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ANALYSIS AND VISUALIZATION OF PROJECT STRUCTURE USING LINKOGRAPHY: FOCUSSING PROJECT RISK MANAGEMENT

Kilian Gericke
Technische Universität Berlin
Berlin, Germany

Björn Kleinod
Technische Universität Berlin
Berlin, Germany

Lucienne Blessing
University of Luxembourg
Luxembourg

ABSTRACT

Product development projects are difficult to plan due to complexity, dynamics, lack of transparency and polytely. Risk Management is often used to cope with this situation. Linkography (originally proposed by Goldschmidt) is adapted with the aim to ease the effort of the Risk Management process. The elements of the original method are transferred to the area of Project Risk Management, complemented by a real time scale, and cost information of elements.

Linkography is used to focus all Risk Management activities on those work packages, which might affect the project the most in the case of failing the expected outcome. The number of links to other work packages, its duration and its costs defines the criticality of a work package. By applying Linkography as a Risk Management method, a prioritized list of work packages can be generated which pass consecutively through the usual Risk Management process. Unlike other methods, Linkography supports the user in a visual manner. Hence, Linkography can easily be used for communication with unskilled stakeholders.

1 INTRODUCTION

Engineering design is nowadays usually conducted using principles and methods of project management [1]. Despite the long history of project management, a multitude of projects fail their goals [2]. Complexity, intransparency, dynamics and polytely are barriers for the planning and execution of product development projects [3, 4]. Causes for deviations in projects were identified in several empirical studies e.g. changes of project goals, poor forecasts and inadequate communication [5]. The design process is affected by uncertainty [6] caused by technical or organizational factors and the market, as well as other issues. Even if uncertainty offers the chance of innovative solutions and is a precondition for creative new product development, it holds the risk of project failures.

Project Risk Management is a common approach to cope with risks resulting from uncertainties and the mentioned barriers [7-9]. The identification and assessment of risks and the subsequent adjustment of the project are challenging tasks and need a skilled person who is able to balance chances and risks and to moderate this process involving concerned stakeholders. A restriction for the Risk Management process is to realize this with minimal impact on the project budget [10]. This means that the Risk Management process has to be lean and decisions have to be comprehensible. The Risk Manager has to find a compromise to solve this trade-off (see Figure 1).

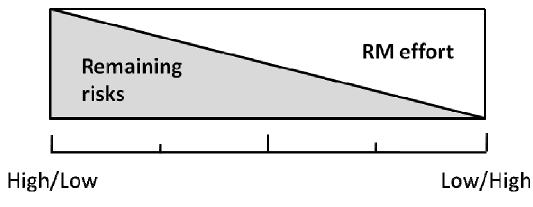

Figure 1. Risk Management trade-off

In the following, different approaches aiming at a reduction of the Risk Management effort are discussed. The analysis of the project structure as a means to put this into practice will be studied in detail. By adapting Linkography, an approach is proposed which enables Risk Managers to focus their activities on those work packages which might affect the project the most in the case of failing the expected outcome and to ease communication of decisions.

2 STATE OF THE ART

In the following, a short overview about related terminology and methods for visualization is given.

2.1 RISK MANAGEMENT PROCESS

Project Risk Management aims at ensuring the successful execution of projects. For this purpose, different process models were developed in the past. They differ in their number of process steps and in their level of detail. Irrespective of differences in their terminology and detailing, these models follow a common approach. The Risk Management process consists of four key phases [6]:

1. Risk identification
   The phase of identifying, collecting and specifying risks
2. Risk assessment
   The phase of risk analysis and estimation
3. Risk treatment
   The phase of risk-strategy selection and implementation of measures to avoid deviations from project goals
4. Risk monitoring, review and communication
   A continual process of re-examining assumptions, reviewing developing risk and communicating likely impacts to stakeholders

The RM-process is an iterative process (see Figure 2).

