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A METHOD FOR REVEALING MISALIGNMENT IN ENGINEER-TO-ORDER PRODUCTS AND PROCESS STRUCTURES

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Abstract: *Unique solutions for unique requirements is typical for Engineer-to-Order companies. This entails variance in products and processes which is often mitigated by efforts in standardization, modularization or platform design, etc. Such portfolio strategies depend on coherent system definitions like well defined solution spaces, common definitions and shared nomenclatures. A method is proposed to systematically uncover, reveal and visualize variation in system definitions and decompositions to support such strategies. The method is tested with an industrial case company and three projects are subject to analyses. From this application, three sources of system variation are identified.*

Key Words: ***Systems Engineering, Variation Analysis, Project-Based Development, Portfolio Management***

1 INTRODUCTION

Engineer-to-Order (ETO) products are characterized by high levels of variety and low production volumes. The products are typically created in a project-based organization where every project focuses on controlled customization of a known solution space or previous designs to fit a set of specific customer requirements. Ultimately it results in a changing organization that creates one-of-a-kind products and does so with project-specific processes to support the high levels of customization needed [1]–[4].

The variance of customer requirements, product solutions and processes makes ETO projects more unique and risky compared to Make-To-Stock or Configure-To-Order manufacturing which operates with more static solution spaces. The uniqueness originates in the diverse customer requirements and the business concept of designing to specific needs. The risk originates from the uncertainties of contracting complex product engineering based on preliminary rough designs, cost estimates and functional expectations. Signing an order for a product that will take years of development to complete entails a lot of uncertainty, uncertainty of solution details, performance levels and cost. There are thousands of product aspects that are subject to change and such changes ultimately risk the financial success of the project [5], [6].

Control of the product and project variance is needed in order to minimize the uncertainty and risk of conducting ETO projects. Popular strategies to mitigate this product and process variance include standardization, modularization, platform-based design and mass-customization solutions like configuration systems. The aim is typically to reduce the variance internally (i.e. streamlining and re-using solution within the company) whilst maintaining external variety (i.e. still being able to delivery variety to the customer) [6]–[13]. Focus is often on cost reductions, lead time reductions, product commonality, design re-use and managing customization actively instead of reactively [6]–[13].

Most portfolio management initiatives focus on the product and how this can be split up, re-used, optimized, re-designed, etc. What is often neglected is the ecosystem of processes around the product. The introduction of a product platform is more than just the shared product-base, it is also the shared processes across the organization, the platform knowledge base, internal and external collaboration, management strategies and so on. The efforts taken to optimize ”must concern all aspects of the firms strategy” [14], [15]. It can be beneficial and sometimes necessary to go beyond the company and include more of the supply chain (e.g. suppliers and customers) in such strategies [16]. It must also include the system in which that design is embedded: The tasks around it, the behavior it entails, the interactivity with other system elements, etc. All of the aspects needs to be accounted for, in order to get a just evaluation. ”The reality of failing to take a systems approach is all too often evidenced as a failure or as an inefficient process.” [10]. The proper integration of systems when performing portfolio management is one of the most often missed parts of such efforts. Systems integration is crucial in ensuring that benefits endure and hard earned improvements do not diminish due to old work habits [17], [18].

Portfolio changes need to be linked to the system of the product, the processes, the organization and the business structure. The system needs to be fully defined in itself to avoid confusion and errors. Unclear system decomposition (e.g. how products are broken down into sub-solutions and the split between processes and activities) might cause confusion concerning responsibility and hand-overs between organizational units. Any handover is prone to mistakes if the subject of the handover is not consistent, e.g. one department uses one set of names and labels and another department has their own set. Changing system definitions along project lifecycles also de-links the project aspects. If initial and final system definitions do not match, then any work related to the first will not match the latter.

Complex one-of-a-kind production needs to be varied to meet the customers' requirements, but the systems and the systems definitions what guide development need to be consistent. They need to be consistent for collaboration purposes, for traceability, to avoid or reduce re-work and to optimize the workflow of the organization. Systems and model-based engineering prove that "The defined ontology helps to increase the traceability during the system development and enables the impact analysis of changes" [19]. Separate system definitions, changing system decompositions and inconsistent nomenclature can significantly reduce the ability to trace cost through projects or do portfolio comparison between projects. Detailed cost follow up analysis and portfolio management becomes difficult to conduct.

