Characterizing and Measuring Activity Dependence in Engineering Projects

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Abstract--**In an increasingly complex business environment program managers have to take dependencies within the product domain, process domain and organization into account. While activity dependence is still predominantly perceived as only an input-output relationship, a more detailed understanding of activity dependence is expected to improve program and project performance. This paper contributes to the understanding by presenting eight characteristics of activity dependence and 21 respective measures, all derived from literature and expert discussions. We further present an attempt to validate the characteristics and measures by means of a survey with 139 responses. While we could not prove the proposed characteristics wrong or right, we learned about the understanding of activity dependence and show future paths for further research in the paper. The possibility to significantly characterize activity dependence should support program and project managers with the identification of unknown but important dependencies and facilitate to select appropriate means for coordination.**

I. INTRODUCTION

Rapid and numerous changes are inevitable in an increasingly volatile and ever changing business environment characterized by concurrent engineering, globally dispersed teams, and increased requirements regarding product quality, costs, and time to market. In this context, program management plays an important role, whereas program managers must account for increased interdependence inherent to their projects or programs due to the rising complexity of products, processes and organizations.

However, traditional project and program management theory and literature spend little attention to the phenomenon of interdependence. Only few try to fully understand the concept of activity dependence in projects (e. g. [6, 22]). Dependencies are mostly perceived as a matter of only sequence, a downstream activity needing input from an upstream activity. However, dependence should be seen more generally as demand for interaction, which can be achieved by coordination (activities that satisfy the dependence) [29]. Understanding the mechanisms of activity dependence and being able to significantly characterize dependencies between activities should provide the basis for more effective project and program management.

In fact, multidimensional views of dependence should be considered. We expect the characterization of activity dependence to contribute in two ways: supporting (1) the identification of unknown but important dependencies; and (2) the selection of appropriate means for coordination. The deepened understanding is needed in order to develop new management tools. These could provide a characterization of all dependences within a given project or process and thus support the identification of unexpected dependence. Making these unknowns known could help program managers predict impacts of actions and avoid unforeseen outcomes. Hence, planning risks regarding schedule and cost overrun due to coordination efforts and rework can be reduced. Moreover, the characterization of the dependences enables to emphasize activities that are deemed to be very critical for overall performance. The description of activity dependence not only by its cause (e. g. shared resources, common component, etc.) but by its characteristics creates a more meaningful typology closer to the phenomenon. This is expected to support the selection of appropriate processes and methods for coordination in order to effectively and efficiently satisfy dependencies.

As an ongoing research, we aim to elaborate a holistic framework that captures direct and indirect dependence of individual activities within engineering projects or processes in detail. Previous work already propagated the understanding of activity dependence (beyond the traditional representation in projects as precedence) being continuous, concurrent and mutual (e. g. [33] based on [5]). As a consequence of dependence, continuous coordination between the activities is demanded and of value, as shown by [5] in his PhD thesis. Reference [30] enriched this understanding by considering delay, quality and exception handling when an activity dependence is violated. Further, a framework has been presented that addresses the mechanisms of activity dependence [29]. This research describes the development and evaluation of a way to characterize and to measure activity dependence. The approach aims to objectively assess activity dependence across project scenarios a priori.

After giving a brief overview of our research approach in section II, we elaborate our understanding of activity dependence in section III derived from literature. Section IV describes the detailed research setting for the evaluation of the presented characteristics and measures and discusses the results. Finally, a critical conclusion and outlook is given in section V.

II. RESEARCH APPROACH

In order to describe activity dependence more detailed, the following questions were guiding this research:

- What types of dependence do exist, how are they characterized and how can dependence be measured?
- What impact does a detailed understanding of activity dependence have on project optimization?

First, characteristics of activity dependence are derived based on a broad review of related literature. In a second step, reasonable measures are defined for each characteristic. The measures are either derived from the identified literature or are defined based on our experience and discussions with subject matter experts.

