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A GQM FRAMEWORK TO GUIDE PROCESS IMPROVEMENT USING STRUCTURAL ANALYSIS

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1. Introduction and focus of this paper

Customized products, the increasing number of product derivatives and shortened product life cycles have led to a rise of product complexity, which usually has to be handled in a shorter time in order to achieve the required time-to-market. In other words, designers have not only to deal with the increasing product complexity but also need to speed up the design process while maintaining or improving the product's quality, typically with reduced resources. Hence, product development processes have to be carefully planned and adapted as well as improved in order to achieve reduced lead times. To do so, it is important to examine existing processes for possible improvements.
To purposefully manage such improvements, it is important to choose the right methods for modeling a process, analyzing the model and deducing improvement measures. In this paper, process analysis using methods from structural complexity management is in focus, i.e. the use of dependency models interrelating the entities of a process and appropriate analysis methods. Such analyses, however, have not been ordered towards certain goals so far that they cater for; this paper is intended to fill this gap.
Being part of a larger research effort to systematize the structure of a process and relate it to the behavior of a process, a set of structural metrics was designed to embody the different facets of structural complexity found in engineering design processes [Kreimeyer 2010]. The structural metrics were collected from different disciplines and were completed through different empirical efforts.
The paper is set up accordingly: First, an introduction to the necessary basics is given, which are used to develop a concept for a framework that interrelates the means of structural analysis to the necessary modeling and the interests of process management. The implementation of the framework as currently available is shown in the following, and its application in process analysis is demonstrated using an industrial case study, before the paper is concluded.

2. Related state of the art

As an introduction to this research, first, the basics of managing complex structures are introduced. With the focus on processes improvement, the second section regards possible interests and foci of process management that can be catered for using the methods from structural complexity management. Last, different kinds of frameworks that can be used to guide an analysis are presented.

2.1 Structural analysis of complex systems

A system is, in this context, understood as a set of entities of (possibly) different classes (called "domains") that are related to each other via various kinds of relations (called "relationship types"). The system is delimited by a system border, across which inputs and outputs of the system are possible as an interaction with the environment. The system fulfills a purpose, which guides the meaningful arrangement of entities and relations (called “structure”). The behavior of the system is, in turn, due to the arrangement of the system’s elements [Lindemann et al. 2009]. Here, more specifically, processes are regarded, which form a class of systems that are commonly formed by tasks, business objects, organizational units and other entities that are related in different ways.

In turn, the complexity of such systems is characterized by a number of aspects. Above all, a complex system is potentially highly structured, making it possible to infer the behavior of parts of the system by how its entities are structured, i.e. related. In fact, complex systems have a large number of possible arrangements of their parts, i.e. their configuration is relevant to the system’s behavior, as its different parts interact in many different ways [Kreimeyer 2010]. Therefore, the structure of a process is defined here as the emergence of patterns within the set of a process’ entities (mostly tasks) and their relationships. Structure-based methods analyze this interplay of entities to draw inferences about the behavior of a process; a common method is, for example, the Design Structure Matrix (DSM) that, through banding, sequencing, or triangularization, is used to obtain an optimum sequence of the tasks [Browning 2001].

Different authors regroup the means of analyzing structures. [Lindemann et al. 2009] collect different methods from graph theory and matrix-based methods that [Kreimeyer 2010] extends using methods from network theory to compile 52 different metrics to analyze complex process structures in the form of graphs, matrices, or other dependency models. Here, an intermediate level of structural analysis is chosen by addressing only generic structural patterns (referred to as principles for structural analysis [Kreimeyer 2010]), as e.g. provided by graph theory. These patterns bridge both the above approaches (both above authors use it to classify their patterns) as well as other classifications and therefore provide a wide basis for analyzing complex networks. Table 1 lists them.

Table 1. Principles for structural analysis

Principle	Description
Size and density	Occurrence of domains, entities, and relationships; also includes isolated nodes and leafs (as e.g. start- or end-nodes)
Adjacency	Adjacency regards the relationships of a node within its immediate environment, while secondary or farther impacts are not regarded: as such, the direct impact among nodes and the distribution thereof within the overall network are in focus
Attainability	Regards nodes towards their embedding in the overall network, also called reachability
Closeness	Refines attainability by how closely related any two nodes are; more specifically, centrality uses a count of path lengths to attribute a node with a value of its centrality within a network
Paths	Characterizes how a network can be navigated; also, each individual path can have special properties, as it constitutes, in fact, a dependent subset of the overall network
Clustering	Assessing clusters, i.e. densely or completely connected groups of entities are counted; equally, transitivity, i.e. potentially existing clusters, are regarded; also, modules as pre-defined groups of entities that possibly form a cluster are of interest
Connectivity	Analysis towards the resilience of a network, i.e. its robustness against individual entities and relationships dropping out
Cycles	Characterizes iterations, the involvement of different entities and relationship in the cycles, and possible decision points that start or re-start iterations within a process
Several domains	Addresses the alignment between networks made from more than one domain; regards especially n-partite-ness and mixing patterns
Cognition	Evaluates human capability to understand a network using empirical models or planarity
Boolean Operators	Used for structures that are modeled using decision points that are explicitly as e.g. AND, OR, or XOR operators