Any misalignments between the work of different departments or systemic mistakes in the design, must be mended before project closure, adding excessive cost to the final project phases.

1.1. Contribution

A long list of methods exists for managing portfolios and the complexity and variance of the portfolio. There is even a surplus of toolboxes to define product systems and do systems-based development. However, the authors were not able to identify tools or methods that enable analysis of the variance of the underlying system definitions and decompositions for ETO products.

This paper presents a method for mapping the variation of systems across a suite of engineering projects. The method is tested with an industrial case study where three customer ETO projects were subject to analyses. The method is intended to aid in systematically retrieving system definitions and decompositions from available project and product documentation, allowing the comparison of system structures and identification of key misalignments. This can be used to pinpoint key improvement potentials from streamlining and coordinating system definitions across projects, products, departments and project lifecycles.

The paper proceeds as follows. Relevant state-of-the-art research, methods and tools are reviewed in Section 2 followed by a presentation of the method in Section 3. In Section 4, the application of the method in an industrial case setting is presented along with produced results. Section 5 interprets the case results and discusses the key benefits and limitations of the method. Lastly, the method, application and results are concluded in Section 6.

2. BACKGROUND

Systems are fundamental for ETO product development and the proposed method of this paper. *Systems Engineering* is a topic that covers the definition of systems and the approach of engineering based on systems thinking. It covers theories and methods developed for managing and analyzing engineering systems and definitions and approaches for defining and decomposing systems. The state-of-the-art knowledge which form the foundation for this paper are presented in the following summaries.

2.1. The Power of Thinking in Systems

Products and processes of complex nature need to be founded in a well-defined system. The product-centric part of this system is often known as the *Product Architecture* which forms the blueprint of the overall structure of the product and how those products are built from standard solutions with common interfaces, like modules or likewise. The architecture defines the boundaries of the solution and construction of systems, in which design choices can be made to fully shape the product that matches the requirements [20], [21]. It is imperative to have (or develop) an architecture for the intended solution before the work on the actual solution commences. The system structure is very similar, only that it covers the entire system including processes and organization around the product [22].

Early decisions are forming the basis for many of the later decisions in product development processes. Hence the early decision making carries a high influence. When 20% of the product has been developed, 80% of the cost has already been allocated or committed [22]. Any changes or fixes to mistakes is consequently affecting large portions of the already-defined product. Hence there is a strong incitement to get the system right in the first place, since these early conceptual decisions are representing a lot of value. Errors or misalignments in the initial definition of systems can propagate through the project lifecycle and cause a lot of harm in terms of re-work, changes and errors, an event known as *Change Propagation* [20], [22]–[25].

These system definitions and decompositions will shape the overall structure of the product and the realization process. They draw boundaries of responsibility, they link customer requirements to functional specifications and they translate one departments design choices into another department's requirements. Product details or functionalities can be defined by their role in the system. If then the system definitions are altered, it might blur the obvious value of those details. Consequently, they might need to be replaced or redone. Changing a system or any of its definitions, ultimately changes the game for anyone playing. [26], [27]

In a report on modularization, the consultancy firm *Roland Berger* found that the problem of modularizing products properly was not entirely product-centric, rather the challenges include: Baking it fully into the organization with an organization-wide product strategy; Proper management alignment and support; Standardization of processes [15]. A frequent pitfall for portfolio rationalization activities is neglecting to properly incorporate them into the systems of processes – making the benefits they bring easily diminished [17], [18].

The American National Aeronautics and Space Administration (NASA) works diligently and systematically with systems to ensure consistent work and a common understanding of responsibility across all stakeholders. Their formulated definitions, defined system structures and common nomenclature are fundamental for their ability to work consistently and precise [28].

2.2. Defining Systems

Specifying, designing and engineering complex products can be a mammoth task. Not only by size and effort, but also structuring, planning and organizing the processes it takes to realize it. Especially the dependencies between requirements, functionalities, design choices, operational criteria, etc. This is where the school of *Systems Engineering* becomes valuable. It is an umbrella term that encapsulates nomenclature, tools, methods and skills that are beneficial, and sometimes necessary, to employ when systematic system creation is needed [20], [22], [26].