The evaluation of the validity of the defined measures and the impact of a more detailed understanding of activity dependence on project optimization is undertaken with the help of a workshop and the data collected from a survey. The workshop is conducted in the context of a System Design and Management class with 138 participants taught at MIT in the spring term of 2015. The exercise during the two hour workshop was to optimize a project based on an existing project model. With the help of a survey, participants are asked to assess a given dependence between two activities based on our measures. A statistical analysis of the survey data then provides conclusions about the validity of the suggested measures. In order to evaluate the impact of a more detailed understanding of activity dependence, the participants are divided into a control group and a treatment group. The control group only receives the survey after the exercise, the treatment group gets an introduction about activity dependence and receives the survey before as well as after the exercise. Hence, our experiment objective was to determine whether comprehensively engaging in the project model changes the perception of dependence characteristics. Furthermore, it can be assessed whether a more detailed understanding of dependence leads to the achievement of better project optimization results.

Finally, a revised set of characteristics and measures is derived from a critical analysis and discussion of the same based on the survey results.

III. UNDERSTANDING ACTIVITY DEPENDENCE

Dependencies in project management are commonly seen as only a matter of sequence where a downstream activity needs input from an upstream activity in order to be executed. In contrast, the framework of dependence mechanisms presented in [29] reveals that the phenomenon of activity dependence comprises more aspects (see Fig. 1). It describes causes of dependence as initiators for the demand to interact. Only with awareness of and attention to the dependence, interaction can be allocated in order to satisfy the dependence. Local effects related to the degree of satisfaction have systemic effects on the product, process and organization. Finally, local and systemic effects again affect the demands to interact. This paper proposes characteristics and measures that complement this framework and hence enriches the understanding of activity dependence.

A. Terminology

First, we want to clarify the term 'dependence'. In literature, it is usually not clearly differentiated between the terms 'dependence', 'dependency', 'interdependence' and 'interdependency'. Based on definitions given in dictionaries we define the terms as follows:

> *Dependence is the quality or state of an entity relying on or being determined, controlled, conditioned or influenced by another entity. Interdependence describes a mutual dependence between two or more entities.*

While 'dependence' is a quality of an entity, the term 'dependency' refers to the relation between two entities. A dependency between two elements always implicates that they need to interact or have to be coordinated. Since interdependence can be seen as a special case of dependence (mutual dependence), we generally use the term dependence in this paper to refer to both phenomena.

B. Literature on Dependence

Literature dealing with dependence in our context can mainly be found in the domains of portfolio management, process management, complexity management, social relationship analysis, and the study of team performance. The domains address structural aspects (related to organization, product and processes) and social aspects (team internal or interpersonal dependence). Within these fields of research many authors base their work on the definitions and categorizations of dependence introduced by [40] who focuses on the organizational effects of dependence and mainly distinguishes sequential, reciprocal and pooled dependence.

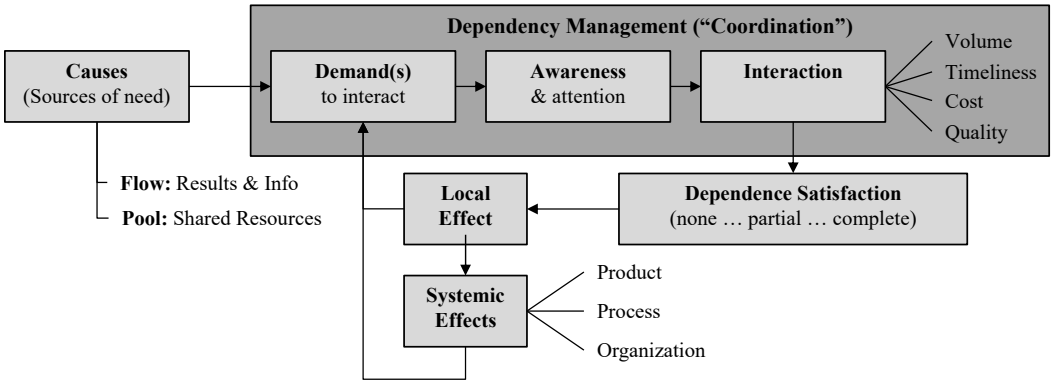

Fig. 1 Framework of Dependence Mechanisms [29]

In portfolio management, dependence is found to originate from resource sharing, time constraints, project outcomes or risk profiles (e.g. [21, 35, 42]). A number of frameworks have been developed to help understand and manage the effects of dependencies in projects (e.g. [26, 42]). Literature centered on improving product development processes addresses dependence of specific tasks or activities (e.g. [3, 12]). However, the links between entities are commonly understood to be a result of work outputs that needs to be passed from an upstream to a downstream activity, thus making it an issue of sequence [3, 34]. Only a few characterize activity dependence as a broader concept in need of further investigation beyond precedence, functional, and probabilistic dependence [19, 28]. Literature on complexity management has its origin in considering dependencies between product system components and functions. The focus is on structural aspects rather than on the dependency itself (e. g. [25]). Work related to the study of team performance investigated activity dependence regarding its effects on team efficacy [4, 4, 15, 37]. Feedback and goal dependencies are often included in these studies and it is generally stated that activity dependence in teams produces positive effects (e.g. [41]).