So far, none of the means of analysis have been embedded in a generic framework to guide the analysis of a structure in a goal-oriented manner. So far, only [Lindemann et al. 2009] proposes two ways to approach the analysis of a system, either following a goal-oriented strategy or in an opportunistic manner; they, however, define these two strategies as “define what you need”, i.e. the requirements-driven approach, opposed to “see what you can get” without giving further details.

2.2 Foci in process improvement

Processes are managed for a number of reasons, satisfying different stakeholders, and there are various classifications of the concepts and goals of process management. Table 2 lists those aspects that are related to the structure of the process. These are adapted from relevant literature on typical errors, common problems or general intents of process management, listed in the left column. Their categorization as shown in the top row can be understood as common goals that processes are analyzed and improved for. To construct this categorization, from each reference, relevant concepts in process management were collected as listed in the table. In fact, some references directly address the goals of process management directly or as common problems. All of these concepts were classified with a regard to their structural content, i.e. only those concepts that relate to the structure of a process to at least some extent were kept. For the context of this research, the concepts shown will be used as a framework to systematize a process in a goal-oriented manner.

Table 2. Common foci in process management

Concepts and references	Planning	Resource consumption	Quality	Flexibility	Organizational decomposition	Interfaces	Transparency of process
[Zimmermann 2008]	Long runtimes	Effort for coordination, redundant tasks	Intercept errors, propagation of errors			Inefficient interfaces, insufficient information	
[Best & Weth 2009]	Long lead times	Redundant work, resource limits, resource availability	Fragmented tasks, errors in paperwork		Hierarchical reporting, coordination	Disruptions, information oversupply, outdated or incomplete information	Complexity of content, effort for mainte-nance
[Kreimeyer, et al. 2008]	Speed of design process	Optimum between time, quality, and resources	Quality		Teams: setup and coordination	Information exchange, workflow mmgt.	Coordinate distributed design
[Becker et al. 2005]	Critical paths, Time buffers	Costs, obsolete processes, administr.		Adaptation, flexibility, robustness	Adaptation of capacities	Integrating participants, optimization of interfaces	Process knowledge, standards (workflows)
[EFQM 1995]	Repetitive tasks, iterations		Information consistency		Respon-sibility	Interfaces within process	
[Schmelzer & Sesselmann 2006]	Expenses for coord.	High performance of process			Distinct respon-sibility	Few interfaces	
[IDS Scheer 2007]	Optimi-zation, automati-zation of processes	Efficiency, reduction of costs	Effective process			Standards, harmoni-zation, roles, external partners	
[Gaitanides et al. 1994]	Speed	Use of methods, efficiency	Coherence, robustness, precision	Flexibility			

2.3 Frameworks

A number of frameworks are possible, such as e.g. Quality Function Deployment (QFD). Here, the Goal-Question-Metric (GQM) framework as commonly applied in software engineering and the Balanced Scorecard (BSC) that is applied in general management using metrics are reviewed, especially as they can be implemented using matrices similar to those found in QFD.

The Goal-Question-Metric approach is a systematic method to set up a quality model in software development, breaking down overall quality goals into intermediate questions down to metrics to reply to these questions. On the way back from the questions to the goals, the measures are interpreted to obtain indications to the software quality. As such, the GQM-approach bridges the conceptual level (goals) via an operational level (questions) to a quantitative level (metrics). The metrics serve as concrete and quantifiable entities [Basili et al. 1994]. An important part of GQM are the goals that are described towards the issues, objects, and viewpoints that are in regard. They are detailed using the direction of how the goal should be developed. GQM is similar to the Munich Procedural Model, as it makes overlapping use of basic metrics to answer different questions that relate to different overall goals. As such, it recognizes the fact that individual metrics are not fully independent but rather form a network of metrics. Figure 1 shows an example of a QGM framework.

