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Procedia CIRP 91 (2020) 415–420

www.elsevier.com/locate/procedia

30th CIRP Design 2020 (CIRP Design 2020)

Literature-based identification of success-relevant influencing factors of distributed product development

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Abstract

Increasingly complex products and processes, tougher international competition and increasing customer requirements are some of the trends leading to the current organizational change. Companies are more and more conducting their development activities across locations and national borders. The aim is to optimally exploit the potential created by the changed environment and to gain an advantage over the competitors. Furthermore, companies are facing additional challenges, such as increased organizational effort, a lack of personal contact and the resulting communication delays. In order to be able to react flexibly to the changed boundary conditions, companies are increasingly trying to implement agile measures. The implementation of these measures and the addressing of the heterogeneity of the distributed development environments increase the complexity of the entire product development process. In order to successfully master this complexity in the transformation process, the question arises which influencing factors are decisively contributing to the success of distributed development processes. This contribution is therefore dedicated to the literature-based identification of the success-relevant influencing factors in distributed product development. In addition, the success-relevant influencing factors were assigned to the dimensions people, technology and organization to further be able to investigated what effect changing an influencing factor has on the dimensions and thus also on the influencing factors classified under them. Finally, the collection of success-relevant influencing factors indicates which influencing factors must be considered when adapting processes, methods and tools as part of the operation system of the product development process to the prevailing distributed development situation. Additionally, it must be considered that the transformation process can only be successful if the integrated consideration of the three dimensions technology, organization as well as the individual people affected by change as the center of product development is taken into account.

Keywords: Distributed product development; virtual engineering; influencing factors; managing complexity

1. Introduction

The global expansion of numerous companies and the growing need for interdisciplinary communication due to increasingly complex products lead to intensified collaboration between developers from different locations. Distributed product development is a promising enabler for overcoming the multiple interfaces in the development of mechatronic systems. This development is additionally driven by the availability of new technologies to support communication and collaboration [1]. Especially in the early phase of PGE - Product Generation Engineering, the early integration of experts in the process is essential to cope with the increasing product complexity [2]. Thus, the distributed and interdisciplinary collaboration not only increases the complexity but also the heterogeneity of the entire product development process. In addition, many companies experience difficulties in adapting their processes, methods and tools to the changing conditions due to a lack of

10.1016/j.procir.2019.11.007

experience. Therefore, many companies are increasingly trying to act flexible by implementing agile approaches in order to respond to the dynamic boundary conditions and to exploit the advantages of distributed product development. Based on the ASD – Agile Systems Design approach, measures have to be derived that especially address the transformation on the micro levels of the activities and the method implementation in the product development process [3]. In order to successfully master this transformation process, it is of crucial importance to aim for the integrated consideration and inclusion of the dimensions technology, organization as well as the individual people affected by change as the center of product development [4]. A multitude of influencing factors that can be assigned to these three dimensions describe the context of distributed development processes. Unfortunately, there is currently no knowledge about the key influencing factors in distributed product development that are essential for the success of distributed development processes.

2. State of the Art

2.1. Distributed product development

In order to be able to respond to the further increase in international competitive pressure, companies continue to expand their product development activities to different locations. In the second half of the century, companies operating world-wide expanded their production system to globally distributed production sites. As a second step of globalization, the first distributed product development teams could be observed in the USA in the 1990s [5]. KRAUSE ET AL. describe distributed development as the cooperative execution of different sub-tasks in product development, which are brought together under exchange of information and focus on the aspects of coordination, cooperation and communication [6]. Coordination is understood as the linking of partial solutions, cooperation as the collaborative work on a problem solution and communication as the exchange of information during cooperation [6]. In addition, SELIGER ET AL. emphasize a correlation between increasing product complexity and distributed product development, which DUEHR ET AL. additionally extend to the correlation with process complexity [7,8]. Further, distributed product development presents itself as an opportunity to address the rising complexity [7]. Therefore, GRIEB considers different organizational structures and IT infrastructures, geographically distributed locations with different working cultures and mentalities as well as interdisciplinary tasks in the same or different phases of the product development process as consequences of distributed product development processes [1]. Thus, the operation system of the product development process as a social technical system, which includes according to ALBERS ET AL. activities, methods and tools as well as the resources needed for their execution, is distributed across different locations [9]. In addition to the term distributed product development, collaborative product design, collaborative product engineering and virtual product development are generally used [10–13].