Dependencies also play a large role in literature focused on interpersonal relationships (e.g. [2, 36]). Two main theories serve as a basis for the research about dependence in interpersonal relationships. *Interdependence Theory* describes the motivations for behaviors as balancing of a person´s social costs and benefits in a relationship [18]. The theory of *Cognitive Interdependence* describes relationships that have matured to the point where both partners are committed and try to maximize the benefits of the couple as opposed to those of the individual [1].

Summarizing, dependence is addressed in literature in terms of activities, projects and individuals. Different typologies are defined and both formal techniques (e. g. process modeling, simulation, mathematical methods) as well as informal factors and practices (e. g. company culture, review meetings, leadership) are recommended for the management of dependencies. However, it is rarely attempted to examine and describe the phenomenon of activity dependence itself. As already introduced, [29] address this issue in a framework describing the mechanisms of dependence. Dependence is seen as the demand for coordination and interaction between two activities. Causes leading to this demand are distinguished as flow (results and information) and pool (shared resources). The management of these dependencies not only refers to the means of interaction itself, but also includes influencing the demands and increasing awareness and allocating attention. Building on this framework, we define characteristics and measures for activity dependence in the following.

C. Defining Characteristics and Measures of Activity Dependence

Within the investigated literature, a total of eight characteristics are identified: degree of dependence, level of dependence, closeness, importance, delay, degree of mutuality, interaction frequency, and activity diversity (see Tab. 1).

TAB. 1 CHARACTERISTICS OF DEPENDENCE IDENTIFIED IN LITERATURE.

Interdependence characteristics	References
Degree of dependence	[10, 12, 31, 32, 38]
Closeness	[2, 23, 24]
Level of dependence	[1, 7, 11, 12, 20, 36]
Importance, criticality	[14, 20]
Delay, wait	[14, 30]
Interaction frequency	[14, 17, 24]
Degree of mutuality	[27, 36]
Activity diversity	[17, 20, 24]

Using these as a basis, characteristics that are suitable to describe and measure activity dependence in engineering projects are derived from discussions with subject matter experts (cf. Fig. 2). Interaction frequency, activity diversity, and delay/wait are not seen fit to characterize activity dependence, since they all relate to the interaction taking place (which is a consequence of dependence) and not to the dependence itself. Interaction is the consequence of a dependence (cf. [29]) and hence does not directly characterize the dependence. The other characteristics are adopted (partially aggregated and rephrased) and four new characteristics are introduced that are seen as relevant based on our literature review. This leads us to the following eight characteristics: strength, closeness, impact, urgency, awareness, degree of mutuality, satisfaction criteria, and feedback mechanism. They are elucidated together with their respective measures in the following sections and are summarized with their definition in Tab. 2.

For the definition of measures, particular emphasis is placed on objective measures of the characteristics of a specific activity dependence that can be assessed prior to project execution. Literature provides three different general approaches that aim to measure dependence:

- Measuring Interaction (e.g. [2, 14])
- Estimating the Strength (e.g. [12, 39])
- Examining Relationships (e.g. [20, 31])

A number of issues arise with these approaches. When measuring the interaction taking place, it is implicitly assumed that the amount of current interaction adequately represents the dependence. However, too much or too little interaction actually taking place leads to a flawed assessment. Thus, the interaction that is necessary should be addressed instead of the interaction that is taking place. The second approach relies on subjective estimations of the strength. Because of this, it can result in different scores depending on the circumstances. The third approach, examining the

relationships of a given activity with others, appears to be promising as it is objective and can be assessed prior to project execution. Here, the number of dependencies of an activity or the number of shared customers of an activity are assessed.

