INTERNATIONAL DESIGN CONFERENCE - DESIGN 2016
Dubrovnik - Croatia, May 16 - 19, 2016.

SYNCHRONIZATION IN PRODUCT DEVELOPMENT PROJECTS: A LITERATURE STUDY ON CHALLENGES AND PRACTICES

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Keywords: project management, activity interdependency, synchronization, coordination

1. Introduction

Today's product development projects face a high degree of complexity resulting from e. g. modular product portfolios, ambiguous goals, distributed teams and cross-functional teamwork. This creates challenges in aligning and coordinating interdependent activities within the project's processes, to which practitioners often refer to as "synchronization" (e. g. [Negele et al. 2006]). In a survey about challenges in the mechatronic development process, 68 % of 140 companies state that proper synchronization during the development process is a major challenge [Aberdeen Group 2006]. The report concludes that the synchronization of mechanical and electrical design representations is the most important challenge during mechatronic product development. Generally, the management of complex, dependent activities and their interactions can be seen as a key factor in coordinating interdisciplinary product development efforts [Duffy et al. 1993], [Miao and Haake 1998].
Following the argumentation by Moser et al. [2015], activity dependence in projects is mostly modelled as an input-output relationship using activity precedence diagrams. However, as enumerated above, a lot more dependencies exist, which lead to a need for coordination. There is plenty of research in the area of coordination. For example, the issues communication, information flow and collaboration are addressed in several fields such as social science, computer science, management science and design science.
However, in these works only certain aspects of the problem [Tristl et al. 2013] and concrete methods that support coordination (as noun of the process to coordinate) are adressed. Synchronization as a phenomenon on a meta-level of coordination (the coordination of coordination if you will) has not been addressed very thoroughly nor in a systematically and actionable way. Therefore, we aim to support synchronization in product development projects by summarizing potential challenges that hinder the alignment and coordination of dependent activities, and by providing a list of practices that aim to overcome these challenges (section 2). In section 3, we further present an approach that intends to support the selection of practices for a given set of challenges. A discussion of our study and approach constitute section 4, before conclusions are drawn in section 5.

2. Literature study on challenges and practices

First, we want to clarify our understanding of the phenomenon we refer to with the term synchronization. Synchronization is defined as the process (a) of defining the project system in a way that dependent processes are aligned and (b) of planning efficient and effective coordination. Hence, it involves more than just temporal alignment. It includes the establishment of alignment and the planning of coordination, while alignment is the state of being aligned and coordination is the act of coordinating. Figure 1 illustrates the correlation between the terms.

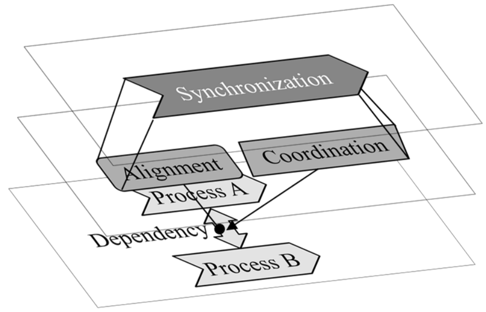

Figure 1. Schematic illustration of the terminology

2.1 Challenges

The overall need for synchronization in product development can be transformed into elementary challenges for effective and efficient coordination. In the case of successful synchronization, two entities in a project system A and B are aligned all the time and coordination is effective and efficient throughout the course of a project (Figure 2, left). Regarding the identified challenges and the holistic perspective of synchronization, the placeholders A and B can stand for any entity type such as organizational units (teams, individuals), processes (activities), tools (software, hardware) or products (components, product data).

The definitions of the challenges here are kept on an abstract level in order to cover many application scenarios and possibilities for transfer to different domains. We identified six challenges based on a review of the synchronization literature, which are depicted in Figure 2 and are described in detail in the following.