By definition, the term *System* has an abundance of meanings. Generally it refers to a collection of functions, components, control measures, people or even all of the mentioned. A system is comprised of system elements, which in turn can be systems themselves, with subsequent system elements. Parts can be within parts or functions can be within functions. *Systems* in *Systems Engineering* are no definitive thing. It refers to the goal of systematically making sure that all aspects of the product is accounted for, and that dependencies and interactions across systems and system elements are resolved [22], [26], [29]. The *International Council on Systems Engineering* (INCOSE) describe *Systems Engineering* as "(…) a transdisciplinary and integrative approach to enable the successful realization, use, and retirement of engineered systems, using systems principles and concepts, and scientific, technological, and management methods." [30].

In accordance with the described fundamentals of S*ystems Engineering*, The International Electrotechnical Commission (IEC) and The International Organization for Standardization (ISO) jointly published the international standard 81346 [29]. Here they define a *Technical System* as "a group of components working together for a specific purpose".

2.3. Decomposing Systems

There are many options on the decomposition of systems, however they abide by the same principles of division and definition. D.H. Meadows writes that "a system must consist of three kinds of things: elements, interconnections, and a function or purpose." [26] essentially agreeing that "a system is a purposeful whole that consists of interacting parts" [22].

Everything within this system, being functions, components, etc. can be viewed as *Objects* which is an instance of something with associated information [29]. This object can be viewed from multiple *Aspects*, e.g. Function: "Intended or accomplished purpose or task". Component: "Product used as a constituent in an assembled product, system or plant" Location: "Intended or accomplished space". They also define the creation of the product (e.g. assembly, construction, etc.) and any interacting operations that transform, transport or store information, materials and energy as *Processes*. [29]

Decomposition of such a system can then refer to a separation of the system's constituent elements and mapping their interaction [31]. Systems can also be decomposed into different perspectives of objects. So objects carrying information can be looked at differently, depending on what information is needed. [29]. Likewise, the before mentioned *Product Architecture* is a system definition and can be decomposed and viewed in different aspects, e.g. operational, functional and technical perspectives [20]. A functional system decomposition is a great tool for supporting proper integration of modules, components and sub-systems in product development processes when dealing with modularization or standardization efforts [18].

Ultimately, thinking in systems and rigorously defining proper systems and accompanying definitions early on in product development can expedite development, mitigate change propagation and reduce re-work. These systems can advantageously be decomposed into different system aspects and perspectives that can then drive system integration efforts and efficient product processes.

3. METHODOLOGY

According to the reviewed literature and the case work undertaken by the authors, the formation of systems is important for ETO product development. Thus variation analyses of such systems must be enabled to mitigate the variance of such systems. This paper proposes a method do enable exactly this.

The method is designed to reveal inconsistencies and misalignments of systems in projects and products. By comparing these systems and highlighting the present variance in decomposition and nomenclature, the most typical and fundamental deviations can be identified and possibly rectified. The method consists of four overall steps that are described in detail in the sections below.

1. **Framework**.
   Establish the framework for analysis.
2. **Documentation**.
   Structure the available information and documentation according to the framework.
3. **Systems**.
   Retrieve and visualize system definitions and decompositions from available documentation.
4. **Analysis**.
   Analyze the variance of system decompositions within and across projects to identify systematic variance and potential improvements.

3.1. Framework

The aim of this study is to enable analyses of the variation of system definitions within and across engineering projects. That relies on system information and definitions to be available for analysis. To structure this work and convey the information, a framework is established. It will form the foundation for the subsequent steps of the method.

The definitions and decompositions must be consistent across the different aspects of both products and processes, as well as through the lifecycle of the development. As ETO products are often done in project-based development, references to these systems must likewise be consistent throughout the project lifecycle. Hence, the first dimension of the established framework must describe this lifecycle. The columns of the framework, as seen in Figure 1 (Step 1 – Framework Establishment) separates the project into phases.

The other axis of the framework splits the project into the possible views or perspectives. These are labeled *Aspects* which represent the different views of information, relevance or context. As the definition of *Aspects* states that it can essentially be anything, they are further separated into two main categories; *Product* (i.e. what the system is supposed to do, be and comprise of) and *Process* (i.e. what goes into making the product). Inferring the definitions from IEC and ISO [29] the *Product* aspect is further divided into *Function*, *Components* and *Placement.* The *Process* aspect is further divided into *Workflow* (i.e. the activities and processes that are conducted to realize the product) and the *Resources* needed to fulfill them.