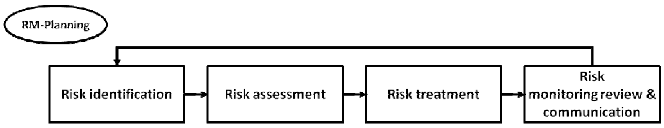

Figure 2. Risk Management process [6]

2.2 RISK MODELS

A precondition for the successful integration of Risk Management processes is a sound understanding of risks. A risk is defined as "a measure of the probability and consequence of not achieving a defined project goal." [7] This definition implies two components for a resulting event:

- Likelihood of occurrence of an event
- Impact of the event occurring

In this context an event is an encountered risk [8]. Smith and Merrit concretize this by giving the following definition: "The happening or state that 'triggers' a loss." [9] Smith and Merrit gathered different Risk models which depict influencing factors on a risk. They propose the use of the "Standard Risk Model" (see Figure 3). The Standard Risk Model describes drivers which influence the probability of occurrence and the probability of an impact.

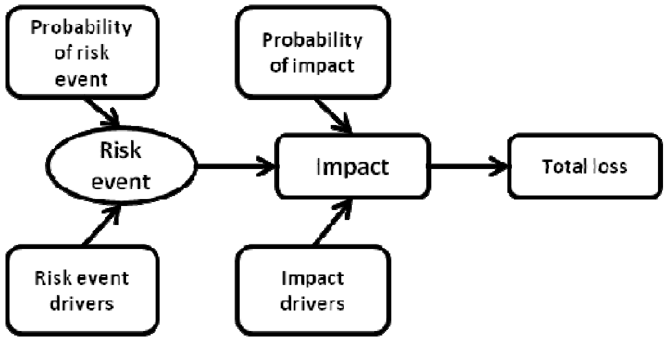

Figure 3. Standard Risk Model [9]

Following the given definition of a risk, the riskiness is quantified by the likelihood (probability) and the possible impact (loss) if the risk occurs. Such quantitative analyses of risks imply that a risk is already identified. Hence, a quantitative analysis is not possible before the phase of risk assessment. This means that criteria typically used for risk assessment will not work for the purpose of focusing Risk Management activities.

The approach proposed in this paper is independent from risk assessments of specific risks. It assesses the criticality of an event. This assessment is independent from identification of causes (drivers) and probabilities, which define a risk. A precondition for the assessment of criticality of an event is the assumption that, for whatever reason, the work package has failed. Thereby, the likelihood of the risk is 100 percent. The analysis of causes and the estimation of probabilities are subject to the subsequent focused Risk Management Process.

2.3 RISK MANAGEMENT PLANNING

Prior to a detailed risk analysis, Risk Management planning has to be conducted (see Figure 2) [7]. Related activities such as development of a risk management strategy, selection of appropriate methods and allocation of resources are affected by the project's criticality. Available information during this phase is basically contained in the project proposal and the project planning documents, such as a work breakdown structure and Gantt-charts. This work deals only with the analysis of the project planning documents and related risks. Keeping the overall aim to reduce the required effort of the Risk Management process in mind, the focusing of Risk Management activities can be founded on:

- the experience of the Risk Manager [7],
- the level of confidence regarding forecasts (estimations) of durations and costs [11] and
- an analysis of dependencies between work packages (which might influence the propagation of risk impacts [12]).

The experience and level of confidence may provide a basis for a skilled Risk Manager. Those who are not especially experienced but who have to manage project risks should have a closer look at the interdependencies of work packages (the project structure).

2.4 METHODS FOR VISUALIZATION OF DEPENDENCIES BETWEEN WORK PACKAGES

The Risk Manager is also responsible for communicating the results of the project criticality analysis and selection of work packages. Visual representations of complex issues support this task by concentrating the relevant information. Dependent on the used coding (abstraction of the contained information) this might ease the communication of such representations. Common methods supporting the visualization of dependencies between work packages (project structure) are presented in the following.