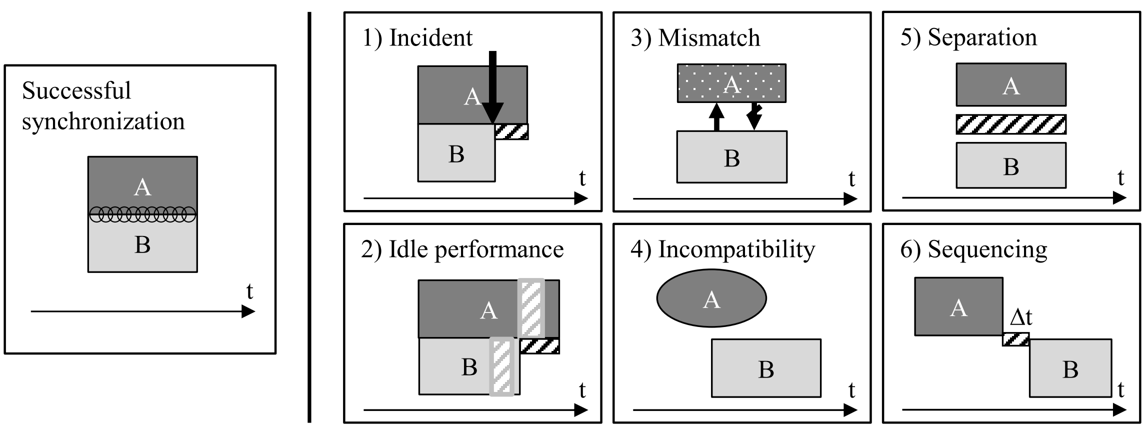

Figure 2. Two aligned entities that allow effective and efficient coordination (left) and six identified challenges that imply needs for synchronization management

- Incident

The challenge incident represents a change in the original project plan with a negative influence on the project. It can appear because of an unforeseeable event [De Meyer et al. 2002] that was triggered by internal or external influence factors. A might not be aware that B is affected by the incident, which leads to a failure of coordination in the end.

- Idle performance

This problem can occur due to a lack of documentation. Results or procedures might not be mentioned in reports or documents which could trigger different groups to do the same work again. These aspects lead to unnecessary rework and overproduction, which means the creation of the same information multiple times and hence wasting time and resources.

- Mismatch

Mismatch is defined as a one-sided lack of information exchange. B could provide correct information to A, which A receives successfully. However, due to a misunderstanding in A or a misinterpretation through A, the task is understood differently than B expects [Clark 1996]. Another possibility of a mismatch would be an one-sided lack of interfaces between tools.

- Incompatibility

When two entities in a project system have no mutuality and therefore cannot interact, they are regarded as incompatible. An incompatibility can exist e. g. between two different kinds of tools, such as a CAD tool and an on-board electrical system development tool. Furthermore, humans can be called incompatible if they do not have enough in common [Ickes 1985].

- Separation

A lot of literature is identified that addresses the phenomenon of separation. Consequently, we break down this challenge into several subcategories, which are listed in Table 2. All the subcategories of separations can occur during a project. They lead to disturbed or decreased communication between the parties.

Table 1. Subcategories of the challenge separation

Spatial gap	A spatial gap results from different locations of the two considered entities, e.g. in distributed project environments or department-specific work spaces. It induces a lack of implicit communication. [Tang 1991], [Carroll et al. 2003], [Lientz 2013], [Salas 2013]
Knowledge gap	Different knowledge backgrounds, e.g. in an interdisciplinary environment, lead to a knowledge gap. Also different implementations of the same system in different disciplines or the lack of understanding of the whole system due to “overspecialization” can lead to separation due to knowledge gaps. Last, missing information leads to knowledge gaps. [Clark 1996], [Bréchet 2001], [Carroll et al. 2003], [Tristl et al. 2013]
Cultural gap	A different way of working due to cultural habits or misunderstandings due to language and expression differences are related to cultural gaps and hinders collaboration. [Clark 1996], [Carroll et al. 2003], [Huang and Trauth 2008], [Lientz 2013]
Behavioral gap	A behavioural gap can lead to different ways of working due to age and generation differences (different priorities and working methods) or due to different educational backgrounds and therefore different ways of thinking, wording and opinions. Also missing soft skills can hinder effective cooperation. [Carroll et al. 2003]
Capacity gap	When one entity has less time due to a higher workload and therefore hinders multiple activities to end at the same time, a capacity gap exists. This problem can develop out of a suboptimal capacity distribution. The resulting time pressure can hinder a proper coordination because the processing of work is prioritized. [Gaul 2001]
Low intensity of cooperation	Separation is also existent when only few communication takes place during the process and only final results are exchanged. [Bar-El and Malul 2008]
Many hierarchy levels	Usually, the more levels of hierarchy established in an organization, the more time-comsuming are decisions. This could lead to different working speed in two processes. Further, the interaction between two individuals who are on different hierarchy levels within an organization might be decreased due to “social” separation. [Malone and Crowston 1994], [de Corbière and Rowe 2013]
Domain-specific standards and tools	Different standard processes in different deparments or different tools for subsystem development lead to separation. [Tang 1991], [Tristl et al. 2013]

- Sequencing

Sequencing results from time shifts between two dependent entities, which can be inevitable for example due to exclusively available resources [Carroll et al. 2003], [de Corbière and Rowe 2013]. Examples for sequencing could be people working in different time zones or the usage of a common tool or machine, which can be only used for one purpose at the same time and needs an idling time after usage.