Positive effects of distributed development processes can be found in the areas of costs, time and quality. Cost savings can be achieved by reducing travel costs [10]. An indispensable prerequisite for this, and a further advantage with a successful implementation, is the centralization of distributed knowledge. Both of these factors also have a positive influence on the development time, which can be further improved through the intelligent use of different time zones [14]. The market proximity gained and the increased creativity potential due to the heterogeneity of the development teams can be linked to an increased quality [15,16]. The presented opportunities are facing challenges which can be mainly traced back to the physical distances and the resulting organizational effort [13,17]. The challenges include longer reaction times and the bridging of cultural differences [13,16]. In addition to human factors, organizational and technical challenges are also of great importance, such as mutual dependencies of product structures, knowledge management and data security risks [7,15,18].

2.2. Characterization of development situations

A comparison of the prevailing development situation with the required development situation regarding the upcoming development task enables the addressing of the described challenges and the exploitation of the potentials. Therefore, a characterization of distributed development situations is needed. Influencing factors are often used to make statements about the nature of development contexts [19]. According to GERICKE ET AL., the context of product development can be understood as the sum of the context factors that influence the course of development projects and the application of processes, methods and tools [20]. WILMSEN ET AL. describe the development situation as a time-dependent section of the context factors, which thus reflect the current status and the direct boundary conditions of the innovation project [21]. In addition to the description of general development contexts, several approaches exist which consider the description of distributed development contexts and which provide a basis for the analysis of the influencing factors in this contribution [15,22–26]. However, these approaches often refer to a specific field of observation and therefore do not form a collection of influencing factors that can be used across the board [27].

2.3. Design dimensions human, technology and organization

The terms people, technology and organization represent fundamental dimensions of distributed product development [17]. Especially in order to achieve a successful implementation of new processes, methods and tools, it is necessary to aim for the integrated consideration and inclusion of the connecting systems, the organization as well as, according to ALBERS ET AL., the individual people affected by change as the center of product development [4]. It should be noted that the three aspects correlate with each other, so that

mutual influence cannot be ignored when implementing new measures [17]. In general, the standards of distributed teams are similar to those of traditional teams, but they are facing additional challenges (see chapter 2.2) [1]. In order to handle the upcoming challenges, it is essential to address the increased demands on communication [28], performance ethos, self-confidence and self-discipline due to the increased personal responsibility [29]. The development of information and communication technology makes it easier to overcome the challenges related to the distances between stakeholders in distributed product development processes [1]. The focus of the cooperation support is on the selection and adaptation of existing tools ensuring the consideration of users' needs and the given framework conditions [17,30]. Due to the high number of interfaces between the team members, there is an increased coordination effort. This can be accomplished by thorough organizational planning of tasks and interfaces [17].

3. Aim and Methodology of Research

Looking at the current state of research, it appears that distributed product development entails many opportunities, but also many challenges. In order to meet these challenges, it is essential to develop an understanding of which influencing factors contribute significantly to the success of distributed development projects. With a manageable amount of success-relevant influencing factors, processes, methods and tools of product development can be adapted to the prevailing distributed development situation. Based on the multitude of existing approaches for the description of development contexts, the aim of this contribution is to identify the success-relevant influencing factors in distributed product development and to assign them to the fields *people*, *technology* and *organization*. This leads to the following research questions:

- Which influencing factors from literature describe the context of distributed product development?
- What influencing factors determine the success of distributed product development projects?

In order to address these questions, a detailed literature review in the field of distributed product development was conducted to identify the overall influencing factors of distributed on the one hand and on the other hand the success factors of distributed product development. A number of 16 pre-defined search terms was applied to five databases (Scopus, Web of Science, Design Society, IEEE, and Google Scholar). From the total of all search results obtained, 111 publications were considered particularly relevant after the examination of the title and the abstract and have been further analyzed. 11 contributions provided influencing factors for distributed product development processes. 168 influencing factors were identified, the number of which decreased to 105 after the elimination of duplicates. In addition to exact duplicates, logical duplicates were also understood as duplicates, such as the influencing factors *language* and *number of different languages*. In order to ensure that all relevant areas of product development are considered, a comparison was made with the influencing factors for the description of general product development contexts according to WILMSEN ET AL. [21]. The aggregated number of 208 influencing factors were subsequently assigned to the following cluster based on BLESSING AND CHAKRABARTI [31]:

- macro-economy,
- micro-economy,
- organization,
- product,
- process, methods and tools,
- people.

Regarding the success factors, the literature research identified five contributions that provide a collection of success factors for distributed product development. The success factors were reduced by duplicates and, like the influencing factors, divided into the 6 previously mentioned clusters. In total 36, success factors were identified.