Figure 1 (Step 1 – Framework Establishment) presents the framework. It unfolds a matrix of lifecycle-aspect pairs. These are referred to of *Framework Cells* and will be important for the subsequent analysis described in this paper.

3.2. Documentation

Complex product development includes creation of vast amounts of documentation. These can be specific pieces of specification, guides for further work, project plans, budgets or task descriptions, technical drawings, etc. The available, and relevant, documentation for the projects must be gathered and structured. The documentation is structured into the established framework in step 1. Individual pieces of documentation are annotated into the *Framework Cells* they supply information about. If the document supplies information for several cells, this span is marked as well. Figure 1 (Step 2 – Documentation Overview) presents the framework as described with the following examples of available information:

A. Functional requirement specifications might be used early in the project to describe the functionality.
B. Engineering bill-of-materials are used in later project phases, to describe constituent parts of the solution.
C. Project plans relate system elements specific activities and/or timeframes.
D. Hourly budgets link resource allocations to specific systems or system elements.

3.3. Systems

With an overview of available information, each piece of documentation can be inspected with the goal of extracting its system description for the specific residing framework cell. The identified systems are visualized in that particular cell in the framework. Single documentation pieces can span multiple cells in the framework, so it might be possible to identify several different systems within a single source. When multiple systems are identified for the same framework cell, both visualizations are shown in that particular framework cell. To exemplify this, a product order tender can be considered. It might describe functional requirements (Phase 1, Function), the delivered goods (Phase 1, Components) and the overall project plan (All phases, Workflow). This piece of documentation is spanning multiple cells within the framework. System information for each of these cells can be extracted from this single piece of documentation. The extracted system information is then visualized in the respective framework cells. Hence not everything from a document is used in every cell, only the information that is relevant to the particular cell.

When visualizing the extracted system information, it is important to include the naming of the systems and system elements. Though two system definitions might look alike, share structure or number of system elements, the naming of the constituents might reveal that the system have been defined and labeled entirely different in the two sources, e.g. two departments might agree that the products have two main functions, but if those are not labeled identically it might lead to executional or realization problems. Figure 1 (Step 3 – System Information) presents an example of this methodical step including the following examples:

E. A description of the components comprising the product in the earliest project phase, broken down into a tree-like system decomposition.
F. Four separate decompositions of the product components, as described by the four pieces of documentation
G. Two separate decompositions describing the process workflow of the earliest project phase.

3.4. Analysis

A framework including system definitions and decompositions now exist for each project included in the analysis. The goal in this step is to assess the variance within each of these overviews and finally between them, as visualized on Figure 1 (Step 4 – Variance Analysis). To structure the analysis of system variation, four analytical steps are undertaken for each included project.

System definitions can vary within a project yet still be consistent across projects if only comparing a single project aspect. The opposite is also a possibility, where the system definitions are consistent within a project, but vary significantly between projects. Figure 1 visualizes the four following analytical steps:

4.1 Going through each row of the framework, noting inconsistencies and possible clashes of systems definitions regarding that particular aspect (function, components, etc.)

4.2 Going through each column of the framework, noting variation across a single project phase.

4.3 Looking more broadly at the whole framework at identifying critical variation across single cells, e.g. differences between the definition of *Components* in *Phase 1* and the manufacturing budgets in *Resources*, *Phase 4.*

4.4 Comparing system definitions across projects, based on individual framework cells.

Finally, the aggregated observations and insights from the variance analysis are used for drawing conclusions on systemic variation and possible improvement potentials in the way systems are defined and used in the projects.

4. CASE RESULTS

The described method is applied in an industrial setting with an ETO case company. For a selection of recent projects, the framework was established, documentation structured and system information extracted. Finally the inter- and intra-project system variance analysis was conducted. The following sections present the progress and results for each of the methodical steps.