2.4.1 PROJECT PLANS

Standard methods for the visualization of Project Plans are Gantt-charts and network diagrams (e.g. PERT) [2, 7]. Both diagrams include dependencies but as a result of their original intention also contain additional information (duration, information flow, dates, budget, responsibility, identity numbers …). Because of this, they are complex and it is difficult to read/analyze the project structure. A limitation for the use of project plans as a means to analyze the project structure is the lack of information regarding dependencies between contents of work packages.

2.4.2 DESIGN STRUCTURE MATRIX

A Design Structure Matrix (DSM) can be used for the representation of dependencies between work packages [13]. The advantage of a DSM compared to a Gantt-chart is the focused editing of the relevant information e.g. dependencies of dates and contents. This enables the analysis of effect propagation for the modeled system (which might be a project or a product) [12]. The disadvantage of DSMs is the lack of an intuitive visual representation. Therefore, it is difficult to communicate the content of a DSM to untrained people. However, the integration of graph representations [14] might enhance this situation, but do afford the use of special software.

2.5 DISCUSSION

As argued, a focused Risk Management process relieves the strain on the project budget. The focusing has to be done during the Risk Management planning, prior to the risk identification. A way to achieve this is the analysis of the project structure. The visualization of dependencies between work packages (the project structure) enables analysis and communication with involved/concerned stakeholders. Existing methods contain excessive information or lack an appropriate visualization. Too much information might hinder the understanding for untrained people and can be a problem by revealing sensitive information.

3 LINKOGRAPHY

"During the process of designing, designers continually reason about prospective features of the designed entity and the rationale for accepting or rejecting them. This is taken to be true whether the designer is an individual working by him or herself or a team working on a design assignment jointly." [15]

3.1 ORIGIN

Linkography was originally developed by Goldschmidt [16] as a method that enables researchers to evaluate the process of design reasoning by measuring characteristics of this process in a quantitative manner [15]. Therefore, relevant sessions of the design processes (conducted using the think-aloud technique) have to be recorded by video or audio. Afterwards, individual design propositions are parsed into design moves. Identified links between these design moves are transferred into a visual representation called a Linkograph. A persuasive example for the usefulness of Linkography is given in the *Delft Protocol Workshop* [17].

3.2 PURPOSE

One important element while analyzing design activities is the structure of design reasoning. The observation of design propositions of designers reflects the process of design reasoning. Analyzing relations between single design propositions depicts the underlying structure. While analyzing the structure, different patterns might be identified and therefore conclusions can be drawn. Linkography supports such analysis by displaying geometric patterns which reflect the structure of design reasoning [15].

3.3 ELEMENTS

Linkography displays the design reasoning process by using two basic elements: design moves and links. A Linkograph is a sequential depiction of these elements.

3.3.1 DESIGN MOVES

Goldschmidt describes a design move as follows: *"a step, an act, an operation, which transforms the design situation relative to the state in which it was prior to that move."* [17] Keeping this statement in mind, the design process can be depicted by a finite number of design moves. The number is dependent on the minuteness of the analysis. As a precondition for generating a Linkograph, the identified design moves are sequentially marked on the move-line, which represents a non-scaled timeline (see Figure 4) [16].

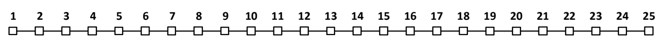

Figure 4. Moveline example

3.3.2 LINKS

Linkography describes the relation between two design moves as a link. The 'linkaging' of design moves reveals the pattern of their relationship [16]. Goldschmidt differentiates two types of links (see Figure 5) [17]:

- Backlinks - A backlink is a representation between a design move and a related prior design move.

Backlinks are common because of the illplanned nature of design meetings.
- Forelinks - A forelink connects a design move with a dependent subsequent move. Forelinks are usually not planned during design meetings.