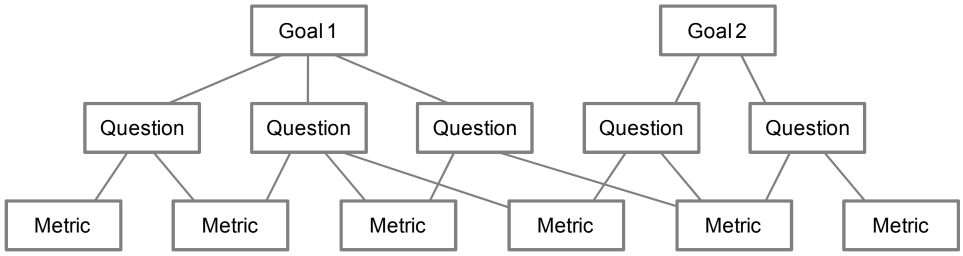

Figure 1. GQM model hierarchical structure [Basili, Caldiera & Rombach 1994]

A Balanced Scorecard (BSC) [Kaplan & Norton 1992] is a method to achieve a balance among short-term, medium-term and long-term management objectives through a diverse measurement of performances by creating a sense of understanding for the full spectrum of financial and non-financial quantitative indicators that take shape as performance indicators. As such, the BSC links overall strategic perspectives to goals that are to be achieved and measures via performance indicators. For each goal, drivers that enable the company to reach the goal are determined, and suitable "Key Performance Indicators" are attributed that show the level to which level the driver is achieved. They therefore rate a goal, differing from the more descriptive viewpoint a metric takes. The performance indicators are obtained by setting up goals for the different perspectives of all stakeholders. For each perspective, cause and effect chains are set up of how the goals are to be achieved. These cause and effect chains are used to determine measures to represent the level of implementation to satisfy the customer's expectations.

Overall, common frameworks, especially GQM can be adapted well to work with process management. Especially as GQM has been developed to be used with metrics (in software management), it is well suitable to work with structural patterns and structural metrics, therefore. In fact, GQM can be adapted to map the goals as collected in the previous section to structural measures.

3. Concept of a framework to systematically guide process improvement

Figure 2Figure visualizes the solution elements and their relations: Different parts are relevant for the overall analysis of a process from a structural point of view: Globally, goals and, more generally, concepts guide the analysis. While this strategic level does not necessarily address goals (e.g. "Interfaces" does not state a goal but only a concept), nevertheless, the term "goal" is used to be coherent with the GQM scheme and to address the focus of the analysis of a process. To concretize these goals, questions are asked to detail the analysis at a more concrete level. In fact, structural patterns can then be used to analyze an existing process to provide answers to these questions; here, structural patterns can be embodied e.g. as structural metrics. At the same time, questions are related to certain issues within a domain and its relationship types, i.e. the meta-model of the analysis. In fact,

questions typically limit the focus to certain domains. Equally, the structural significance of a metric is only given for a domain and a relationship type, which, of course, can alternatively be represented as an aggregate view that encompasses two or more domains and relationship types. Lastly, this structural significance provides answers to the initial questions.
To implement this concept, a basic hierarchy like the one shown in Figure 1Figure can be used, mapping goals to more detailed questions, and questions to more detailed metrics; similarly, each metric needs to be attributed with the relevant domains and relationship types that can be represented as an aggregate view (i.e. condensed view onto one domain that includes relations that go via other domains that are not represented, e.g. a view on tasks (represented as e.g. a Design Structure Matrix) that exchange information via intermediate documents that would, otherwise, be represented as an additional domain. For each question, the set of metric, domain, and relationship type provides certain answers; at the same time, there are manifold possibilities for the combination of these three parts; therefore, a basic meta model is used that reduced the set of choices to the most common domains (and relationship types) that can be found in process management [Kreimeyer 2009]: Task (precedes), artifact (transists into), event (leads to), organizational unit (communicates with), resource (transmits message to), and time (leads to). While this basic meta-model simplifies a given model slightly, it reduces the complexity of the threefold attribution of a structural significance to an analysis importantly, allowing for a much easier implementation that can, where necessary, be adapted, of course, to suit more specific or individual needs.