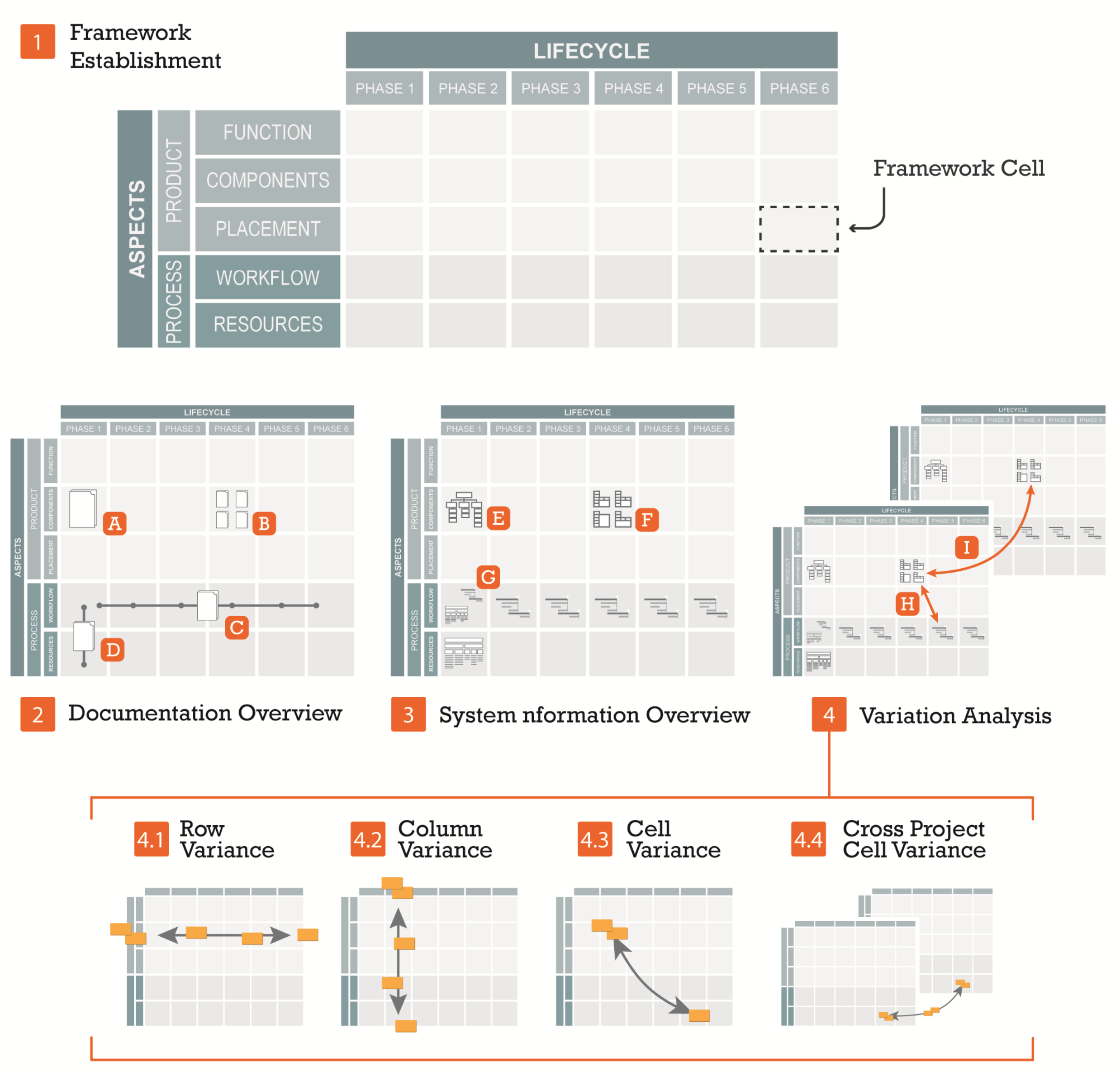

Fig. 1. *Steps of the proposed method. (1) Establishing the framework with project aspects and lifecycle phases on either axis. (2) Structuring project documentation and available information according to the framework. (3) Retrieving and visualizing systems decompositions. (4) Analyzing variance within and across projects. (4.1) Observation of variation within rows. (4.2) Observation of variation within columns. (4.3) Observation of variation*

4.1. Case Company and Case Projects

The company operates on a global market, selling custom processing plants. They are involved in the entire development process of the order: Selling, designing, engineering, procuring, building, installing and commissioning the plant. The plants are done specifically to the requirements and order of a certain customer, often leveraging and customizing previous builds and past solutions to fit the new challenge at hand. The plants are done by project teams within the organization, collaborating and working together with a suite of supporting functions e.g. calculation teams, engineering departments, simulation experts, etc.