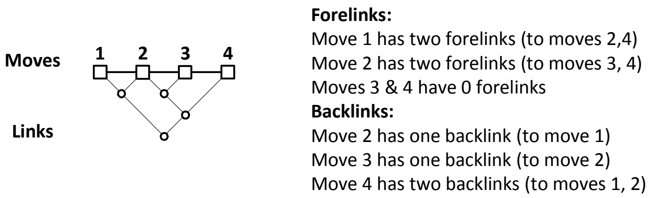

Figure 5. Types of links [17]

3.3.3 LINKOGRAPH

An example for the graphical representation of a design meeting sequence using a Linkograph is given in Figure 6. Three attributes of the 'linkaging' of the analyzed design moves can be seen:

- the number of links,
- the distance of a link and
- underlying patterns.

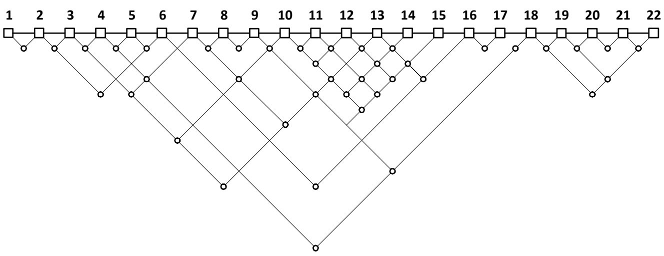

Figure 6. Linkograph example

The advantage of Linkography is its simplicity and the possibility to identify patterns in a visual manner. The method reduces the analyzed process to the underlying structure and highlights design moves, which are important for the whole process. These highlighted design moves have to be analyzed separately because Linkography does not explain causality.

4 LINKOGRAPHY AS A RISK MANAGEMENT METHOD

As argued in section 2 the criticality of a work package is affected by its interdependence to other work packages. In the following, an adaptation of Linkography for the domain of Project Risk Management is presented and discussed. The main reason for adapting Linkography to Risk Management is the ambition thereby to reduce the effort of Risk Management processes and to ease communication with concerned stakeholders.

4.1 ADAPTATION OF LINKOGRAPHY

With the premise of a skilled Risk Manager, the effort is mainly determined by the size of the project, the project structure and the Risk Management methods used [9]. The idea is to scale down the size of the project by focusing only on those work packages which are critical. Hence, the subsequent Risk Management effort can be reduced. The interdependencies of a work package, as a criterion for the criticality of a work package, can be analyzed using Linkography. The visual representation thereby supports the communication of the analysis' outcome between the Risk Manager and other stakeholders. Applying Linkography causes only a little additional effort because all relevant information is contained in the planning documents of a project e.g. the work breakdown structure.

4.2 ELEMENTS

Linkography applied for Risk Management uses the same basic elements of the original method. In the following, the transfer of those elements into the domain of Project Risk Management is described.

4.2.1 WORK PACKAGE AS DESIGN MOVE

The design move is a representation of a finite process step. In Project Management, work packages are used to represent the process on an abstract level [7]. The work packages, documented in Gantt-Charts or a work-breakdown structure, are the basis for the linkograph. The moveline represents the sequence of all work packages of a project. Milestones are distinguished from ordinary work packages by using filled squares (see Figure 7).
The issue of parallel-executed work packages is known, but will not be addressed in detail in this paper. Parallel executed work packages do not affect the use and results of Linkography. An example for the visualization of work packages, executed in parallel, is given in Figure 8. The optimization of the visualization of the linkaging between parallel work packages is object of current work.

4.2.2 TIME

In contrast to the original method, the moveline is scaled. By implementing a scaled moveline, useful information is added. The modified moveline represents the course of the project and gives information about the starting date of each work package (see Figure 7).

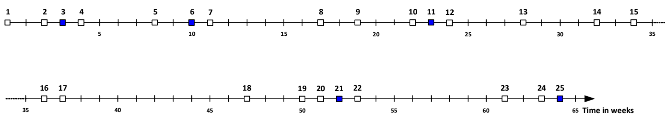

Figure 7. Example of an adapted Moveline

Parallel work packages are represented by placing them among each other (see Figure 8).