In order to deal with the large number of 208 influencing factors, the degree of their influence on the success factors was discussed to identify the most relevant influencing factors regarding the success of a distributed development process. The level of influence was assessed on the basis of the designations and explanations of the factors in the literature and the following evaluation scale was applied: 0 - no influence, 1 - low to medium influence, 2 - high influence. Each factor was independently scored by two researchers and then discussed until mutual agreement was reached. The subsequently formed sum value indicates the degree of impact of each influencing factor on the success of distributed development projects. The *Scree-Test* [32] was used to identify the limit value of the sum values, which specifies the number of influencing factors relevant to success, on the basis of the sum values sorted in descending order. Finally, 76 success-relevant influencing factors were identified and allocated to the fields *people*, *technology* and *organization* and their intersections.

4. Success-relevant influencing factors of distributed product development

Table 1 shows the numbers of influencing and success factors after clustering. Whereas the highest amount of influencing factors can be attributed to the clusters "product" (77 out of 208) and "people" (51 out of 208), most of the success factors belong to the *people* cluster (18 out of 36).

Table 1. Number of influencing factors and success factors per cluster.

Cluster	Influencing factors	Success factors
macro-economy	17	0
micro-economy	13	0
organization	31	9
product	77	5
process, methods and tools	19	4
people	51	18

For the determination of the most relevant influencing factors, the Scree-test showed a significant gradient variation at the

point with the highest difference in the number of influencing factors per sum value [32]. Considering this background, this difference can be noted at the position ≥4 when looking at the graph, which is shown in Figure 1 and results in a total number of 76 success-relevant influencing factors. Adding the influencing factors with the sum value 3 would considerably increase the complexity for further investigation of the success-relevant influencing factors. In relation to the significant increase in the complexity of the investigation, the additional information from the influencing factors could only result in a marginal added value. For this reason, the limit for the identification of the success-relevant influencing factors results at the sum value 4. The complete list of success-relevant influencing factors can be found in table 2.

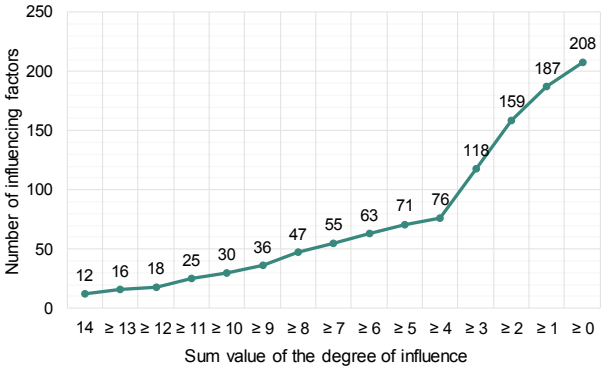

Fig. 1. Number of influencing factors per total value for determining the success-relevant influencing factors

Table 2. List of literature-based success-relevant influencing factors in distributed product development.

Macro-economy	Micro-economy	Organization	Product	Process, methods and tools	People
Politics	Customer involvement	Collaboration with suppliers	Industrial sector	Support through methods and tools (integration in teams)	Language
Publicity		Location	Integration in company	Change management	Culture
Legislative design		Size (company characteristic)	Number of interfaces	Tool compatibility	Number of different nationalities
Testing and certification facility		Long-term focus	Access to data	Techniques / Technologies (communication)	Time difference between time zones
Globalization of the product		Focus on vision and objectives	Security	Type of interaction	Qualification of team members
		Clarity of objectives	Integration in processes	Cross-system method usage	Experience team members
		Leadership styles	Degree of formalization	Support of the method application	Competence (methodical, social and technical)
		Product development strategies (R&D)	Understanding of goals	Decision for a selection of technical solutions	Creativity
		Knowledge management	Project boundary	Decision for a selection of concepts	Productivity
		Interdepartmental cooperation	Project size / scope		Quality of work
			Project budget		Knowledge of methods
			Project risk		Team size and composition
			Process approach		Team organization
			Cross-functional interaction		Team structures at locations
			Complexity		Type of distance
			Share of new development		Mobility
			Existing knowledge about reference system		Use of different collaboration technologies
			Degree of virtuality of the prototype		Different working possibilities
			Availability of technology		Understanding different framework conditions (economic, social and legal)
			Reliability (communication)		Project work when team members change
			Frequency (communication)		Independence of the team
			Availability of required information		Experience with communication technologies
			Actuality of the information		Experience in working with virtual teams
			Adaptation to cultural circumstances		Frequency of personal meetings
					Relationships between teams
					Stage of team development / maturing
					(Individual) Personality

As has already been observed with the presented influencing factors, after the Scree test, the majority of the identified success-relevant influencing factors are also assigned to the two clusters product and people (see table 2). Figure 2 shows some examples of the results from the assignment of the success-relevant influencing factors to the three design dimensions as presented in Chapter 3 covering the three fields and their intersections.