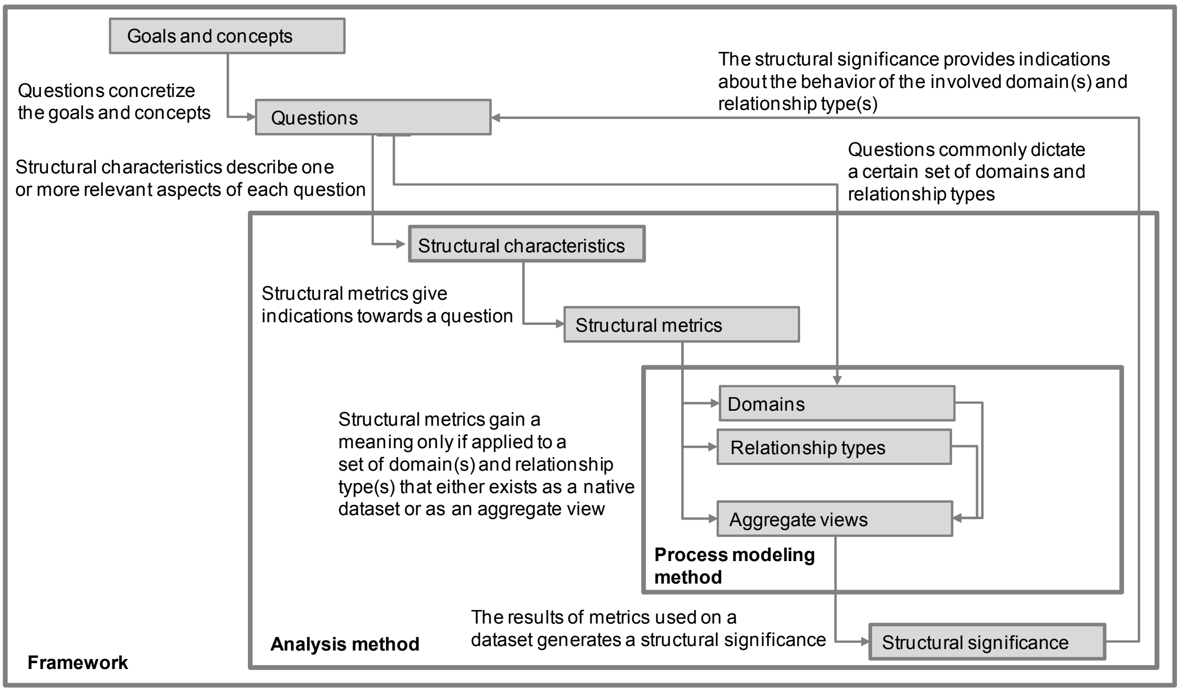

Figure 2. Different parts of the framework and their relations

4. Goals and questions of structural process analysis

The goals shown here are based on the different foci of process management as shown in Table 1. For each focus, a goal was deduced, and two further ones that can be extracted from the principles of structural analysis (Table 1) were added to also cater for analyses towards Boolean Operators and cognition. Overall, eight specific goals were therefore designated: Planning, resource consumption, quality, flexibility, organizational decomposition, interfaces, transparency, and decision making.
For each goal, relevant questions were detailed out of the references provided in section 2.2, and purposeful structural analyses were attributed in a series of workshops, from literature research, and through empirical research based on different process improvement. For limitations of space, these are not detailed here. This attribution is not always ideal, as literature does not always have a focus on

structure. Therefore, the goals were also consolidated in workshops with researchers and process managers from different industries to be as relevant as possible. Among other, different larger research and industrial projects on process improvement, within which different means of structural analysis were applied, were reviewed to deduce suitable structural patterns that have a significance towards each goal.

Planning addresses the degree of pre-determination that is possible for a process by regarding bottlenecks, tasks that can be worked on independently, or rework cycles; these occur especially as cycles among points in time, tasks and artifacts, as bridges within the process network and as densely crosslinked interfaces among several domains. Thus, e.g. drivers for the runtime of a process, its critical paths, and repetitive tasks can be identified using the following questions:

Q01: To what extent is it possible to incorporate risks into the process planning?
The question addresses especially the fact that a densely networked process implies a higher risk of delays towards a milestone. Especially clusters and, more generally, cycles are the drivers of such delays. Furthermore, the less linear a process, the more complex is its planning to break up cycles among the artifacts or points in time that hinder a linear process flow.

Q02: How can the focus be put on important process steps?
This question aims at identifying important tasks that have the highest impact on the process flow, being central sinks or distributors of information (i.e. leafs or busses), coordinating the overall process thereby, and driving and/or controlling cycles.

Q03: What are bottle necks in the schedule?
Bottle necks in the structure are those communication channels or tasks and documents that, if defective or incomplete, hinder the further process execution. Therefore, bridge nodes and edges as well as the connectivity of the graph are in the scope of this question.

Q04: What parts of the process are substantially impacted by iterations?
Iterations are a major driver of costs and delays with the goal of improving the quality of an artifact by reworking part of its contents. Therefore, entities that are impacted by iterations deserve particular attention. Cycles, their start- and end-nodes, their main communication paths as well as existing and possible clusters contribute to such iterations.