2.2 Synchronization management practices

In addition to common challenges we aim to identify practices that support to overcome these challenges. During the literature study, we came across different practices that address synchronization issues. On the one hand, there are practices that aim to establish successful coordination and alignment, on the other hand, there are practices that represent different ways to cope with challenges during the project. Table 2 provides an overview of the identified practices which are described in the following.

Table 2. Identified synchronization management practices in literature

Practices establishing coordination and alignment	Practices for situational coordination support
a) Linking product and process models	f) Planning mini-synchronization
b) Creating a generic synchronization framework	g) Pulsing
c) Establishing a synchronization plan	h) Unconditionally starting processes
d) Planning synchronization points / quality gates	i) Changing boundary conditions
e) Establishing common background knowledge	j) Cooperating with configuration management

2.2.1 Practices establishing coordination and alignment

a) Generally, the definition of a process and product model helps to support the collaboration of parallelized but interacting domain-specific processes [Wenzel 2003]. Establishing a process model including effort, duration of each process and resources structures the project plan. The modeling of process dependencies especially helps to notify affected stakeholders of dependent processes in case of delays. The process model can be complemented by a product model that supports the interdisciplinary understanding and serves as a basis for discussion. With a Multiple-Domain Matrix (MDM), the models can be linked in order to show correlations between product information and process information.
b) This also supports to create a generic synchronization framework. The framework can be defined project-independent and can be adapted and applied to several development projects. One advantage of an overall framework for different projects is the improved communication within the company. The creation of such a framework implies the definition of terms as well as common views on procedures and dependencies. This promotes an interdisciplinary understanding of the structure of projects and therefore provides transparency during project implementation [Negele et al. 2006], [Tristl et al. 2013].
c) A more specific version of a generic framework is achieved through establishing a synchronization plan or master plan for each project [Negele et al. 2006]. By building and using it, mutual dependencies across departments are discovered and the communication between them is supported, respectively. Moreover, milestones are chronologically classified and process results are synchronized.
d) The systematic information exchange in a synchronization plan can be supported by defining synchronization points. These help to structure interactions and processes chronologically and to combine different development processes. Synchronization points can consist of interdisciplinary milestones, reviews, quality gates, workshops, collaborations over departmental boundaries, approvals as well as decisions and are used to exchange important information as early as possible in the development lifecycle [Schuh 2013], [Tristl et al. 2013]. The application of quality gates allows for a splitting and realigning of several developments of subsystems without limiting the individual processes in their own development procedures. It is possible to assess the project's progress by assessing the product’s maturity at important points of development using quality requirements.
e) Another way of supporting interdisciplinary understanding in a project is by establishing a common background knowledge [Carroll et al. 2003]. The approach aims to ensure that the stakeholders have the same knowledge about the system. Hence, the involvement of their own work and consequences of changes can be better assessed, which allows for quicker and more effective decisions.

2.2.2 Practices for situational coordination support

f) On the level of situational coordination support, the definition of more frequent synchronization points (rolling wave planning) for strong process dependencies is suggested by Zielinski [2009]. This "mini-synchronization" supports the pulsing of the project and a close coordination between dependent tasks. As it implies more effort, it is recommended predominantly for critical short-term synchronization.

