D. M. Bowen, and V. S. Sohoni, "Avoiding engineering changes through focused manufacturing knowledge," *IEEE Transactions on Engineering Management,* vol. 40, no. 1, pp. 54-59, 1993.
[38] P. Thoms, J. J. Dose, and K. S. Scott, "Relationships between accountability, job satisfaction, and trust," *Human resource development quarterly,* vol. 13, no. 3, pp. 307-323, 2002.
[39] J. Y. Lee, S. S. Choi, G. Y. Kim, and S. D. Noh, "Ubiquitous product life cycle management (u-PLM): a real-time and integrated engineering environment using ubiquitous technology in product life cycle management (PLM)," *International Journal of Computer Integrated Manufacturing,* vol. 24, no. 7, pp. 627-649, 2011.
[40] M. Alemanni, F. Destefanis, and E. Vezzetti, "Model-based definition design in the product lifecycle management scenario," *The International Journal of Advanced Manufacturing Technology,* vol. 52, no. 1-4, pp. 1-14, 2010.
[41] J. D. Pemberton and G. H. Stonehouse, "Organisational learning and knowledge assets – an essential partnership," *The Learning Organization,* vol. 7, no. 4, pp. 184-194, 2000.
[42] H. Schonenberg, R. Mans, N. Russell, N. Mulyar, and W. M. van der Aalst, "Towards a Taxonomy of Process Flexibility," in *CAiSE forum*, 2008, vol. 344, pp. 81-84.
[43] M. Wickel, N. Chucholowski, F. Behncke, and U. Lindemann, "Comparison of seven company-specific engineering change processes," in *Modelling and Management of Engineering Processes*: Springer, 2015, pp. 125-136.
[44] S. Aral, E. Brynjolfsson, and M. Van Alstyne, "Information, technology and information worker productivity: Task level evidence," ed: National Bureau of Economic Research Cambridge, Mass., USA, 2007.
[45] T. Yan and K. J. Dooley, "Communication intensity, goal congruence, and uncertainty in buyer–supplier new product development," *Journal of Operations Management,* vol. 31, no. 7-8, pp. 523-542, 2013.
[46] C. Prahinski and W. C. Benton, "Supplier evaluations: communication strategies to improve supplier performance," *Journal of Operations Management,* vol. 22, no. 1, pp. 39-62, 2004.
[47] C.-J. Chen, "Information Technology, Organizational Structure, and New Product Development---The Mediating Effect of Cross-Functional Team Interaction," *IEEE Transactions on Engineering Management,* vol. 54, no. 4, pp. 687-698, 2007.
[48] U. Lindemann and R. Reichwald, *Integriertes Änderungsmanagement*. Springer-Verlag, 2013.
[49] F. Hertrampf, R. Nickel, and M. Stirzel, "Produktionsanläufe als Erfolgsfaktor zur Einhaltung der Time-to-Market: Planung mit einem Anlaufreferenzmodell," *ZWF Zeitschrift für wirtschaftlichen Fabrikbetrieb,* vol. 103, no. 4, pp. 236-239, 2008.
[50] A. Größler, A. Grübner, and P. M. Milling, "Organisational adaptation processes to external complexity," *International Journal of Operations & Production Management,* vol. 26, no. 3, pp. 254-281, 2006.
[51] F. Damanpour, "Organizational complexity and innovation: developing and testing multiple contingency models," *Management science,* vol. 42, no. 5, pp. 693-716, 1996.
[52] M. Hobday, "Product complexity, innovation and industrial organisation," *Research policy,* vol. 26, no. 6, pp. 689-710, 1998.
[53] K. Thomas, "Complexity Steering within Pre-Series Planning for The Ramp-Up Phase in Low Volume Assembly," Masters, WZL, RWTH Aachen University, Aachen, German, 2017.
[54] A. Pulkkinen, P. Huhtala, S.-P. Leino, J.-P. Anttila, and V. V. Vainio, "Characterising the Industrial Context of Engineering Change Management," vol. 467, pp. 618-627, 2016.
[55] H. Winkler, M. Heins, and P. Nyhuis, "A controlling system based on cause–effect relationships for the ramp-up of production systems," *Production Engineering,* vol. 1, no. 1, pp. 103-111, 2007.