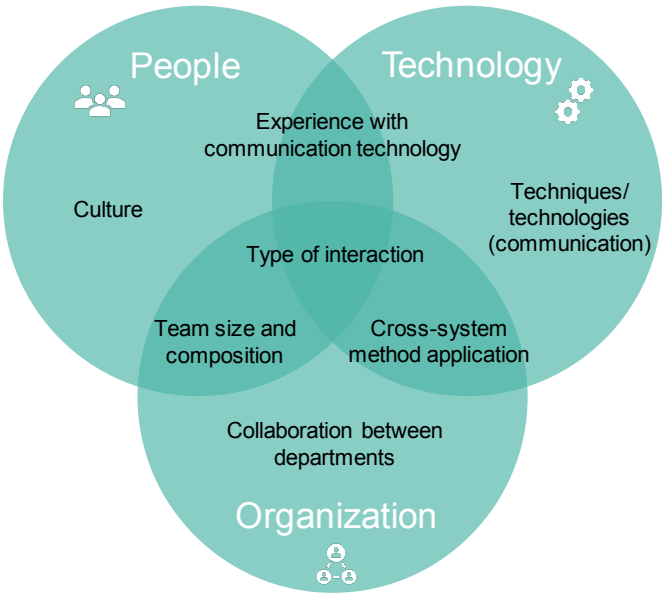

Fig. 2. Assignment of the success-relevant influencing factors to the dimensions of people, technology and organization.

- **Techniques/technologies (communication):**
  Techniques and technologies are presented as characteristics of the communication abilities. This success-relevant influencing factor has a high influence on other factors related to the aspect of communication. For example, the quality of communication is determined among other things by the technology provided for communication [24].

- **Team size and composition:**
  The size and composition of the team determines to a large extent the collaboration within the team [33]. Against this background, the relevance of this influencing factor for the success of distributed development projects is highlighted by the fact that "effective and efficient teamwork, especially in the context of globally distributed product development projects, is seen [as] the basis for [the] successful fulfilment of [...] complex tasks" [34].

- **Type of interaction:**
  This influencing factor describes how the different project participants collaborate and communicate with each other. A distinction is made between communication and collaboration in face-to-face meetings and those that are using technical systems. This description can be used to support the determination of the degree of virtuality [26].

5. Discussion

The results of the study are based on a detailed literature review in the research field of distributed product development. Accordingly, the results obtained at the current state of the investigation are based solely on the literature. In order to validate and verify the applicability of the literature-based results in practice, a subsequent validation and verification of the identified success-relevant influencing factors in a practical environment is essential.

As already becomes clear with the consideration of Figure 2 from chapter 4, it is not always possible to clearly assign the individual influencing factors to one of the dimensions. Rather, the influencing factors address several dimensions or their intersections. For this reason, it should be investigated what effect changing an influencing factor has on the dimensions and thus also on the influencing factors classified under them. Therefore, it is necessary to further analyze their interdependencies in order to be able to include possible effects on the prevailing context. Ultimately, it is intended to be able to make recommendations about the TARGET-state of the influencing factors for the exploitation of potentials in distributed product development.

6. Conclusion and Outlook

With the help of the analysis of the identified influencing and success factors, a manageable number of influencing factors was defined, which are relevant for the success of distributed development projects. In this way, for the first time, a centralized framework for the characterization of distributed development situations was developed. The reduction of the number of influencing factors to be considered also reduced the complexity for subsequent analyses. Against this background, it is possible to undertake further specific case studies in practice to an acceptable extent in order to gain insights about the applicability and potential effects of the success-relevant influencing factors.

In the following research, studies on the characterization of development tasks and their influence on the success-relevant influencing factors a further basis for the evaluation of the relevance of the influencing factors identified based on literature will be developed. This further development of the obtained results should lead to an adequate source of information for the desired comparison of actual and target performance of distributed product development contexts. Based on this, measures from literature and from analysis of distributed development processes can be derived in order to exploit the existing potential. Thereby, it is of particular importance that for a successful implementation of these measures all three of the design dimensions people, technology and organization are always jointly considered.

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