Q05: What is the stakeholder situation?
The stakeholder situation is characterized by the number of different domains that are relevant for a process model; therefore, the stakeholder situation mostly relates to the size of the network and its different measures.

The **resource consumption** covers the attribution of resources that emerge out of the attribution of two domains to each other. Thus, e.g. redundant work, the availability of IT systems and other resources, and the homogenous layout of the process are addressed. To this end, structural characteristics such as attainability and parallel paths (called sync graphs) among tasks, organizational units and resources are in focus.

Q06: Is the process laid out in a homogeneous manner?
Here, the even distribution of tasks within the process and their allocation to organizational units as well as their inputs and outputs is analyzed to identify such tasks and artifacts that collect the knowledge of the process, which will mostly cluster in those tasks and organizational units that are the most involved throughout the process. Equally, those organizational units that represent the core competencies of the process can be pinpointed this way.

Q07: Where is it possible to remove redundancies to reduce waste?
Multiple allocations to tasks and other entities in the process can be an indicator towards the unnecessary use of resources; another driver of resource consumption is the frequent change of responsibility, causing additional coordination effort. The metrics grouped under this question

therefore regard multiple allocations and interruptions in the alignment of different domains.

Q08: Are the resources well accessible?

The availability of resources is essential for the efficient execution of any task in a process. Therefore, this question focuses on the attainability of resources.

The concept of **quality** in a process includes the consistency, the integration and the distribution of information and errors. By looking at the reachability, the resilience, the hierarchies, and the alignment of the artifacts with the rest of the process network, its propagation can be characterized.

Q09: Does the process allow for the consistent transfer of information?

Similarly to the accessibility of resources, the continuity of information transfers, i.e. the attainability of one resource from another resource, is the essence to information consistency. This also applies to artifacts, representing the intermediate results of the process.

Q10: Is the documentation in line with the process?

The alignment of artifacts and the tasks point to possible issues within the exchange of information throughout the process. Dissimilar structures of these two domains (size, degree distribution, cycles) are an indicator for inefficient documentation.

Q11: What is the risk of error distribution across the process?

The propagation of information also includes the propagation of errors among the tasks and artifacts. Therefore, short and wide hierarchies point to root nodes within these two domains that have a high impact across the whole process network and that are, thus, susceptible to collect incoming errors or to distribute errors rapidly across the process.

The goal **flexibility** addresses redundancy, robustness, and adaptation. As many of these aspects can only be judged from the semantics of the process network, only buffers and the general robustness are regarded closely, evaluating the adjacency and attainability of e.g. points in time, tasks, and artifacts.

Q12: What buffers are available in the process to absorb delays and errors?

Points in time, tasks, and artifacts with a high degree can serve as buffers if used correctly; a node with a high incident degree will collect many inputs before continuing the process. Therefore, these entities can be identified as buffers.

Q13: How robust is the overall process to individual failures?

The resilience of the overall network facilitates the adaptation of the process if nodes (e.g. key personnel) fail. Thus, nodes that could compromise the integrity of the network point to a lack of flexibility to cope with problems at these entities. Similarly, multiple paths across the overall process point to more flexibility to cope with unforeseen changes in the process structure.

The **organizational decomposition** is intended to establish efficient communication channels by means of a purposeful decomposition of organizational units. Here, coordination of all tasks, the adequate setup of teams and distinct responsibilities are of interest. Hence, organizational units are in focus, being analyzed for straightforward crosslinking with especially the tasks, their internal attainability, clustering, and resilience.

Q14: Is the organization of workgroups and teams adequate?

This question addresses the alignment of the process with the organizational setup. The clustering of tasks in the process points to necessary workgroups.

Q15: How well is the organizational structure suited to provide efficient communication?

The possibility of each organizational unit to be able to reach other organizational units is an important driver for communication; therefore, the attainability of organizational units as well as the mean path length are of interest to characterize the communication within a process; also, bridge nodes and central organizational units are of interest. Similarly, the metrics of this question point to entities that are possibly not well integrated, being little or not reachable at all.

Q16: What is the internal structure of an organizational unit?

Being a socio-technical system, a process is driven to an important extent by opinion leaders and information hubs that coordinate the process, even if they are not the executives that formally manage the process. Therefore, their identification is targeted by the metrics focusing on the centrality and the degree distribution and correlation of the network formed by the organizational units.

Interfaces are another important concept in process management. Disruptions among resources, artifacts or organizational units are addressed as well as errors in the transmission of information, the supply of information, and the integration of organizational units. To this end, hierarchies point to the propagation and the belonging communication channels.

Q17: Which entities of the process need to be synchronized?

Addresses the need for information exchange among tasks and organizational units, the analysis of the degree as well as the attainability is of interest. Especially the distribution of degrees and their correlation point to those entities that are of high importance for the process.