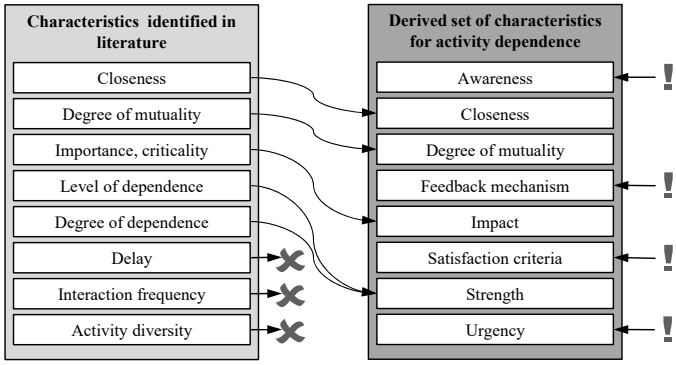

Fig. 2 Illustration of the derivation of characteristics for activity dependence based on characteristics identified in literature. The characteristics from literature are directly adopted, merged, renamed or excluded and new characteristics that are seen as relevant by the authors are added.

A total of 21 measures for seven of the characteristics are developed and refined through discussions with subject matter experts. No measurement was derived for the characteristic awareness, since awareness of a dependence itself is a precondition to be able to assess the dependence. Tab. 2 gives an overview of all characteristics, their definition and their measures. More details about each characteristic and the measures are given in the following sections.

Awareness

Awareness is obviously a precondition for the characterization of a dependence. In combination with allocated attention it is crucial for satisfying a dependence. Without awareness of a dependence between two activities it can only be satisfied unknowingly by chance or unconsciously through experience. It is, however, far more likely that the dependence remains unsatisfied. The dependent partners then affect each other in unforeseen ways likely leading to unexpected and negative consequences.

Closeness

Closeness is a characteristic used in the study of interpersonal relationships, particularly in romantic relationships (e.g. [23]). It is also suitable in describing activity dependence when thinking of how much impact actions of one activity have on a dependent activity and how quickly this activity is able to respond to these actions.

All three measures of closeness aim at determining how directly the tasks are impacted by the actions of each other. D1 (component connection within the product) aims to assess how directly product components, on which the dependent activities are working on, are connected. If both are working on the same components or if their components have a direct interface within the product architecture, closeness is likely high. D2 (flexibility of budget) aims to measure closeness of financially dependent activities. An unexpected cost increase may lead to an overrun of the planned budget of two activities. A highly flexible budget allows to directly solve the issue by adjusting budgets. Data dependence (D3 – number of tasks altering data) is present when activities share a common knowledge database. If only a small number of activities share a database, effects of changes in the data are likely to be more direct in comparison with a database used by many activities.

TAB. 2 CHARACTERISTICS AND MEASURES FOR ACTIVITY DEPENDENCE IN ENGINEERING PROJECTS.

Characteristic	Measures
Awareness The extent to which the interdependence is recognized within the process.	No measures defined
Closeness The extent to which the actions of dependent activities have an immediate effect on each other.	**D1** Component connection within the product **D2** Flexibility of budget **D3** Number of activities altering data
Degree of mutuality The extent to which the dependent activities have equal need for each other.	**M1** Difference in amount of needed information **M2** Difference in activity priorities **M3** Difference in data usage
Feedback mechanism The way feedback is passed between dependent activities.	**F1** Frequency of scheduled information exchanges **F2** Frequency of scheduled budget reviews **F3** Number of times data is needed
Impact The extent to which not fulfilling the dependence in the desired manner affects the dependent activities.	**I1** Fraction of activity dependent on input **I2** Rework caused by faulty input **I3** Excess capacity **I4** Specification connectedness
Satisfaction criteria The criteria necessary to fulfill the dependence.	**C1** Understanding of what is necessary to fulfill the dependence **C2** Consensus on what is necessary to fulfill the dependence
Strength The amount of required interaction as a direct result of the dependence.	**S1** Volume of necessary exchanged information **S2** Variability of costs **S3** Number of shared components **S4** Degree of concurrency
Urgency The time-criticality for fulfilling the dependence.	**U1** Milestone flexibility **U2** Variance of activity duration

Degree of Mutuality

Reference [36] uses the degree of mutuality as a characteristic of interdependence. It aims at describing the directionality of the dependence. A high degree of mutuality indicates that both activities are equally dependent on each other. A low degree of mutuality suggests that one activity demands more interaction than the other one.