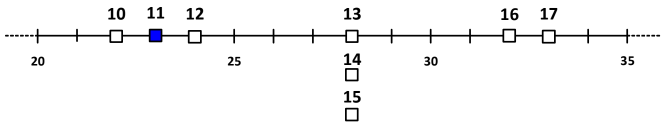

Figure 8. Example for the representation of parallel work packages

4.2.3 LINKS

Similar to the original method, a link represents a relation between two work packages. Likewise, the links are classified as forelinks and backlinks. Backlinks are subdivided in two different categories.

- Forelinks - Contrary to the original method, forelinks gain importance. They represent the planned dependence of a following work package. This implies that failing a work package affects all linked work packages.
- Backlinks Type I - Every forelink creates a backlink of type 1. Such backlinks contain no additional information for a risk analysis. It is assumed that the consequences of a failed work package for the dependent work package are already considered by analyzing the forelinks. Important backlinks are caused by milestones and design reviews.
- Backlinks Type II – Type II backlinks represent a planned iteration in the process. If necessary, backlinks of type II are marked above the moveline (see Figure 9).

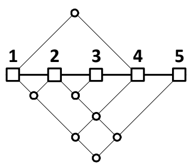

Figure 9. Illustration of links

4.2.4 COSTS

Costs are an important factor for Project Management and Project Risk Management [7, 9]. The costs resulting from failing a work package are marked near the link, as depicted in Appendix A1. The aggregated costs of failing a work package influence its criticality. The failure costs are influenced by the costs of the failed work package and the costs of the following work package. Costs information is extracted from the project plan and is based on estimates. Different concepts for the calculation of failure costs are possible.

- Minimum cost concept – It is assumed the failure is detected before starting a dependent work package. Costs are defined by the iteration of the failed work package (where the forelink starts).
- Maximum cost concept – It is assumed, that the failure is not detected until the dependent work packages have started. The costs are defined by the sum of all related work packages.
- Average costs concept – It is assumed the failure is detected early during the processing of the dependent work package. The iteration does not regard the whole work package. The costs are defined by the failed work package and proportionate by the dependent work package.

The selection of the appropriate concept is the duty of the responsible Risk Manager and depends on the course and the nature of the affected work packages. Thus, generic recommendations for the selection of a concept are inappropriate.

The failure costs represent only costs of process iterations. Costs caused by a failed product are not included.

5. ANALYZING CRITICALITY OF THE PROJECT STRUCTURE USING LINKOGRAPHY

The visualization of the Project structure and relations (links) between work packages are described above. Aside from the visual representation and subsequent support of communication with other stakeholder, the prioritization of critical work packages is also important. An analysis of the prepared information is necessary for the use of Linkography as a Risk Management method. Presented below is a proposal for the use and relevant criteria for a qualitative and quantitative analysis of the Linkograph.

5.1 QUALITATIVE ANALYSIS OF LINKOGRAPH

The first step for analyzing a Linkograph is qualitative. The criticality of a work package is influenced by:

- its number of forelinks and
- the distance of its links.

5.1.1 NUMBER OF FORELINKS

The number of forelinks indicates the importance of the work package's outcome for the subsequent (linked) work packages. If the outcome is a fail (independent of the cause), the linkaging is an index for the possible propagation of this failure and thus for the resulting loss caused by the additional effort for iteration of affected work packages.

5.1.2 DISTANCE OF A LINK

Usually the later the failures are detected, the greater the failure costs. The distance of a link indicates the time between two linked work packages. If a failure is not identified immediately, it will be propagated to the next linked work package. Hence, the distance is an index for the resulting loss. To ease the visual (qualitative) analysis, or more precisely to ease the reading of the distance between two linked work packages, an additional (vertical) axis is proposed (see Appendix A1).