g) Schuh [2013] suggests pulsing as a similar practice, which focuses on temporal synchronization. Pulsing can be used as a technique to ensure temporal alignment and control by generating a basic structural grid for coordination. In contrast to synchronization points, pulsing defines the frequency of coordination practices regardless of project content, e. g. weekly meetings.
h) Especially for the challenge sequencing, Wenzel [2003] recommend to start a process even though not all necessary resources are available yet - what we refer to as unconditionally starting a process. Synchronization can be achieved by using preliminary information, estimating missing information or processing non-related activities first. In the case of missing data, this approach might generate more work load since the activity might have to be reprocessed [Loch and Terwiesch 2005]. However, the approach prevents further delays of subsequent tasks as well as idling team members and keeps stakeholders up to date in terms of project progress.
i) Wenzel [2003] further suggests the change of boundary conditions and the system environment in order to enable synchronization. Especially for changes of requirements or innovations as well as company internal or external influences, an adaptation of according factors might lead to a successful synchronization basis.
j) Moreover, to inform stakeholders about changes in dependent processes is supported by close cooperation with configuration management [Ebert and Man 2008]. Communicating important modifications of the system via a formalized tool helps the team stay informed and keep interfaces adjusted. In addition, a structured documentation of the changes is performed to achieve transparency of the entire development process.

3. Approach to select practices

3.1 Approach

Literature mostly either elaborates on challenges regarding successful coordination or describes practices for synchronization management. Thus, no linkage is provided between the distinct challenges and practices. In order to support the selection of appropriate synchronization management practices for a given set of challenges, we need to link them. To do so, we decided to define a set of characteristics that characterize synchronization management practices in the sense of design criteria. Subsequently, the applicability of each characteristic to the different practices was assessed predominantly based on statements in literature and documented in a matix representation (step 1, matrix B). In step 2, the relevance of each characteristic was assessed (also based on literature) regarding the different challenges and also documented in a matrix (matrix A). In both cases, the assessment was binary with the choices low (0) or high (1). The resulting linkage of challenges and practices was achieved by matrix multiplication (step 3, matrix C).

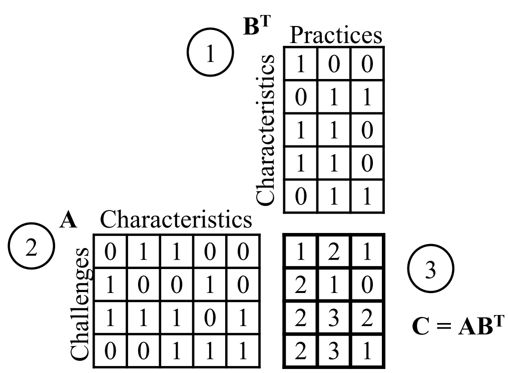

Figure 3. Three step process to link challenges with practices

The entry in one cell of the result matrix C indicates how many characteristics relevant to a challenge are fulfilled by a practice. The higher the number, the more appriopriate is a practice to meet the challenge. The following sections introduce the characteristics and present the resulting matrices.

3.2 Characteristics

In total, we define ten characteristics based on statements in literature. They are summarized in Table 3. The characteristics quality, degree of interdisciplinarity, compatibility and degree of alignment are considered as important in order to assess synchronization management practices with respect to coordination and collaboration. Furthermore, frequency and flexibility are included regarding timing as an important factor. Finally, the implementation of synchronization management is essential for its success. For that reason scale, formality, robustness and costs are added.

Table 3. Ten characteristics for synchronization management practices

Quality	How good does the synchronization have to be to achieve a satisfying result? [Pufahl et al. 2014], [Lämmer and Theiss 2015]
Degree of Interdisciplinarity	How many cross-functional departments need to be synchronized? [Klein 1990]
Compatibility	How well-defined are the existing interfaces within the system? [Lämmer and Theiss 2015], [Wiesner et al. 2015]
Degree of Alignment	How likely will each stakeholder have the same understanding of the project? [Biahmou 2015], [Wiesner et al. 2015]
Frequency	How often do we need to synchronize? [Giachetti 2006], [Lämmer and Theiss 2015]
Flexibility	Does the situation change over time and does that affect the approach? [Sanchez 1995]
Scale	Is synchronization happening locally or globally? [Begel et al. 2009]
Formality	Is the synchronization explicit, e. g. by using a framework, or is it implicit and tacit through informal meetings or emails? [Malone and Crowston 1994]
Robustness	How many challenges are considered and is it critical not to handle all of them? If some of the challenges are not handled, will the approach still be successful? [Grossi et al. 2007], [Biahmou 2015]
Cost	How much effort is the application? [Malone 1987], [Malone and Crowston 1994]

3.3 Results

The assessment of the applicability of the characteristics to the practices and the assignment of characteristics to challenges (see Figure 4) is predominantly based on statements in literature. For some entries no proofing statement in literature could be found. Thus, these entries are based on estimations by subject matter experts (marked grey in Figure 4). Since the relevant characteristics of the challenge "separation" depend on its type, the three most important subcategories "knowledge gap", "spatial gap" and "cultural gap" are considered separately – the other subcategories are seen as less important and are excluded from the analysis. Also the challenge "idle performance" is excluded from the analysis, since it is considered less important regarding the impact on project performance. On the other side, the two practices "establishing common background knowledge" and "cooperating with configuration management" are excluded because they are seen as general practices, which do not specifically support synchronization management.