M1 (difference in amount of needed information) attempts to determine which activity needs more input from the other one in order to function successfully. The comparison of the priorities of the activities (M2) within a project is also likely to be an indicator of the degree of mutuality. In any situation where a decision has to be made for one and against the other activity, it will likely be ruled in favor of the activity with higher priority thus making the lower priority activity strongly dependent on the other. Finally, M3 (difference in data usage) aims to determine which task is more dependent on a common knowledge database.

Feedback Mechanism

This characteristic essentially describes in what manner the dependent activities exert influence on each other, i. e. by which means influence is carried from one dependent activity to the other and vice versa. This interaction can take place directly by passing on work results and necessary input or indirectly through a database or a virtual product model.

It is of particular interest to determine how quickly the feedback mechanisms allow the tasks to respond to actions or changes in the business environment. This can be the estimated frequency of scheduled information exchanges (F1) or budget reviews (F2). Feedback can be passed in the moment that input from a common knowledge database is used for execution. The number of times input is needed (F3) therefore appears to be a meaningful measure of the feedback mechanism.

Impact

References [14] and [20] use criticality and importance, respectively, to characterize dependence. These are combined to form the characteristic impact. Their constructs emphasize the influence of the activities on project performance. Our definition focuses on the activities and how they are affected if the dependence is not or insufficiently satisfied. As such, the goal is to emphasize the fundamental mechanisms of dependence.

All measures of impact attempt to assess the consequence of not satisfying the dependence in the desired manner. I1 (fraction of task dependent on input) is aimed at determining the consequence of delayed input. If only a small fraction of the downstream activity is dependent on input, a delay probably has insignificant effects. I2 (rework caused by faulty input) focuses on input that is of insufficient quality. Particular emphasis is placed on rework effort in the downstream activity. Further, a large amount of excess capacity (I3) indicates little consequences of not fulfilling the dependence in the desired form. The available excess capacity can be used to resolve any issues and hence satisfy the dependence. The measure I4 (specification connectedness) addresses the connections between the specifications of the product components the activities are working on. If many specifications are dependent on another component´s specification, not satisfying the dependence is likely to cause significant consequences while independent specifications mean little impact.

Satisfaction Criteria

A number of different conditions can lead to the satisfaction of a dependence. For instance, it may be passing results from one activity to the other or simply completing both dependent activities before a specific point in time.

A frequent source of problems within a project is uncertainty about what is necessary to satisfy a dependence (C1) or two activities with different understanding of what is necessary (C2).

Strength

The two characteristics degree of dependence and level of dependence identified in literature differ only slightly. As such, they are combined to form the characteristic strength. Some use the interaction taking place between two tasks to define similar characteristics (e.g. [32]). Yet, these authors do not take into account that the amount of interaction actually taking place may not be the adequate amount for satisfying a particular dependence. For instance, if two tasks are not aware of a strong dependence between them they might not interact at all, although they should. Alternatively, a large amount of interaction may take place between two tasks while much less could be sufficient. This type of behavior (e. g. many, unnecessary meetings) creates waste in the process. Strength emphasizes the required interaction as opposed to the actual interaction. Strength is a crucial characteristic of dependence as it aims to describe the most fundamental aspect of dependence – the need for interaction.

It is fairly obvious how S1 (volume of necessary exchanged information) impacts the amount of necessary interaction between two tasks whereas S2 (variability of costs) and S3 (number of shared components) require a more detailed explanation. For S2, it is assumed that one activity, which exceeds the planned costs, leads to a strong dependence to another financially dependent activity. The dependent activities have to interact in order to transfer budget or lower costs elsewhere and ultimately resolve this issue. A high variability of the costs results in increased risk of exceeding the planned budget and thus to a strong activity dependence. In the case of product dependence it is proposed that two tasks working on the same components means that they have a strong influence on each other. Finally, highly concurrent dependent activities are likely to require a larger amount of interaction than sequential activities (S4 – degree of concurrency).