Q18: How fast is communication in the process?

Similarly to the propagation of errors, the propagation of information is represented by hierarchies across the process that show what information can reach other entities from its root node. Therefore, the attainability as well as hierarchies among the tasks and among the organizational units are regarded to characterize the potential speed of communication.

Q19: What are relevant communication channels?

While communication within the process takes place at particular tasks or organizational units, there are also characteristic paths within these networks that this question aims to identify. Therefore, path-based metrics are applied.

Furthermore, **transparency** assesses the degree of complexity of grasping and understanding the process and the involvement of individual entities therein. This transparency affects, of course, all domains of a process network.

Q20: Are the organizational units aware of their impact on the overall process?

The more an entity (organizational units, mostly, but also tasks and points in time) is coupled to others, the more difficult it is for it to judge its long-range impacts. Hence, the size of the network, the degree of its crosslinking and its planarity are assessed.

Q21: How transparent is the overall process organization?

The cognitive ability of humans is limited to comprehend only few objects at a time; here, empirically founded measures evaluate the degree of complexity of a process network.

Lastly, **decision making** addresses the fact that the structure of a process reveals many decision points, both those that are explicitly modeled as Boolean operators and those that drive iterations, i.e. the start-nodes and end-nodes of cycles that govern a process in particular. While such decisions impact especially tasks, they can relevant for all domains, thus the domains are not limited.

Q22: Which decision points are of high impact on the process?

This question relates to metrics that evaluate the impact of a decision point onto the process, mostly through the degree and hierarchies of tasks and business objects. However, also the assessment of overall processes is possible.

5. A case study to demonstrate the use of the framework

To illustrate the use of the framework, a process model from automotive body design was analyzed towards the goal “Interfaces”. The process model was designed as an EPC model depicting the interaction of design and simulation departments, and it was converted into a DSM that interrelates the 160 tasks of the process via precedence relationships via the intermediate business objects. A second DSM was calculated to show how the departments that are responsible for each task are interrelated. For these two domains, the following structural patterns were regarded to identify those entities that stick out in a particular way, i.e. that appear as structural “outlier”. Table 1 lists the three relevant questions and the principles for which patterns were sought.

5.1 Which entities of the process need to be synchronized? (Q17)

Adjacency is assessed via each task's degree. It points to the fact that few tasks are highly connected, acting as hubs in a hub-and-spoke-like network. This is confirmed by the visual impression (Figure 3Figure), showing a strength based graph that arranges around few central hubs. Particularly the highly connected tasks drive synchronization in the process, acting as main coordinators, especially as tasks with high in-degrees also exhibit high out-degrees for the highly connected tasks. Above all, the task "Coordinate simulation of crash" shows up as most connected, which is reasonable, as here the model building as well as the use of results are managed. Other patterns confirm this central role. It also shows the highest results concerning its relative centrality, having the highest value for it, too. This points to the fact that most communication paths in the process run across this task, making it highly relevant to build the opinions about the concept being developed; in fact, here, the importance or the Euro-NCAP rating (crashworthiness) reflects in the process: The car body in total is used to absorb the energy from an accident, which improves crashworthiness; therefore, the overall body (and thus all of its components together) need to be optimized towards this property, and therefore an important part of systems architecting takes place in the simulation coordination task.

Table 1. Questions and regarded structural principles

	Q17: Which entities of the process need to be synchronized?	Q18: How fast is communication in the process?	Q19: What are relevant communication channels?
Size / density	Tasks		Departments
Adjacency	Tasks		
Attainability	Tasks	Tasks, departments	
Closeness		Tasks, departments	
Paths			Departments
Cycles			Departments

Similarly, this task ranks high in its attainability, i.e. information generated here will be relevant to many subsequent tasks, and the task processes much information from previous tasks. Thus, it is highly susceptible to possible errors in the process, but it can serve, at the same time, as a task that can be used to screen for errors efficiently before they are distributed further. Lastly, the task shows up importantly in many cycles, which confirms the fact that many long iterations are run across the task.

The task "Simulate Crash" ranks second in the overall model, and it is equally closely embedded. However, the crash simulation is only one of 11 simulation foci that are equally regarded in the process. This points to the crash simulation as the driving force, especially as its results are the only results that propagate quickly across the process: In fact, only one task is directly connected to the simulation, but it is able to reach 109 different other tasks out of all 160 tasks in the process, thus impacting the process to an important degree. Similarly, the weighted impact of this task (i.e. how many other tasks can be reached while being only a short path length away) is very high, pointing already to fast communication at this task.