The resulting matrix C was sorted in order to underline which practices are most powerful for the given set of challenges and is shown in Figure 5. Additionally, the highest possible value for each challenge is provided in the black column. For example, the challenge sequencing is only assigned with two characteristics. Thus, the matrix multiplication result can only be 2 or lower for sequencing.

All characteristics apply to the practice of building an integrated model of the product and the development process, which is why it always has the maximum value for each challenge. Also mini-synchronization and building a generic synchronization framework seem to be promising approaches. Creating a synchronization plan, pulsing, quality gates and changing boundary conditions appear to address most of the challenges. The practice to unconditionally start a process with preliminary information cannot be seen as a practice that sufficiently supports synchronization.

Step 1, Matrix B

Practices \ Characteristics	Frequency	Quality	Scale	Formality	Robustness	Cost	Interdisciplinarity	Flexibility	Compatibility	Alignment
Synchronization plan	0	1	1	1	1	0	1	1	1	1
Mini-synchronization	1	1	0	1	1	1	1	1	1	1
Unconditionally starting the process	0	0	0	0	0	0	1	1	0	1
Change boundary conditions	0	1	0	1	0	1	1	1	0	1
Quality gates	0	1	1	1	0	0	1	1	0	1
Generic framework	0	1	1	1	1	1	1	1	1	1
Product and process model	1	1	1	1	1	1	1	1	1	1
Pulsing	1	0	1	1	1	0	1	1	1	1

Step 2, Matrix A

Challenges \ Characteristics	Frequency	Quality	Scale	Formality	Robustness	Cost	Interdisciplinarity	Flexibility	Compatibility	Alignment
Separation (knowledge gap)	1	0	0	0	1	0	1	1	1	1
Incompatibility	1	1	0	0	1	1	1	1	1	1
Mismatch	1	1	1	1	1	1	1	1	1	1
Incident	1	1	1	0	1	1	1	1	1	1
Sequencing	0	1	0	0	0	0	0	1	0	0
Separation (spatial gap)	1	1	1	0	1	1	1	1	1	1
Separation (cultural gap)	0	0	1	0	0	0	1	1	1	1
Domain specific standards/tools	0	1	1	1	1	1	1	1	1	1

Figure 4. Mapping of practices and characteristics (left) and of challenges and characterstics (right). Both matrices have binary values (0 = low; 1 = high)

Challenge \ Synchronization practice		Product and process model	Mini-synchronization	Generic framework	Synchronization plan	Pulsing	Quality gates	Change boundary conditions	Unconditionally start the process
Mismatch	10	10	9	9	8	8	6	6	3
Domain-specific standards/tools	9	9	8	9	8	7	6	6	3
Spatial separation	9	9	8	8	7	7	5	5	3
Incident	9	9	8	8	7	7	5	5	3
Incompatibility	8	8	8	7	6	6	4	5	3
Separation of knowledge	6	6	6	5	5	6	3	3	3
Cultural separation	5	5	4	5	5	5	4	3	3
Sequencing	2	2	2	2	2	1	2	2	1

Legend [# matching characteristics]	10 to 8	7 to 6	5 to 4	3 to 2	1 to 0

Figure 5. Sorted result matrix showing relevant synchronization practices for the given set of challenges. The black column indicates the maximum possible values

4. Discussion

The identified challenges, synchronization practices and the presented approach to select practices are discussed based on an interview with a practitioner and own reflections. The interview-partner is project manager in a company that develops products for construction and building maintenance. The company is known to the authors for its systematic efforts regarding synchronization management, which is why it is chosen as a partner in the discussion of the literature-based findings.