Urgency

Urgency refers to the time left to satisfy a dependence. It is inversely proportional to the difference between the available time until the dependence must be satisfied and the time needed to complete the necessary steps for fulfilling it. The less this difference is, the higher the urgency of the dependence. Urgency is highest if the difference is negative meaning not enough time is available to satisfy the dependence in a timely fashion.

When measuring urgency one must compare the available time to the necessary time for completing a given task. U2 (variability of activity duration) attempts to measure the same concept but is closer to the actual phenomenon. If the variance of activity duration is high, the likelihood of exceeding the planned completion time is also increased. Thus, this results in high time-criticality for fulfilling the dependence. U1 (milestone flexibility) approaches the issue from a different perspective. A flexible milestone means that exceeding it does not have significant consequences, as it can be adjusted. It is therefore argued that low time-flexibility results in high urgency of a dependence.

IV. EVALUATION AND DISCUSSION

A. Research Setting

The set of developed characteristics and their respective measures are evaluated through a survey with participants of a workshop. In a two hour workshop, the participants work with an existing model of an engineering project using a modeling software that supports project optimization. The 138 workshop participants already have significant work experience in engineering projects. They are grouped into 16 teams (team sizes vary from five to nine team members) and asked to analyze the structure of a given project and develop improvements for it. For this task, they have the option of modifying a variety of different aspects of the project model (project team sizes, responsibilities, project team locations, etc.). The impacts of the changes to the performance of the entire project can be evaluated in real-time through an agent based Monte Carlo simulation provided by the software tool. It predicts likely schedule and cost outcomes for a given project configuration.

For the sake of the survey, the participants are asked to focus on a particular dependency between two activities in the given project model. The survey includes 1-2 questions for each measure that ask the participant to quantify the dependence. Tab. 3 provides an overview of the numbers of completed questionnaires. Five different constructs of two dependent activities as focus of the survey are distributed throughout the teams in order to evaluate the characteristics and measures for different kinds of dependences. Further, a control group and a treatment group are differentiated in order to examine whether a detailed introduction about activity dependence prior to the exercise (treatment group) has an impact on the perception of dependence characteristics and whether it leads to better project optimization results. In addition to the introduction, the treatment group receives the survey before and after the exercise. Hence it is determined whether comprehensively engaging in the project model changes the perception of dependence characteristics.

B. Survey Results

A total of 139 completed questionnaires are available for analysis of which 66 are collected before and 73 after the workshop exercise. 40 of the 73 questionnaires after the exercises are completed by the control group (cf. Tab. 3). Fig. 3 exemplarily shows the average score per measure assigned by the respondents investigating dependency #3. Even though the average scores differ for each measure, the responses fairly correspond to each other. This is also true for the other four investigated dependencies.

TAB. 3 NUMBER OF COMPLETED QUESTIONNAIRES.

Investigated construct of dependency	Before Exercise	After Exercise	
	Treatment Group	Treatment Group	Control Group
#1	14	8	7
#2	13	6	10
#3	14	6	9
#4	13	7	8
#5	12	6	6
Total	66	33	40
		73	
	139		

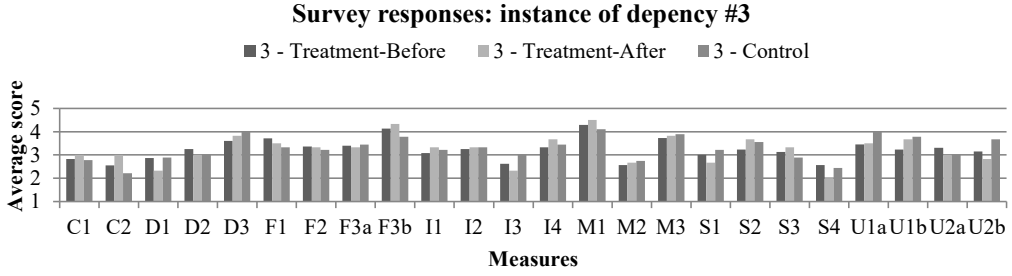

Fig. 3 Average scores (on a five point ordinal scale) of responses for the different measures regarding the investigated dependency #3.