Together with the company, a sub-type of processing facility was chosen as subject for this analyses. Three recently conducted projects were chosen. The three plants are comparable in size and type, but located in different parts of the world. All three involve a great deal of internal collaboration as well as external partners and suppliers. Given the size, timeframe and cost involved, any development mistakes, delays and unforeseen troubleshooting can are costly for such projects.

4.2. Establishing the Analysis Framework

The proposed analysis framework is set up to match the execution process of the company and the three included projects. The aspects (rows) are kept methodical: *Product* is split into *Function*, *Components* and *Placement* while *Process* is split into *Workflow* and *Resources*. The columns were chosen to match the 7 overall phases of project execution in the company: *Sales, High Level Design, Detailed Engineering, Procurement, Installation, Commissioning, and Service.*

4.3. Structuring the Documentation Overview

For each of the three plants, available project documentation was noted onto the framework. From these overviews, a few observations were made; The focus of the documentation seemed to change along the progression in project phases, with initial emphasis on product documentation and later focus on process documentation; Like most real life cases, perfect data is not available and the available documentation was not identical in all three case projects. Although some information seems to be missing, the majority of each project can still be represented by the available information; There were numerous occasions, where several pieces of documentation/information overlapped the same framework cell, hence supplied several sources for the same system information.

Ultimately the three frameworks containing the overviews of documentation supplied a consistent and sufficient bundle of information to continue the analysis.

4.4. Visualizing System Information

With the three analysis frameworks in place and the available documentation structured, the extraction of system decomposition information could follow. This entailed looking through each piece of documentation with the intent on extracting just the system information regarding the framework cell in which the document was listed. An order tender can still be used as an example for this: Given that the order tender contains much of the product information in the early phases, it can be browsed with the sole intent of extracting the functional system decomposition. Looking through the order tender to find descriptions of sold functionality and then the way this information is structured. This information can then be used to fill the information in the framework cell containing the product-function aspect in the sales phase.

The extraction of system decompositions was done for each document listed in the three established frameworks. The result were three large collections of information. This information was then listed and visualized on three large posters. The posters still contained the established frameworks, but instead of listing documentation, they now contain visual representations of the extracted systems. Significant efforts were put into the visualization of the system information, to aid the following observations of variance.

4.5. Analyzing System Variation

According to the method depicted in Figure 1, the system information frameworks were evaluated for the individual projects on row-basis, column-basis and cell-basis and then lastly between projects.

Comparing the overview of observations of system variance lead to many relevant insights. For reasons of paper length, method simplicity and company data confidentiality, only a selection of these observations are presented below.

The Leap from Sales into Execution

The collection of insights indicate that there exist a significant gap in system definition between the sales project phase and the subsequent project phases. The system hierarchies and nomenclatures seem to change in every case. The system and product descriptions done at the point of sales might not be sufficient and typical to ETO products it needs further detailing throughout the project lifecycle. However, the way the products are detailed in the coming phases and various departments are not coherent and identical. It seems the systems are detailed differently every time, even though they set out from roughly the same starting point. It is as if the rest of the organization does not find the systems used in sales sufficient, so they define their own detailing.

Top-Down versus Bottom-Up Engineering

When looking broadly at the lifecycle of the projects, there is a shift in the perspective on product engineering, from top-down to bottom-up design. The documentation in the sales phases describe the customer requirements, product capabilities and intended product structure in a top-down perspective. They enforce restrictions and boundaries on the further detailing, ultimately describing the solution space of the product. When the project execution starts and designers take the lead, the project perspective switches to bottom-up engineering. The product is now described almost exclusively from its constituent components and as a collection of detailed sub-solutions. This is especially visible in an observable gap in system definitions between the initial top-level systems used in sales, and the absence of systems hierarchies when engineering the product components:

There is no description of which constituent components belongs to which of the initially described systems.

Allocation of Resources

The system definitions observed in the allocation of resources represent an organizational compromise. They only partially match everything else but matches nothing else perfectly. A possible reason for this can be observed in the way the products are described using systems or not. Systems are generally used to describe the supply in the projects – deliveries, components, procurement, etc. However, the functionality of the product and the processes undertaken to realize that functionality are missing system contextualization. Hence the system structure needed to contextualize resource allocation is absent and a miss-match between these systems are almost unavoidable.