5.2 How fast is communication in the process? (Q18)

The previous question already answered this question in part. It equally relies on the combination of reachability and the actual path length, which is reflected in the closeness of the tasks in the network, which pointed to the crash simulation task and its coordination task.

To further detail the speed of communication that shows up to be high for these two tasks, in addition, here, the communication among the involved departments is regarded. To do so, the DSM on organizational units is used. Here, not the development department but the simulation department that is responsible for safety applications shows up as most important outlier towards its closeness (centrality). This points to the fact that this department is the broker to settle conflicts among components and progress the systems architecture to a large part. This is confirmed by the outgoing hierarchies from this department, which occur most here. Therefore, the department is well embedded in the process and thus able to communicate with all other units across short communications channels. However, it is not well able to generate the crash simulation easily, as the low count of incident hierarchies points out: in fact, this is due to the high effort for the collection of relevant information to constitute the simulation model. This analysis also holds true for the other two simulation departments that are involved, as they support the safety applications department.

In contrast, the body-in-white department is much better integrated into the process, showing well-balanced incoming and outgoing degree, reachability, and closeness; therefore, the efficient transfer of both input and output information is assured much better.

This picture is somewhat archetypical for such German car makers: While the development of the products functions is actually run in the simulation departments, the "classic" embodiment engineers are still seen as the driving force in a process, thus having the process centered on their work.

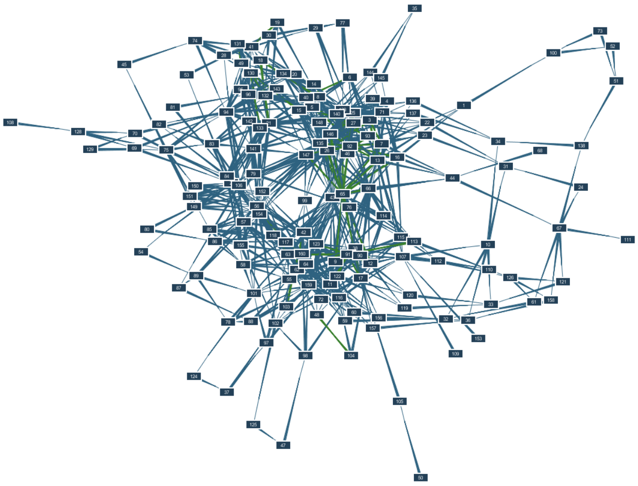

Figure 3. Graph for task network of process model

5.3 What are relevant communication channels? (Q19)

The computation of path-based metrics could not be calculated due to computational reasons; therefore, the relative centrality (as part of closeness) was used to deduce indications, as it implicitly evaluates paths, too. Additionally, the degree was used, as the in between the departments many parallel communications paths could be found, and a measure of the number of paths between adjacent departments could therefore be approximated through the number of edges connecting any pair. Figure 4 shows the paths between any pair of departments (OU: "organizational units") as a DSM with multiple edges. Here, e.g. the simulation department (OU 10) has 38 different communications channels to the body-in-white design department (OU 6); however, the other way around, only 16 communication paths exist (read "row communicates to column"). This confirms the picture from the previous question, stating that collecting information to build simulation models demands high effort, while the dissemination of the results is much easier.

5.4 Findings from the case study

The core findings of this case study point to a limited set of tasks, artifacts, organizational units, and IT systems that appear as the most important structural outliers. These findings were reviewed with engineers along with a series of discussions and workshops, and the results largely coincide with the engineers' intuitive understanding of their work and involvement in the process that was reviewed. On the whole, all results were judged meaningful, and the three questions that guided the operationalization of the goal "interfaces" were deemed correct by all engineers. Initially, it was suggested by the engineers in the company that the risk in planning and the consistent transfer of information should be considered as further questions; however, the engineers later dismissed these as too vague to be answered from the structure.

However, the order of importance obtained through this case study was judged differently from the results of the outliers, which prescribe a certain priorization of the entities. In contrast to the structural outliers, the three most important tasks were identified as "Support development of body structure", "Coordinate simulation of crash", and "Coordinate simulation of passenger safety". All of these tasks showed up as important in this case study; however, the order suggested by the engineers deviated slightly. In discussions, the reasons for this different weighing in industry were that all engineers had more background information available on the entities that did not show up in the structure, such as the actual informational content of each artifact, the cost determination of a particular task, or the criticality of timing of information availability. Furthermore, certain political aspects and their own involvement in certain tasks caused the engineers to weigh the entities according to other standards, not just the structure of the process.