In order to determine whether the proposed measures reliably assess the defined characteristics of activity dependence, Cronbach´s Alpha coefficient (see [9]) is calculated (cf. Tab. 4, top). Measures resulting in a coefficient over 0.7 are generally seen to be measuring the same phenomenon [8] whereas in exploratory research that value may be decreased to 0.6 [16]. Factor analysis is used to determine which measures should be excluded from the calculation. In the given research setting the following characteristics of activity dependence can be measured reliably by their corresponding adjusted measures (cf. Tab. 4, bottom):

- **Feedback Mechanism** ($\alpha = 0.702$)
  F1 (frequency of scheduled information exchanges), F3a (number of times data is needed by activity A), F3b (number of times data is needed by activity B)
- **Impact** ($\alpha = 0.701$)
  I1 (fraction of activity dependent on input); I2 (rework caused by faulty input); I4 (specification connectedness)
- **Satisfaction Criteria** ($\alpha = 0.685$)
  C1 (understanding of what is necessary to fulfill the dependence); C2 (consensus on what is necessary to fulfill the dependence)

Two more characteristics can be measured somewhat reliably by the corresponding measures:

- **Strength** ($\alpha = 0.550$)
  S1 (volume of exchanged information); S2 (variability of costs); S3 (number of shared components)
- **Urgency** ($\alpha = 0.540$)
  U2a (variance of activity A duration); U2b (variance of activity B duration)

In the given research setting the characteristics of **closeness** ($\alpha = 0.195$) as well as **degree of mutuality** ($\alpha = -0.045$) cannot be measured reliably with the developed measures.

Independent t-tests [13] are applied to determine difference in responses between the groups. As already indicated, the answers do not significantly vary between the groups (cf. Fig. 3). Indeed, the tests confirm this observation. It is found that neither the introduction about activity dependence nor taking part in the project improvement exercise leads to statistically significant variations of the responses.

By analyzing data captured by the project modelling software and through self-reports of the participants it can be concluded that the approaches to the project improvement exercise vary. The treatment group conducts less simulations with longer periods of time between the first simulations. During the improvement of the project model, teams of the treatment group focus on changing total work effort and dependence within the project while teams of the control group emphasize changing the number of people involved in the model. Although different approaches are used, the improvement of cost and schedule is very similar in both groups. Thus we conclude that – in the given research setting – the achieved optimization of project performance is independent of an introduction to activity dependence prior to the exercise.

TAB. 4 CALCULATED CRONBACH´S ALPHA VALUES. TOP: INITIAL VALUES BASED ON SURVEY RESPONSES FOR ALL MEASURES. BOTTOM: VALUES AFTER EXCLUDING SOME MEASURES FROM THE ANALYSIS WITH THE HELP OF FACTOR ANALYSIS.

Initial values						
Dependence	**1**	**2**	**3**	**4**	**5**	**Overall**
Closeness	-1.804	0.119	0.326	-1.013	0.296	-0.84
Degree of Mutuality	0.276	-0.168	-0.432	0.182	-2.037	-0.2
Feedback Mechanism	0.693	0.57	0.245	0.821	0.533	0.611
Impact	0.452	0.192	0.376	0.147	-1.427	0.462
Satisfaction Criteria	0.706	0.723	0.636	0.913	0.321	0.685
Strength	0.3	0.209	0.705	0.666	0.253	0.522
Urgency	0.13	-0.157	0.315	0.113	-0.444	0.098

Values after excluding the measures D1, F2, I3, M2, S4 and U1						
Dependence	**1**	**2**	**3**	**4**	**5**	**Overall**
Closeness	-1.1013	0.434	0.193	-0.353	0.735	0.195
Degree of Mutuality	-0.098	0.267	-0.49	-0.357	-0.098	-0.045
Feedback Mechanism	0.668	0.677	0.445	0.775	0.827	0.702
Impact	0.633	-0.057	0.819	0.391	0.213	0.701
Satisfaction Criteria	0.706	0.723	0.636	0.913	0.321	0.685
Strength	0.33	0.26	0.718	0.583	0.231	0.55
Urgency	0.664	0.701	0.664	0.387	-0.114	0.54

C. Discussion

Only three characteristics are found to be reliably described by their measures. A possible cause for unreliable measures in general can be the lack of information on the project model. The participants are given a model showing workflow and team responsibilities. No additional information is given and the participants use their experience to choose an answer. When assessing dependence in an actual project setting the members of the project likely have significantly more information on the project. In this setting, some of the excluded measures could possibly be suitable to measure activity dependence. Furthermore, the manner of developing the measures is also a possible cause for unreliable measures. Different measures of one characteristic are created while having different types of dependences in mind (e. g. shared resources vs. information flow, cf. [29]). The five constructs of activity dependence investigated in the survey showed different types of dependence. Most likely, different types of dependence have to be differentiated and should be assessed separately. Finally, another cause for unreliable measures can be that the presented characteristics are not appropriate for describing the characteristics of activity dependence. This explanation implies that degree of mutuality and closeness are no observable characteristics.