Working in Silos

The main project phases are headed by different organizational units and they use different hierarchies for top-level systems. Although many of the systems are recognizable, they differ slightly in the order of appearance, the nomenclature used and the hierarchical relationship between system elements. However, it seems that within a single project phase they are quite aligned and coherent. The discrepancies are mostly visible between phases.

Project-Based Development

As described, ETO businesses typically operate in project-based manner. This is observable in the way the projects are increasingly detailed throughout the project lifecycle. The product is not entirely defined (maybe not even entirely known) at the point of sales, and it is up to the design teams to work out a solution. However, this subsequent work is not guided by fixed system definitions and hence they alter between projects and the resulting work differs slightly in definitions and nomenclature. The further away from the point of sales they get, the more they have moved away from the common starting point and the more the systems differ. There seem to be no common set of definitions that they all abide by.

5. DISCUSSION

The method has been developed to fit project-based product development like ETO business praxis. It has been applied on three case projects of an ETO plant engineering company which produced, amongst other, the described system variance observations and insights. The method and its application is discussed below.

5.1. The Method

The proposed method is intended to be applicable in various product development projects where system definitions need coherency. Hence the underlying framework can be modified to fit the context.

Qualitative Retrieval of System Information and Analysis of System Variation

The presented method is a structured approach for systematizing the gathering of information and the subsequent analysis of this. However, the extraction of system information from the identified documentation is qualitative and subjective to the individual undertaking the task. Hence the identification and extraction of information should preferably be done by experts of the product, processes and projects, at least in collaboration or correspondence with such.

Value-adding and Non-value-adding Variation

This method does not cover the subject of determining value-adding and non-value-adding variation. Given the nature of the products and projects, some variation is necessary. Having variation between systems of separate parts of the supply chain can be justified, if necessary. This is value-adding variation. Other types of variation, however, occur because of misalignments between departments, unclear system definitions or unstructured work processes. The latter are examples or non-value-adding variation, which should be avoided when possible. The assessment of the value of variation types is left for further research.

Framework as a Strategic Tool

The proposed framework and analytical method can be used for streamlining and coordinating improvement efforts and process development in a project-based company. Using this framework to map company initiatives to phases and project aspects, could expose potential overlaps, gaps or possible symbioses possibilities that could be exploited to further improve company operations.

5.2. The Case Application

The proposed method was tested with three case company projects. The produced results were presented in Section 5, and some of the observations of this process are discussed below.

The Inherent Variation of ETO Products

Since ETO products are inherently varied to suit different customer specifications, the product structure, functionality, cost, etc. will vary. This means that a strict system that is kept identical between projects is almost impossible. However, the varied systems can follow the same system definition and overall structure – meaning that there should be no doubt where new system elements or added functionality belong. Essentially allocating system elements in advance. Everything should have their dedicated location in the system descriptions and these locations must be identical between projects that share the same system elements. By doing this, comparison becomes possible across projects and linkage of product/process aspects within projects becomes stronger. Like mass producers building generations of products on an architecture, ETO products must follow a system architecture.

Case Breadth

If the method was tested on a single product development project, it would be possible to analyze the system variation within this project, but not between this and others. It could be either well-defined or ill-defined, without revealing if it was the norm or a mere coincidence. To add analysis perspective, a second project has to be included. A third projects adds perspective to the results of the first two projects. If two out of three projects are concise and consistent in the ways of defining and using systems, it indicates that the third project is out of order. Furthermore, adding more product development projects to the analysis also allows the assessment of typical variation and inconsistencies.

Data Availability and Quality

The execution of portfolio management has a common complication: To collect and access sufficient information in a proper format in order to do satisfactory analysis. In other words, data is typically inadequate and of too low quality to perform the necessary analysis and draw the necessary conclusions. This is important to consider when performing these types of analyses. However, the analytical method described in this paper can still be conducted with an imperfect data-landscape. Though attention must be paid to the fact, that the produced results might not be the entire picture of the situation in case of missing information due to incomplete or erroneous data.

Consequences of the Analysis Findings

When the description of the product changes (e.g. changing systems and nomenclature) it becomes increasingly difficult to describe the targets of the development. Estimated spending of resources, achievable product performance indicators, activity and project planning become increasingly difficult to accomplish when the underlying systems are not static.