	OU 1	OU 2	OU 3	OU 4	OU 5	OU 6	OU 7	OU 8	OU 9	OU 10	OU 11	OU 12	OU 13	OU 14
Concept Development Department (OU 1)		2	0	13	0	1	1	0	1	0	0	0	0	0
Design Department (OU 2)	0		0	1	4	2	2	0	0	0	0	4	0	0
Total Vehicle Intergration Department (OU 3)	0	0		0	0	1	0	0	1	0	0	0	0	0
Technology Development Department (OU 4)	8	6	0		0	24	20	12	0	19	27	5	0	0
Contour and Loft Department (OU 5)	0	3	0	3		2	3	2	0	0	1	2	0	0
Body-in-white Design Department (OU 6)	5	4	0	16	0		4	11	1	16	27	3	0	0
Interior Design Department (OU 7)	7	6	0	15	0	3		6	1	23	18	10	0	0
Comp. Flow Analysis Department (OU 8)	0	0	2	2	0	18	8		6	37	27	7	0	0
Safety Applications Department (OU 9)	2	1	2	10	0	11	19	12		32	19	3	3	0
Simulation Department (OU 10)	0	0	3	9	0	38	25	34	26		46	15	0	0
Simulation Service Provider (OU 11)	0	0	0	3	0	12	5	17	14	42		4	0	0
Development Service Provider (OU 12)	0	0	0	0	0	4	11	4	0	13	12		0	0
Supplier (OU 13)	0	0	0	0	0	0	0	3	6	8	3	0		0
Strategy (OU 14)	2	2	0	0	2	0	0	0	0	0	0	0	0	

Figure 4. Multiple paths between departments (interfaces via task precedence)

6. Conclusion

The GQM framework is an extension to the current methodology of managing structural complexity; it provides a basic orientation towards possible analysis strategies that can be used to better understand a dependency model and to extract knowledge from it towards a certain goal or interest.

6.1 Implications for application

The development of the goals and questions guided by common goals in process management is defined throughout the state of the art. However, these goals and questions are generally quantitatively evaluated in existing analysis methodologies. Therefore, they had to be mapped for their structural content, which reduces their expressiveness to some extent. The structural focus that is embodied in the framework, therefore, generally relies on case studies, of which only a short part was shown; however, several other studies were run that confirmed the general approach.

The goals and questions are possibly not complete, but they are meant as a guideline for common use cases and to demonstrate the application of the structural metrics. Depending on the context of the individual application, an extension and adaption are probably necessary; therefore, no "out-of-the-box" application was designed. At the same time, however, the hierarchical design of the framework, based on the GQM scheme, allows easy adaptation.

The allocation of detailed analysis tools and metrics for the goals and questions was not shown here. However, as the approach needs detailed review before any application in a process improvement project, the individual analysis methods need to be reviewed, too, while the general principles, towards which a process is assessed, remain. For the framework, therefore, a compromise between expressiveness and compactness of the framework was made.

Similarly, the allocation of domains and relationship types is sufficient for the purpose pursued, as it was guided by the semantics transported in each question. Nevertheless, a detailed review of the domains and relationship types for each analysis project is necessary, as again no "out-of-the-box" application is realistic. This is because the underlying meta-model (domains and relationship types) only serves as a generic frame of reference. Yet, in practice, different domains and relationship types might be available, either because they are relevant to the company being analyzed, or simply because the process model that is used as an initial starting point dictates a different set.

6.2 Implications for research

The results can be judged viable and meaningful, which confirms the concept of structural analysis. To this end, the framework appears to be a promising extension to the existing means of structural

management, making use of a simplified GQM scheme. However, certain simplifications were used. In particular, the formulation of goals, which is an important aspect of the original scheme, was not used, as the framework that was designed here is designed to have a wider focus of application.
The benefit gained from the framework was demonstrated in the case study. Although the selection of means of analysis to be allocated to a goal and its questions is difficult and at times fuzzy, the framework serves as a good starting point for any analysis. In comparison to the current state of the art, the framework is the most complete method in this field of research.

6.3 Future work

At the same time, the framework shows that no single means of analysis towards a question is possible; here, it is necessary to use several related metrics to obtain a balanced and holistic picture in a compact form, as the Balanced Scorecard proposes. To this end, however, more research is necessary towards the mutual relations and correlations of structural patterns. So far, the existing framework is based on several empirical studies as well as on common literature.
As of now, the framework is lacking a generic analysis mode. Often, process analysis in industry is done “because there is something wrong”, and a general analysis for possible problems is needed. To do so, a basic set of metrics is required that is not part of the framework; the structural means of a analysis as used here (especially adjacency, attainability, closeness, cycles) appear to be a good set for that. However, no empirical evidence is available yet.

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