The fact that there is no significant variation of survey results between the control group and treatment group as well as between responses prior and after the exercise can be interpreted in two ways. On the one hand, it could mean that the presented measures objectively describe the characteristics, regardless of external influences or circumstances. On the other hand, it could indicate that the introduction about activity dependence did not have an observable effect on the responses. While the groups followed different approaches to change the project configuration, the introduction also showed no effect to the resulting optimization of project performance during the exercise. This may be different in real life projects where overall duration and costs are strongly impacted by not managing or mismanaging unknown dependence. In the given research setting only known activity dependencies could be assessed.

When reflecting on the results, some constraints due to the given research setting have to be regarded. The workshop participants were confronted with an unfamiliar project, so they did not have an in-depth understanding of the examined dependencies. Moreover, the evaluation of the defined characteristics was planned to be undertaken by assessing predefined measures for these characteristics through a survey. However, with these measures not having been validated before, conclusions have to be drawn carefully. Consequently, the analysis results do not prove validity of the defined characteristics but indicate that three sets of different measures seem to describe three different phenomena related with activity dependence. This still presumes that the participants all had the chance to have a similar understanding of the examined dependence. Considering the research setting, also a lot of guessing by the respondents may have been involved. Last, the statistical significance of the analysis results can be doubted since the 139 participants were divided into a control group and a treatment group and the questionnaires were further distributed on five different constructs of activity dependence. This results in an average of 13 respondents for each construct before the exercise and only 6-10 responses (in each control group and treatment group) for each construct after the exercise. Nevertheless, we regard the presented characteristics, measures and survey results as helpful insights on the route towards fully understanding activity dependence.

V. CONCLUSION AND OUTLOOK

In an increasingly complex business environment program managers have to take dependencies within the product domain, process domain and organization into account. While activity dependence is still predominantly perceived as only an input-output relationship, a more detailed understanding of activity dependence is expected to improve program and project performance. So far, it has rarely been attempted to examine and describe the phenomenon of activity dependence itself in detail. As an ongoing research, this paper contributes to the understanding by presenting eight characteristics of activity dependence and 21 respective measures, all derived from literature and expert discussions.

We further share experiences with the attempt to validate the characteristics and measures by means of a survey with 139 responses. The survey is administered in combination with a workshop. Through factor analysis and subsequent calculation of Cronbach´s Alpha it is concluded that only the three characteristics *impact*, *feedback mechanism* and *satisfaction criteria* are reliably assessed by an adjusted set of the proposed measures in the given research setting. By applying independent t-tests it is further found that an introduction about activity dependence prior to the workshop has no statistically significant effect on survey responses.

As stated in the reflection of the results the presented literature-based characteristics and their measures need to be revised. The results of the present exploratory research contribute to the research community as a first step in trying to measure activity dependence. They should be used as a basis for further research. As a next step, we aim to generate a collection of practical examples for activity dependences and derive further implications for reasonable characteristics and measures from there. Moreover, exploratory surveys will help to identify meaningful characteristics and measures. Further descriptive surveys will then be conducted in order to evaluate the significance of the found characteristics and measures.

Following the arguments of our motivation, a significant characterization of activity dependence should support the identification of unknown but important dependences and help to select appropriate means for coordination. Our contribution to industrial practice so far is the identified list

of characteristics and measures, which can be used as a preliminary checklist by program managers. It enables to evaluate critical dependencies within their programs and to monitor means for coordination. Moreover, overall awareness of activity dependence could be increased by sensitizing all the actors in a program about the diverse characteristics of dependence. Last, new management tools could be developed based on our findings. The tools could assist program managers in planning and continuously adapting their projects by always keeping track of critical activity dependences. Hence, planning risks can be reduced and effective and efficient coordination can be facilitated.

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