Without rigid systems definitions, the interactions between the parts of the solution becomes difficult to oversee and manage. And when the interactions between the systems of a solution are unmanaged, the real effect of the work and possible re-work due to changes becomes untraceable. Proper system control is powerful for foreseeing change-propagation, risky project work and forecasting performance issues. Lack of rigid systems control work the opposite way.

Improvement Potentials

One of the key sources of system definition variance, appears to be the lack of a commonly decided set of system guidelines. Such a guideline could dictate the top-level system hierarchies and nomenclatures. That would still allow further detailing and customization in the individual departments and organizational units, but it would ensure coherency between project phases and across project aspects regarding the overall system structure.

There was a noticeable gap between the top-level systems defined at the point of sales, and the subsequent detailing of components and solution parts in project execution. There were no description of the constituent elements of the systems as the documentation skipped directly from top-level systems in sales to detailed sub-solution descriptions in design. A stage could be introduced in-between, to break down the product into its main systems and define what belongs where. This could be on a project-basis, but a set of general system structures to be used in every project would be further beneficial. These could be part of the before mentioned project system guidelines. This definition could also be the foundation for resource allocation to further increase system coherency.

To govern the use of systems, a review process or a governance unit could be established. Reviewing the system hierarchies and nomenclatures throughout the project execution would ensure that the parties of the project are aligned in their use and naming of the systems. An organizational unit with focus on systems engineering could be responsible for these cross-project reviews of project processes and documentation, tasked with the upholding of system coherency.

5.3. The Value of Consistent Systems

The value of consistent system definitions and coherent decompositions across the organization is difficult to determine. It allows other valuable process optimization or cost reduction initiatives to progress more easily and tie into the systems of the organization. Essentially it is boosting the benefits and potentials of those initiatives. Even without these other efforts, it might reduce errors between departments, reduce the amount of work to be re-done, improve cross-organizational communication and ultimately more optimized work because the frame of reference stays constant. Hence the direct value of the consistent systems is difficult to document, as most of the value appear as derivative effects. Research of these effects and their value is much welcomed by the authors.

5.4. Further Work

The method was devised and tested with a single case company, yet across several case projects within this company. The method proved useful for this case. However, using and testing it with multiple cases would allow the method to be further developed and prove its usefulness in varied product creation companies. The authors invites all interested parties to use the method and test it by publishing more case applications.

Extending the method with assessment of value-adding and non-value-adding variation would strengthen the overall variance analysis. The authors invite the research community to extend the method where suitable.

6. CONCLUSION

System definitions are essential for complex engineering as they supply a broad set of boundaries and definitions from which the product solution can be created. The importance of *Systems Engineering* and *Portfolio Management* is widely described, and the severity of making changes to these fundamental definitions during product development is also documented. However, identifying variation of these underlying systems and translating that variation into improvements potentials has not been investigated to the same extent.

To elaborate on the identification of system variance, this paper proposes the following; A systematic approach to reveal variance (i.e. differences) in definitions and decompositions of systems in Engineer-To-Order (ETO) projects. The proposed method (1) Establishes an analysis framework based on the project aspects in ETO project-based product development; (2) Structures the available project information according to this framework; (3) Extracts and visualizes system information and lastly; (4) Undertakes a structured analysis of the present system variation.

The undertaken case application resulted in a lot of interesting insight into system variance. The most prominent sources of variance was observed to be: (a) The project-based development workflow where the products are described on higher levels at first and then gradually detailed as the projects progress. This causes the projects to follow slightly different paths of detailing, resulting in varied use and definition of systems. (b) A noticeable gap between the top-level systems described in the first project phases and the subsequent detailing of sub-solutions and product parts in the later project phases. Without a description of the systems and what system elements belong where, the systems are open for interpretation by the execution teams and that reveals itself in varied system hierarchies. (c) A systematic variance of system nomenclature and a general incoherence between systems in different project phases, possibly due to a lack of a set of shared system guidelines and a governance of a common system definition.

Ultimately the insights produced by this analysis can be exploited directly for improvements to the project management methods, introducing system governance and prioritizing system consistency in execution. This will not only ensure coherency in project execution, but supply a more easily manageable set of systems when dealing with resource allocation and possibly portfolio management. Having everybody describe their work by the same set of system definitions consequently makes it more manageable to oversee project portfolios, analyses project execution and compare projects and product ventures.

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