4.1 Industry feedback

The most relevant challenges in the interviewee's company context are separation, sequencing and incidents. Mismatch is not seen as a challenge and incompatibility is not seen as relevant in the way described here. The interviewee suggests to expand the list of challenges with "changes during the project" such as changes of requirements due to changes in market or company decisions, which often

lead to synchronization issues. Also changes in the project plan or technical innovations demand for synchronization management. Further, synchronization across multiple projects, which develop products with common components, plays an important role and is challenging. For example, a motor is reused for multiple devices and therefore needs various interfaces and functions. Thus, the inner-project development of a product has to consider outer-project constraints.
According to the interviewee, all of the identified practices are used in their development projects and are part of their synchronization management. Creating a synchronization plan is seen as specifically useful for bigger projects. A frequent issue at the company are processes that have to start with preliminary or incomplete information, e. g. when a motor and its electronics are required to be specified to a certain gate, before all technical requirements have been defined. They use integrated product and process models and a generic framework that helps to link different prototype levels. A total of six stages are defined by quality gates as synchronization points and pulsing takes place in the form of frequent project meetings, where organizational issues such as timing and costs are discussed. Additionally, technical meetings are installed on demand when they are seen as necessary, which is kind of a mini-synchronization. The approach towards identifying appropriate practices is basically evaluated as valuable by the interviewee. Especially for specific requirements in a project, the approach may be supportive to achieve a solution.

4.2 Reflection

Our literature study shows that certain challenges make synchronization management an important issue in today's product development but which is not sufficiently addressed in literature. Several practices for synchronization management are published. However, what seems to be missing are methods that particularly address specific challenges and that can be easily adapted to a specific company context. No reference was found to directly link a challenge with a given synchronization management practice. In this regard, the presented approach to link challenges with appriopriate practices is seen as valuable. The classification of needs for synchronization management into elementary challenges is also seen as useful in order to better understand the causes of a problem and to find suitable solutions. Yet, the relevance of each challenge depends on the context. Therefore, the approach could be enhanced by allowing to weight the challenges for different company and project contexts. Moreover, the linkage between challenges and practices is based on a set of characteristics derived from literature. Preferrebly, the assignment should be verified individually for each application context.
Regarding synchronization management and its challenges, further differentiation could be made with respect to different dimensions. For example, Tristl et al. [2013] claim that synchronization has to be considered on four dimensions: communication; processes; tools; and product data. Another perspective is given by Darses and Falzon [1996] (as cited by Da Luz et al. [2011]) who distinguish operating and cognitive synchronization. Moreover, when considering that the need for coordination is caused by interdependencies within the project system, different types of interdependencies can be distinguished. For example, hierarchical, contribution, sequential, influence or exchange links [Vidal and Marle 2008] could relate to different challenges and hence demand different synchronization management practices. All these differentiations might be beneficial in order to specify the underlying problems and to develop or select solutions. In order to provide an holistic overview, the type of the entities affected by a challenge (i. e. organizational units, processes, tools or products) have not been specified in this study.
In the end, the presented collection of challenges and practices is based on a literature study particularly focusing on synchronization management approaches. We were not able to include the extensive volume of literature that deals with specific coordination issues such as information flow, collaboration within teams or across companies and countries, or data modelling and management. These topics were covered to some extent by referring to single works from the different fields.

5. Conclusion

This paper presents a literature study on challenges regarding successful coordination and practices in synchronization management in product development projects. In total, six types of challenges and ten practices are extracted from literature. The practices contain five approaches that aim to support the establishment of coordination and alignment in a project in general, and five practices that provide situational coordination support during a project. Additonally, an approach towards linking the challenges with practices via different characterstics of synchronization is presented. It is intended to support the selection of appropriate practices for a given set of challenges. An interview with a project manager from industry provides initial feedback for the derived list of challenges and practices and the approach to link them.

The key takeaways from the study are manifold. First, we conclude that synchronization management is of increasing importance in today's product development projects. Second, the study helps both researchers and practitioners in understanding the nature and diversity of activity dependency in product development projects, and we believe, advances efforts to better predict the conditions under which certain coordination approaches may be most effective. However, a more detailed specification of underlying challenges (e. g. by distinguishing different types of interdependency) and of the different dimensions of synchronization seems to be promising. Based on this, specific methods that support to overcome particular challenges can be developed and identified. Last, more sophisticated approaches are needed that assist the selection of appropriate methods (in terms of efficacy and efficiency) for a prioritized list of challenges in a specific industrial context.

Acknowledgments

We thank the Project Management Institute (PMI) and the International Council on Systems Engineering (INCOSE) for their support of this research. We would further like to thank our discussion partner for valuable insights into his company's practices.

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