5.1.3 INTERPRETATION OF LINKOGRAPH

Based on the discussed criteria for criticality a Linkograph should be reviewed to identify critical work packages. Work packages featuring a large number of links are easily identified. The number of linked work packages is usually not influenceable, but the effect propagation can be limited. Those work packages which feature long links (distance) should be reviewed carefully. Backlinks of review processes might limit the relevant linked work packages and thereby the criticality. This implies that failures are detected and the effect propagation is stopped. It is important to identify those work packages, which feature long distance links. Such links bear the risk of being reviewed late (or not).

5.2 QUANTITATIVE ANALYSIS OF LINKOGRAPH

5.2.1 CRITICALITY INDEX

The Criticality Index indicates the possible impact resulting from failing a work package and thereby its criticality. The Criticality Index includes no information about likelihood of failing, what makes it different from a typical risk index. A prioritization is possible based on the calculated Criticality Index for all work packages. In the subsequent Risk Management process, only high rated work packages are involved.

The Criticality Index is defined by:

- The number of forelinks,
- Duration of the work package and
- Costs.

The Criticality Index is calculated as follows:

$$\text{Criticality Index} = \Sigma_i \frac{\text{time}_i \cdot \text{costs}_i}{(\text{units})} \qquad (1)$$

$$i = \text{number of link}$$

Hence, the Criticality Index is the product of the time and cost for each forelink of a work package. The product is divided by the chosen units for time and cost to get a dimensionless value. The Risk Manager has to define a threshold value for the Criticality Index that separates those work packages which are included in the subsequent Risk Management process from those which are not [9]. The proposed Criticality Index is an attempt to support the selection of critical work packages based on information delivered by the Project planning documents independent from specific risks.

5.3 VALIDITY CHECK

To ensure focusing on the right work packages the results should be reviewed by an experienced person. Further suggestions for validation of the attained information from Linkography are delivered by checklists and documents from past projects [7, 9].

5.4 FLOWCHART

To summarize the approach, Linkography and the subsequent analysis are depicted in the following as a flowchart. (see Figure 10).

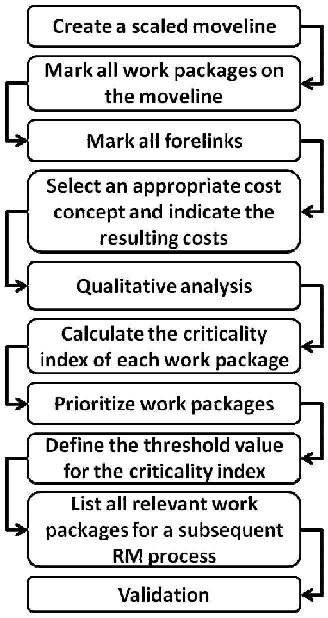

Figure 10. Approach

6 DISCUSSION/CONCLUSIONS

The adaptation of Linkography, originally not proposed for the use as a risk management method, offers the possibility to analyze project structures in a visual manner. The method uses information extracted from existing project plans and therefore generates only minimal additional efforts. Based on a Linkograph, a qualitative and a quantitative analysis offer a basis for systematic Risk Management planning. Linkography focuses on process related risks, hence the leverage is limited. However, a systematic focusing of the search space for potential risks is possible for the intended area.

Due to the lack of empirical validation of the method, the expected benefit in terms of a reduction in Risk Management effort is only theoretical. An advantage of Linkography compared to existing methods like Gantt-Charts or DSMs is its focused visualization of relevant information defining the criticality of a work package. Further research is necessary to assess the usefulness and applicability of the method.

7 OUTLOOK AND FURTHER RESEARCH

Visualization and analysis of parallel work packages are subject to current work. The consolidation of Linkography and DSM offers the opportunity to ease the creation of a linkograph. Following the refinement of the method, a validation of its usefulness will be conducted applying the method in an industrial context. Besides the usefulness and usability of the method, the quality of the delivered outcome is subject to further research. An issue is the comparability and competitiveness of the adapted Risk Management process compared to a usual process.

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APPENDIX

Appendix A1: Adapted Linkograph